LARGE SCALE SESSIONS

MONDAY, AUGUST 18, 2008

MONDAY MORNING ORAL SESSIONS
10:30am - 12:30pm

1LA - Maglev, Bearings and Flywheels – I 10:30am - 12:15pm

10:30am
1LA01 - Theoretical Hints for Optimizing Force and Stability in Actual Maglev Devices
N.Del-Valle, ***A.Sanchez****, C.Navau, Universitat Autonoma Barcelona; D.X.Chen, ICREA and Universitat Autonoma Barcelona*
The achievement of high-quality high-temperature bulk superconductors has created much interest in maglev technology not based on magnets made of superconducting filaments but instead on the use of bulk material as levitating agents. In principle, large levitation forces with stability against small perturbations can be achieved in bulk superconducting material levitating in the presence of external magnetic fields. But the actual force and stability depends strongly on the details of the particular arrangement of the superconductor and magnetic parts and other effects (such as field-cooling and working distances). Here we review some of our recent theoretical calculations of force and stability [APL 90, 042503 (2007); 91, 112507 (2007); 92, 042505 (2008)] and present some new ones, using a realistic model based on energy minimization in the superconductor, assuming a general magnet-superconductor system with translational symmetry. From the calculated results we provide to actual device designers with hints of how to optimize either the levitation force, or the stability or a combination of both, how to choose the field-cooling distance to satisfy each application, and how to realize less reduction of the levitation force after a lateral displacement of the superconductor.

10:45am
1LA02 - Recent development of high temperature superconducting Maglev system in China
J.Wang*, S.Wang, J.Zheng, Applied Superconductivity Laboratory, Southwest Jiaotong University*
After the man-loading high Tc superconducting Maglev demonstrations have been tested successfully, its future application attracts more and more researchers and engineers. The paper will review the recent development of HTS Maglev system in China, which is one of three representative research groups. In the past seven years, dynamic force and running performance have been studied based on static force performance by three HTS magnetic levitation (maglev) measurement series and 11-ch vibration measurement apparatus. For the further engineering application of HTS Maglev train, some practical conditions are considered in details, like inhomogeneous magnetic field along the forward direction, thermal dissipation, restorable guidance capability and so on. On the other hand, a systemic simulation method is presented to analyze or optimize the origin high temperature superconductor and permanent magnetic guideway system. Primary running parameters or notes are obtained for the future practically safe HTS Maglev system design. Besides, a low-mid speed HTS Maglev test line is being on the plan with mix 100 km/h speed, which will be the first step of HTS Maglev engineering.
This work is supported by the National High Technology Research and Development Program of China (2007AA03Z210, 2007AA03Z207) and National Natural Science Foundation in China (50677057, 50777053).

11:00am
1LA03 - Relaxation transition due to different cooling processes in a superconducting levitation system
X.Y.Zhang*, Y.H.Zhou, J.Zhou, Lanzhou University*
Relaxation of levitation force in a high-temperature superconducting levitation system is well known to be unavoidable based on the flux creep phenomenon. In this work, an updated high-temperature superconductor maglev measurement system was used to measure the relaxations of levitation force and lateral force due to different cooling processes simultaneously. The effects of the cooling processes on the relaxations in both the levitation force and lateral force are remarkably observed in the present experiment, and transition phenomena are also found in the relaxation and the force behaviors (i.e., either attraction or repulsion) to both the levitation force and the lateral force. An updated frozen-image is used to calculate the relaxations in the levitation force and lateral force due to different cooling height, the results agree with the experimental results qualitatively. Our results provide the basis for improving the design of high temperature superconductor levitation devices.
This work is supported by the Fund of Natural Science Foundation of China (No. 10472038), the Fund of Ministry of Education of the Program of Changjiang Scholars and Innovative Research Team in University (No. IRT0628), the Science Foundation of the Ministry of Education of China for Ph. D program. The authors gratefully acknowledge this financial support.

11:15am
1LA04 - Magnetic Levitation Upgrade to the Holloman High Speed Test Track
Y.Hsu*, D.Ketchen, L.Holland, D.Doll, General Atomics; A.Langhorn, Startech, Inc.; D.Minto, U.S. Air Force*
The MagLev Upgrade program at Holloman AFB, NM started in 1994 with the goal of providing a low vibration payload environment compared to the existing slipper on rail rocket sled system. The sled is propelled by solid fuel rocket motors. During sled motion, the field from superconducting magnets mounted on the sled interacts with passive copper rails embedded in a concrete guideway to produce levitation and flight stability. Five flight tests have been conducted so far with the most recent reaching 423 mph, setting the world speed record for a magnetically levitated vehicle. This will increase to beyond supersonic speed as more guideway is built during the next few years. The magnets consist of racetrack coils, which are wet lay-up wound with rectangular NbTi wire. They were tested to 245A with a peak field of 7T and winding current density of 38kA/cm2. The coils are bath cooled in one liter LHe volume helium vessels. A passive valving system prevents loss of liquid during rapid acceleration and deceleration. Boil-off gas cools an aluminum thermal shield which operates at about 25K, this gas also cools the current leads. In flight tests, the magnets are cooled from room temperature with LHe through an attached umbilical line. Cooldown time is about two hours. The magnets are charged to 210A and placed into persistent mode. The cooling circuit and power leads umbilical are remotely disconnected immediately prior to launch. A flight lasts about five seconds, the magnets quench due to lack of liquid after about 20 minutes.

11:30am

1LA05 - Design for Field Deployable Flywheel with High-Temperature Superconducting Bearings

***M.Strasik**, P.E.Johnson, J.R.Hull, J.Mittleider, J.F.Gonder, K.E.McCrary, C.R.McIver, The Boeing Company*

A design is presented for a small flywheel energy storage that is deployable in a field installation. The flywheel is suspended by high-temperature superconducting (HTS) bearings that are conduction cooled by connection to a cryocooler. At full speed, the flywheel has 5 kWh of kinetic energy, and it can deliver 1 kW of three-phase 208 V power to an electrical load. The entire system, which includes an S-bracket containment structure, is compatible with transportation by forklift or crane. Design options to minimize the parasitic loads due to vacuum, cryogenic, and power electronics are presented. Laboratory measurements of the bearing loss are combined with the parasitic loads to estimate the roundtrip efficiency of the system.

This work was supported by the U.S. Department of Energy, Sandia National Laboratories Energy Storage Program Contract 598172

11:45am

1LA06 - High Rotational-Rate Rotors with High-Temperature Superconducting Bearings

***J.R.Hull**, M.Strasik, J.Mittleider, J.Gonder, P.Johnson, K.McCrary, C.McIver, Boeing*

Improvements in high-strength fibers are expected to enable the operation of flywheels with very high rim velocities. Small versions of such flywheels will be capable of very high rotational rates and will likely require the low loss inherent in high-temperature superconducting (HTS) bearings to achieve these speeds. The behavior of these bearings at high rotational rates has hitherto been minimally explored. We present results of experiments with small-diameter rotors that use HTS bearings for levitation and rotate in vacuum at kHz rates. Bearing losses are presented as a function of rotor speed. Particular challenges that are discussed are conduction cooling of the HTS bearings, low loss motor/generator design, structural design, and rotor bending modes.

12:00pm

1LA07 - Towards high capacity HTS flywheel systems

***F.N.Werfel**, U.Floegel- Delor, R.Rothfeld, B.Goebel, D.Wippich, ATZ; T.Riedel, Adelwitz Technologiezentrum GmbH (ATZ); G.Reiner, N.Wehlau, L-3 MM*

Adelwitz Technologiezentrum (ATZ) and L-3 Communications Magnet – Motor (L-3 MM) have fabricated a 5 kWh / 250 kW flywheel energy storage system using a high Tc superconducting magnetic bearing. Energy capacity of about 5 kWh is obtained at a speed of about 8000 rpm of the carbon fiber rotor. The integrated motor / generator operates at a maximum power of 250 kW and the flywheel is tested functionally in a German E.ON power station (UPS function). The 200 mm high Tc bearing is cooled by a 35 W GM cryo-cooler up to a temperature of 50 K. The HTS radial bearing on top is capable to carry 1 ton load at kilo Newton per millimetre stiffness and low loss rotation performance. The excellent properties of the HTS bearing have pushed the flywheel concept to a second system of substantial larger storage capacity of 15 – 20 kWh / 400 kW. The larger HTS flywheel is dedicated to operate in an electric utility for UPS and load levelling the local grid of a large Korean plant. The 15 kWh flywheel is scaled up both by larger carbon fiber rotor as well by a higher rotational speed resulting in the larger energy storage capacity. The accompanied scaling of the electric power unit to 400 kW meets requirements of industrial use. It allows studying market and commercialization conditions by modernizing local electricity infrastructure.

Support by the German Ministry of Education and Research under the contract number 13N8737/38 is acknowledged.

1LB - Power Transmission Cables – I 10:30am - 12:30pm

10:30am

Invited

1LB01 - Installation and Testing Results of Long Island Transmission Level HTS Cable

***J.F.Maguire**, J.Yuan, American Superconductor; F.Schmidt, Nexans; S.Bratt, Air Liquide; T.E.Welsh, LIPA*

The first long length, transmission level voltage, cold dielectric, high temperature superconductor power cable has been successfully installed in the Long Island Power Authority (LIPA) grid. The cable is capable of carrying 574 MVA at a voltage of 138 KV. Three 600m long phase conductors were manufactured and shipped to the LIPA site. The installation process included pulling three cables through three separate 600m long underground conduits and assembly of three terminations at each end. The project has been funded by the US Department of Energy and is led by American Superconductor. The project team is comprised of Nexans, Air Liquide and LIPA. This paper will describe the system, installation process, an overview of various testing results before and after installation. In addition, details of an initial successful cool-down process will be presented. It will also include the performance results in grid operation.

11:00am

Invited

1LB02 - Testing and Demonstration Results for Phase II of the 350m Long Albany HTS Cable System

***C.S.Weber**, SuperPower, Inc.; H.Yumura, T.Masuda, Sumitomo Electric Industries*

The Albany Cable Project team (Linde, National Grid, Sumitomo Electric, SuperPower) have built, tested and operated a 350-m long HTS cable and cryogenic system rated at 48 MVA (800Arms, 34.5-kV). In the first phase of the project a 320-meter and a 30-meter cable, fabricated using Sumitomo's Di-BSCCO conductor, were installed in underground conduit and connected together in a vault. The cable was commissioned and began operation in July 2006. During the operation of Phase I, a 30-meter long cable made with approximately 10 kilometers of SuperPower's YBCO conductor was fabricated and tested by Sumitomo in Japan. After approximately (9) months of successful operation of Phase I the cable system was shut down and work began on installation of the YBCO cable. The new BSCCO/YBCO hybrid HTS cable system was re-energized on January 8, 2008. This paper will summarize the testing and operational aspects of the second phase of the project

The authors would like to thank our partners and collaborators at Linde and National Grid Power Company. This work is supported in part by the US Department of Energy and New York State Energy Research & Development Authority

11:30am

1LB03 - Phase II of the Albany HTS Cable Project Update

***H.Yumura**, Y.Ashibe, H.Ito, M.Ohya, M.Watanabe, T.Masuda, Sumitomo Electric Industries, Ltd.*

High-temperature superconducting (HTS) cable systems are expected to be a solution for improvement of the power grid and three demonstration projects in the real grid are under way in the United States. One of them is the Albany, NY Cable Project, involving the installation and operation of a 350 meter HTS cable system with a capacity of 34.5kV, 800A, connecting between two substations in National Grid`s electric utility system. A 320 meter and a 30 meter cable are installed in underground conduit and connected together in a vault. In the phase I of this project, the cables were fabricated with DI-BSCCO wire in a 3 core-in-one cryostat structure. After the installation of HTS cable system, the in-grid operation began on July 20th, 2006 and operated successfully in unattended condition through May 1st, 2007. In the phase II, the 30 meter section is to be replaced by a YBCO cable. The YBCO cable was fabricated with SuperPower's YBCO coated conductors in a 3 core-in-one cryostat. After the replacement of 30 meter section, the joint and one termination were reassembled and the commissioning tests such as initial cooling, critical current measurement and DC withstand test were completed successfully. After the commissioning tests, the HTS cable system with a 30 meter YBCO cable and a 320 meter BSCCO cable will be energized and started again to operate in a live utility network. This paper describes the latest status of the Albany cable project.

11:45am

1LB04 - The 30 m HTS Power Cable Development and Test

***V.S.Vysotsky**, V.E.Sytnikov, A.V.Rychagov, A.V.Taran, K.A.Shutov, N.V.Polyakova, I.P.Radchenko, S.S.Fetisov, A.A.Nosov, Russian Scientific R&D Cable Institute*

In the framework of the Russian R&D Program for superconducting power devices, the 30 m HTS power cable has been developed. The extensive scientific and technology studies have been preceded to the full length cable production [1]. These studies permitted to develop the proper former and cabling technologies for the long HTS power cables. Three 30 m phases with nominal current ~2 kA and 20 kV operating voltage were delivered as the result of the project. Because this is mainly the research project the variations were used in basic HTS materials, cryostats and current leads for the cable design. All phases were made of 1G HTS Bi-based tape. Two phases were made of "Hermetic" HTS tapes from American Superconductor Co and one phase was made of Sumitomo Electric Industry Co. CT-OP tapes. Different basic wires use permitted us to check if the tapes will keep their superconducting properties after passing the full cable manufacturing root. The 30m cables' cryostats were produced by Nexans Co. The details of the design of the cable and test results are presented and discussed. We consider this work as the first step to introduce HTS power cables into energy transportation and distribution grids in Russia. The next step will be development and delivery of 200 m HTS power cable to be used in real city grid. 1. V. E. Sytnikov et al, IEEE Trans on Appl Supercon. Vol. 17, N2, pp.1684-1687, 2007

12:00pm

1LB05 - Development of key technologies for power transmission cables using coated conductors and their demonstration in 20 m model cable

***N.Amemiya**, Kyoto University; Z.Jiang, Yokohama National University; M.Yagi, S.Mukoyama, Furukawa Elec.; M.Ohya, T.Masuda, T.Kato, N.Kashima, Sumitomo Elec. Ind.; S.Nagaya, Chubu Electric Power.; A.Ishiyama, Waseda University; Y.Shiohara, SRL-ISTEC*

In the R&D project of coated conductors in Japan, the key technologies for power transmission cables using coated conductors were developed, and they were demonstrated in a 20 m model cable. We focused on four key technologies in the project: AC loss reduction; application of coated conductors with textured-metal substrate whose production costs will be low; protection against over-current; cable joint. For AC loss reduction, assembling narrow coated conductors with reduced gaps between them is effective, and AC loss below 0.1 W/m @1 kA was achieved. With respect to the application of coated conductor with textured-metal substrate, a cable manufacturing technology using this type of coated conductor, which is relatively soft, was developed, and possible AC loss reduction was confirmed through simulation experiments. Based on the developed key technologies, a 20 m cable composed of two sections of cables and a joint was designed, constructed, and tested. The two sections of conductors as well as the joint withstood the over-current of 31.5 kA and 2 s. The resistance of the joint is less than 0.01 microOhm. *This work was supported by NEDO as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.*

12:15pm

1LB06 - The Overview of HTS Cable in DAPAS Program

***J.Cho**, K.-D.Sim, S.Kim, Korea Electrotechnology Research Institute; S.-K.Lee, H.-M.Jang, C.-D.Kim, LS Cable Ltd.*

DAPAS (Development of Advanced Power system by Applied Superconductivity technologies) program that the superconductivity national program has been started one of the 21C frontier programs from 2001 in Korea. DAPAS is divided to 3 phases, for each 3 years in phase I and II, for 4 years in phase III, and mainly focused on developing HTS power devices and HTS wire. Among HTS power devices items HTS power cable, transformer, fault current limiter, and motor are located as one of the items in DAPAS. Furthermore, the development of coated conductor is the important target of DAPAS program. During the 1st phase, a single-phase and three-phase 50 MVA, 22.9 kV class HTS cable of 30 m length were developed and tested by KERI (Korea Ectrotechnology Research Institute) and LS Cable Ltd. The 22.9 kV, 50 MVA, 3 phase, 100 m HTS cable system with joint box and two compact terminations have been installed and tested during 2nd phase (2004-2007) in KEPCO (Korea Electric Power Company) Testing Center at Gochang, Korea. The 3rd phase of DAPAS program was launched at April 2007, and the ultimate goal of HTS power cable project is to develop 154kV, 1GVA class HTS power cable.

MONDAY AFTERNOON POSTER SESSIONS
2:00pm - 4:00pm

1LPA - Very High Field Magnets – I 2:00pm - 4:00pm

1LPA01
Towards Beyond-1 GHz NMR; Field Stabilization in Driven Mode
Y.Saito, T.Takao, Sophia University, Japan; M.Takahashi, T.Yamazaki, RIKEN GSC, Japan; T.Kiyoshi, National Institute for Materials Science, Japan; M.Hosono, JEOL, Ltd., Japan; M.Hamada, F.Hobo, Kobe Steel, Ltd., Japan; H.Maeda, Riken GSC, Japan
Achieving a high magnetic field is important for enhancing the NMR sensitivity and resolution. It is especially useful for solid state NMR on quadrupole nuclei. We have commenced a project to develop a beyond-1GHz NMR; the Nb3Sn innermost coil of the 920 MHz NMR is to be replaced by a Bi2223 coil. The HTS coil is operated in driven mode; the current fluctuation in a power supply causes field fluctuation which must be stabilized. This paper investigates a field stabilization method for a solid state NMR spectrometer operated in driven mode. The method employed a frequency counter, measuring the NMR oscillation frequency of a Li nucleus; The Li sample was mounted below an NMR sample tube. Based on the deviation of the NMR frequency of a Li sample, a current of a compensation coil was controlled, resulting in stabilization of the field fluctuation. The field fluctuation for a 500 MHz NMR magnet operated in driven mode was stabilized to +/-0.02 ppm by this method; the current fluctuation of the power supply was less than 10ppm. It is sufficient for solid state NMR measurement and furtheremore the method is robust in the face of large frequency changes. This is the first step for HTS application in the field of high field NMR.
This work is supported by SENTAN, JST in Japan.

1LPA02
Development of Novel Spectroscopic Magnet Combining Mass Spectroscopy with Magnetic Resonance
K.Kominato, R.Hirose, M.Takeda, JASTEC; O.Ozaki, Kobe Steel Ltd.; K.Fuke, H.Ohta, M.Sakurai, H.Tou, Kobe University
Conventional X-Ray and NMR (Nuclear Magnetic Resonance) spectroscopy is not available for small amount of samples (e.g., Functional peptide hormone). Recent mass spectroscopy is useful for such samples, however, it can not provide us information about molecular structure. So that structural analysis method for tiny samples is demanded. Fuke suggested a novel method which would enable structural analysis for gaseous tiny samples. It combines NMR spectroscopy with mass spectroscopy. Magnetic resonance is employed in the unusual way unlike typical FT-NMR. Mass selection is followed by measurement of magnetic resonance. We designed a superconducting magnet which is suitable for the novel spectroscopy. The magnet generates gradient field and two homogeneous regions. The magnetic field of two homogeneous regions are 12T and 4T with a room temperature bore diameter of 155mm. Details of designing and development are presented in this report.
This work is supported by SENTAN, JST in Japan.

1LPA03
20 T Compact Superconducting Outsert Employing Y123 Coated Conductors for a 45 T Hybrid Magnet
K.Watanabe, S.Awaji, G.Nishijima, T.Hamajima, Tohoku University; T.Kiyoshi, H.Kumakura, NIMS; S.Hanai, K.Koyanagi, M.Ono, Toshiba
We have been developing high-strength Nb3Sn strand cables to construct a high field superconducting outsert for a 45 T hybrid magnet with a 25 T water-cooled resistive magnet. The prebending effect of repeated bending treatment on Nb3Sn strands internally reinforced with CuNb stabilizer, which exhibits significant enhancement of the critical current density, has been found in the superconducting magnet fabrication process using a react-and-wind method. The designed strand cables are composed of three CuNb/Nb3Sn strands with the prebending effect and four stainless steel strands, which are expected to have a stress limit of 552 MPa at 0.4 % strain and a critical current of Ic = 1000 A at 18.5 T and 2.0 K. In order to design a compact superconducting outsert, high-strength strand cables are adopted in a magnetic field region below 14 T to maintain relatively large current properties. In a higher field region above 14 T, YBa2Cu3O7 (Y123) coated conductors are employed for an insert coil. Using combination of Y123, Nb3Sn and NbTi superconductors, a 20 T superconducting outsert with a room temperature bore of 400 mm consisting of three layers made of Y123, two layers of CuNb/Nb3Sn and two layers of NbTi was designed. The coil parameters are 440 mm inner diameter, 1080 mm outer diameter and 1138 mm coil height. A very compact 20 T superconducting outsert with a magnetic stored energy 72 MJ at an operation current 903 A can be developed for a 45 T hybrid magnet.

1LPA04
Design of Cryogenic System for SCH magnets
H.Bai, K.Cantrell, M.D.Bord, I.R.Dixon, A.Gavrilin, National High Magnetic Field Labotatory; R.Ganni, Jefferson Lab
Two Series-Connected Hybrid magnets are being developed at the National High Magnetic Field Laboratory. One is for neutron scattering experiments with a horizontal bore of 25T or 30T at the Hahn-Meitner institute, Germany. The other is for the National High Magnetic Field Laboratory with vertical bore of 36 T. The Magnet is a hybrid combining a set of resistive Florida-Bitter coils with a superconducting outsert constructed of cable-in-conduit conductor (CICC). Between the HMI and NHMFL systems, the outsets have the same Nb3Sn primary coil. The shield coils are made of NbTi CICC but different in configurations. The two SCH magnets are designed for various operating scenarios including those with multiple ramp cycles at various rates. Both the Nb3Sn coil and NbTi coil are forced flow cooled with supercritical helium at 4.5 K. A refrigerator with a capacity of about 160 W at 4.5K will be used to supply the cooling power and mass flow rate. The cryogenic system of the magnet consists a helium refrigerator, a buffer dewar with a valve box, a magnet interface box, the magnet cryostat and cryolines. In this paper, the design of the cryogenic system is described. Index Terms: Cryogenic system, Series-connected hybrid, Superconducting magnet, Cable-in-conduit conductor(CICC)

1LPA05
Design of NbTi Cable-in-Conduit Shielding Coils for the Series-Connected Hybrid.
T.A.Painter, I.R.Dixon, J.Toth, Y.Zhai, H.Y.Bai, A.Gavrilin, S.T.Bole, M.D.Bird, NHMFL
The design of the shielding coils for the Series-Connected Hybrid at the National High Magnetic Field Laboratory is presented. The shielding coils use NbTi cable-in-conduit conductor (CICC) technology; are cooled with forced-flow supercritical helium; and are charged in series with the main-field Nb3Sn CICC outsert coils and resistive insert coils. The shielding coil requirements and subsequent design details including conductor and coil cross-sectional configuration are presented. The materials choices, electrical joint design and proposed fabrication methods are also presented.

1LPA07

Electrical Joints for the Superconducting Outsert of NHMFL Series-Connected Hybrid Magnet System

T.Xu, A.Bonito Oliva, H.W.Weijers, T.A.Painter, S.Bole, T.Adkins, G.Miller, National High Magnetic Field Laboratory

Here, we report the development of the electrical joints for the superconducting coils in the new NHMFL Series-Connected Hybrid Magnet System (SCH). The superconducting outsert of the SCH consists of three concentric Nb3Sn coils using different size CICC conductors. Therefore, two splices and two terminals are required to connect the coils in series and then to the magnet bus bars. In this design work, the DC power dissipation in the steady state and the AC loss in the dynamic regime like fast ramp and slow insert trip need to be minimized and balanced according to the mission of the SCH. Two different joint designs originating from the 45-T Hybrid magnet and the ITER TFMC respectively are pursued in parallel. Full size samples of both styles were manufactured and tested using an inductive method in the l1-T Wide Bore Resistive Magnet Facility (WBRM). The comparison of the manufacture processes and the DC and AC performance are presented.

1LPA08

Mechanical Design and Analysis of the Superconducting Outsert for the Series Connected Hybrid Magnets

Y.Zhai, I.R.Dixon, M.D.Bird, National High Magnetic Field Laboratory

The NHMFL presently has three new hybrid magnet projects called the Series-Connected-Hybrid (SCH) magnets, two of which are entering a construction phase. The SCH magnets consist of a Florida-Bitter resistive insert nested within a CICC superconducting outsert to provide high fields for less power than traditional hybrid magnets. Each insert for the three systems is unique to the science and constraints of the respective facility. Regardless of the difference in the resistive insert designs, the mechanical design of the superconducting outsert coil is the same. The design of the SCH magnets is based on a CICC configuration using cable of multi-filamentary Nb3Sn and Cu strands inside a stainless steel jacket cooled by forced flow supercritical helium. The primary outsert coil design is presented along with the specific design criteria for the evaluation of conduit and conductor insulation components. The results of detailed finite element analyses performed for normal, quench and fault load conditions are discussed to ensure the levels of stress and strain in conduit and insulations satisfy the design criteria. The conduit evaluation of fatigue life and fatigue crack growth rate (FCGR) is also performed and the results are discussed for a possible cyclic lifetime and a minimum detectable flaw size for the SCH outsert. In addition, the design is shown to be insensitive to variation in insulation thickness, conduit corner radii, and FCGR material properties.

1LPA09

Stress Analysis and Structure Optimization on a Large Warm Split-gap High Magnetic Field Superconducting Magnet System

Q.Wang, Y.Dai, Z.Zhao, S.S.Song, S.Chen, Z.Cao, L.Yan, H.Huang, H.Wang, IEE, CAS; Y.Zhang, USTC, CAS; B.Gao, G.Kuang, HHMFL, CAS

There is a very strong demand for superconducting magnets with very high fields as basis for experimental high field facilities and new generations of special material processing. A high magnetic field superconducting magnet has been designed with the center field of 10 T and warm bore of 100 mm, warm split-gape of 100 mm. Two GM cryocoolers are employed to cool down the whole system. The superconducting magnet system consists of 6 high temperature superconducting coils with the superconducting properties of commercially available Bi-HTS wires and 8 NbTi superconducting coils. The high magnetic superconducting magnets about select of wire structure and stress support are studied, a new stress analysis and protect technology are suggested in the paper.

**The work was supported by National Large-Scitific Engineering in part and NSFC No. 50577063*

1LPB - Detector Magnets – I 2:00pm - 4:00pm

1LPB01

A Project of Solenoid Magnet and Flux Return for the PANDA Experiment

A.Bersani, R.Parodi, A.Pastorino, R.Ballantini, B.Gianesin, M.Macrì, M.Marinelli, INFN Genova

A project of the solenoid magnet for the PANDA detector developed in Genova is presented here. This is a thin, superconducting coil realized with Rutherford-type, aluminum stabilized cable, indirectly cooled using a circulation of two-phase helium in a proper net of pipes welded on an external coil former. The concept of this magnet is the same of many existing detector magnets, such as BaBar, Finuda, Delphi, CMS and many others: we took as a guideline keeping all the critical parameters under the values obtained in working magnets. The way the magnetic (2 T central field, ±2% uniformity, small radial field), thermal (1.8 K safety margin, safe quench behaviour) and mechanical (~100 t magnetic force compensation, path load for nested detectors) requirements were fulfilled is shown here.

1LPB02

Effects of Unequal Inter and Intra-toroid Response Times on the Quench Performance of the System of Three ATLAS Toroids

G.Volpini, G.Baccaglioni, INFN Milano, LASA lab. (Italy); D.E.Baynham, RAL, STFC, (UK); C.Berriaud, CEA, Saclay, (F); A.Dudarev, H.H.J.ten Kate, CERN, Switzerland

The ATLAS Experiment at the LHC (CERN) has a Toroidal Magnet System composed of one Barrel Toroid and two End Cap Toroids powered in series at 20.5 kA with a total stored energy of 1.6 GJ. So far the three magnets have been tested independently. In preparation of the overall magnet system test, here we review the quench behaviour under normal and faulty conditions including the information gained from the test of the three single magnets. In particular the consequences of variations in effective quench detection and quench heater activation times are studied. The effects on energy re-distribution, peak temperatures and internal voltage in the three toroids and between the 8 coils within a single toroid are investigated. Based on simulation studies partly verified by experiments, conclusions regarding the quench performance of the entire system are drawn.

1LPB03

Design of the Super Conducting Super High Momentum Spectrometer (SHMS) for the JLAB 12 GeV Upgrade.

P.Brindza, S.Lassiter, M.Fowler, Q.Sun, P.Medeiros, B.Metzger, JLAB

The 12 GeV Upgrade at Jefferson Lab requires a new particle spectrometer for precision Nuclear Physics studies at the highest electron momentum available. This new spectrometer the Super High Momentum Spectrometer (SHMS) operating at 11GeV/c will be built in Hall C to work in coincidence with the present device, the 7.5 GeV/c High Momentum Spectrometer (HMS). The SHMS design requires five new SC magnets arranged as dipole, quad, quad, quad, dipole or dQQQD. The "d" is a small 3.5 T, SC dipole providing an initial 3.5 degree bend which allows the SHMS to reach a 5.5 degree scattering angle and provide enough clearance for the other much larger magnets of the SHMS. The first SC quad is an upgraded version of a quad that is part of the HMS running at 8.9 T/M in a 40 cm warm bore with a 2 M EFL.. The second and third quads are an identical pair of a completely new design, 60 cm warm bore, 13.5 T/M, 1.8 M EFL cosine type SC quadrupole. Finally, the main dipole is a 60 cm warm bore 4.5 T, 3 meter EFL magnet that provides the momentum analysis for the SHMS. This project is on schedule for the start of commercial procurement beginning in FY2009 to support start of Physics with the SHMS in 2014. The final design details of these four unique magnets will be presented including the coil design, magnetic design, force collar, cryostat and quench protection.

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1LPB04

Structural Analysis of the SHMS Cosine Theta Super Conducting Dipole Force Collar

G.Markham, Novatech; S.Lassiter, P.Brindza, JLAB; B.Wands, FNAL

Jefferson Laboratory is developing a set of innovative superconducting magnets for the proposed 12 GeV upgrade in JLAB Hall C. We will report on the finite element structural analysis (FEA) of the force collar for the Super High Momentum Spectrometer Cosine Theta Dipole magnet. The force collar is designed with an interference fit and intended to provide enough pressure after cool down to operating temperature to counteract Lorentz forces acting on the dipole coil during operation. By counteracting the Lorentz forces and keeping the coil pack in overall compression, movement of the coils is expected to be minimized. The dimensional geometry of the cold mass is maintained in the commercial solid modeling code UG/I-DEAS while the magnetic field design is maintained in the commercial TOSCA code from Vector Fields. The three dimensional FEA was conducted in the commercial codes ANSYS and IDEAS. The method for converting the models and calculating the loads transferred to the structure is discussed. The results show the cold mass response to: force collar assembly preload, differential thermal contraction, and operational Lorentz loads. Evaluations are made for two candidate force collar materials and two candidate force collar designs.

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1LPB05

Coil Winding Experience for the Q1 Super Conducting Quadrupole for the Super High Momentum Spectrometer at Jefferson Lab

S.Lassiter, P.Brindza, M.Fowler, JLAB; R.Locke, S.Milward, P.Penfold, SMI

Trial winding of full size coils the Q1 magnet of the Super High Momentum Spectrometer (SHMS) for JLAB Hall C have been performed under contract by Scientific Magnets Inc. This effort was required to demonstrate that the unique Q1 Cold Iron Quadrupole shape can be executed with a Rutherford type SC cable. Details of the prototype winding tooling, conductor insulation scheme, coil former, the winding process including clamping and curing will be presented. Lessons learned from the initial set of windings were incorporated into the final trail windings of two complete full scale coils that can potentially be used in the actual magnet fabrication. The initial trial windings indicted that the coil end turns would benefit from additional support in the winding form and inclusion of a 5 degree shim along the first turn of the coil would be helpful in improving the fit up of the coils on the symmetry planes and lead to an improved end shape. These changes in coil shape were modeled in TOSCA and the resultant magnetic properties confirmed. The Q1 coils wound were tested for electrical properties and insulation effectiveness and dimensional consistency. Results from the three coils wound will be presented

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1LPB06

Commissioning test of ATLAS End-Cap Toroidal Magnets

A.Dudarev, H.H.J.ten Kate, J.Buskop, CERN; D.E.Baynham, RAL; A.Foussat, L.Deront, S.Ravat, X.Pons, G.Olesen, E.Sbrissa, R.Pengo, N.Delruelle, K.Barth, J.Bremer, J.Metselaar, CERN

The system of superconducting toroids in the ATLAS experiment at CERN consists of three magnets. The Barrel Toroid was assembled and successfully tested in 2006. Next, two End-Cap Toroids have been tested on surface at 77 K and installed in the 100-m underground cavern. The End Cap Toroids are based on Al stabilized NbTi/Cu Rutherford cables, arranged in double pancake coils and conduction cooled at 4.6 K. The nominal current is 20.5 kA at 4.1 T peak field in the windings and the stored energy is 0.25 GJ per toroid. Prior to final testing of the entire ATLAS Toroidal system, each End Cap Toroid has to pass its commissioning test to guarantee a reliable performance in the final assembly. In this paper the test layout and results are described. It includes the stages of test preparation, isolation vacuum pumping and leak testing, cooling down, step-by-step charging to full current, provoked quenches and quench recovery.. A few fast discharges at different currents are performed to check the quench detection and protection system and to demonstrate a safe energy distribution within the magnet after a quench or a triggered fast dump.

This project is funded by the ATLAS Collaboration, presently about 1900 scientific authors from 164 institutes in 35 countries and supported in part by CERN.

1LPC - Other Accelerator Magnets I – Muon 2:00pm - 4:00pm

1LPC01

Design and Construction of Test Coils for MICE Coupling Solenoid Magnet

L.Wang, X.K.Liu, F.Y.Xu, H.Wu, L.X.Jia, Institute of Cryogenics and Superconductivity Technology, HIT; M.A.Green, Lawrence Berkeley Laboratory

The superconducting coupling solenoid to be applied in the Muon Ionization Cooling Experiment (MICE) is made from copper matrix NbTi conductors with inner radius of 750mm, length of 285mm and thickness of 102.5mm at room temperature. The magnetic field up to 2.2 T at the magnet centerline is to keep the muons within the MICE RF cavities. Its self inductance is around 592 H and its magnet stored energy is about 13 MJ at a full current of 210A for the worst operation case of the MICE channel. The stress induced inside the coil during cool down and charging is relatively high. Two test coils are to build and test in order to validate the design method and develop the fabrication technique required for the coupling coil winding, one is 350 mm inner diameter and full length same as the coupling coil, and the other is one-quarter length and 1.5 m diameter. The 1.5 m diameter coil will be charged to strain conditions that are greater than would be encountered in the coupling coil. This paper presents detailed design of the test coils as well as developed winding skills. The analyses on stress in coil assemblies, AC losses, and quench process are carried out.

This work was supported by the Harbin Institute of Technology and 985-2 funds from the Ministry of Education of China.

1LPC02

Performance Tests of Test Coils for MICE Coupling Solenoid Magnet

L.Wang, F.Y.Xu, G.D.Yang, X.K.Liu, L.X.Jia, Institute of Cryogenics and Superconductivity Technology, HIT; M.A.Green, Lawrence Berkeley Laboratory

The MICE RF and coupling coil (RFCC) module consists of four 201.25 MHz RF cavities and a superconducting coupling solenoid magnet around the cavities. The muons are kept within the RF cavities by the magnetic field generated by the coupling solenoid. The coupling magnet is the largest of three types of magnets in MICE both in terms of 1.5 m inner diameter and about 13MJ stored magnetic energy at full current of 210A. Two test coils have been fabricated to validate the design method and develop the fabrication technique required for the coupling coil winding. A cryogenic station mainly composed of a refrigerator system with cooling capacity of 150W at 4.5K, test cryostats, control valve box and cryogenic transfer lines was designed and constructed to test the coils. The test coils have been tested under simulated operating conditions to prove the validity of the design concept. The electrical and thermal performances of the windings were measured. This paper presents the test results for the test coils.

This work was supported by the Harbin Institute of Technology and 985-2 funds from the Ministry of Education of China.

1LPC03

Magnetic and Cryogenic Design of MICE Coupling Solenoid Magnet System

L.Wang, F.Y.Xu, X.K.Liu, H.Wu, L.X.Jia, Institute of Cryogenics and Superconductivity Technology, HIT; M.A.Green, Lawrence Berkeley Laboratory

The Muon Ionization Cooling Experiment (MICE) will demonstrate ionization cooling in a short section of a realistic cooling channel using a muon beam at Rutherford Appleton Laboratory in the UK. The MICE cooling channel consists of alternating three absorber focus coil module (AFC) and two RF coupling coil module (RFCC) where the process of muon cooling and reacceleration occurs. The coupling magnet is a superconducting solenoid mounted around four 201MHz RF cavities, which produces magnetic field up to 2.2 T on the magnet centerline to guide the muons and keep them within the RF cavities. The coupling coil is to be built using copper matrix niobium titanium conductors with inner diameter of 750mm, length of 285mm and thickness of 102.5mm. It will be cooled by a pair of pulse tube coolers that generate 1.5 W of cooling capacity at 4.2 K each, and be powered using a single 300A, 10V power supply. This paper will update the engineering design of the coupling magnet system by ICST in China. The detailed analyses on magnetic fields, forces and stress induced during the processes of winding, cool down and charging, AC losses during charging and discharging and cooling system are presented.

1LPC04

Design, construction and performance test of MICE superconducting solenoids. Author, Bert Wang, Bob Wahrer, Clyde Tayler, Lian Xu and Tiki Juang

B.Wang, B.Wahrer, C.Tayler, L.Xu, T.Juang, Wang NMR Inc

The purpose of the MICE spectrometer solenoid is to provide a uniform field for a scintillating fiber tracker, and thus, it is also called tracker solenoid. The uniform field is produced by a long center coil and two short end coils. Together, they produce 4T field with a uniformity of better than 1% over a detector region 1000mm long and 300mm in diameter. Throughout most of the detector region, the field uniformity is better than 0.3%. In addition to the uniform field coils, we have match coil 1 and match coil 2. This two coils can be independently adjusted to match uniform field region to the focusing coil field. The overall coil package is 2544mm. We shall present the tracker solenoid cold mass design, the cold mass support against 50 ton axial load, the cryogen free system with cryocooler, recondenser, Hi-Tc lead and the vacuum vessel. Finally, we shall present performance test of the two MICE tracker solenoids.

1LPC05

Test Results for HINS Focusing Solenoids at Fermilab

M.A.Tartaglia, V.V.Kashikhin, D.F.Orris, I.Terechkine, J.C.Tompkins, Fermilab

A focusing solenoid R&D program has been completed and industrial production of magnets has begun. Two types of magnets are being built for use in the room temperature RF section at the front end of a superconducting H-minus linac as part of a High Intensity Neutrino Source. All of the magnets are designed as a main solenoid with bucking coils to cancel the field in the vicinity of adjacent RF cavities, and one type incorporates steering dipole corrector coils. We present a summary of the predicted and measured quench and magnetic properties for both R&D and production device samples that have been tested at Fermilab.

1LPC06

HINS Superconducting Lens and Cryostat Performance

T.M.Page, J.Dimarco, Y.Huang, D.F.Orris, M.A.Tartaglia, I.Terechkine, J.C.Tompkins, Fermilab

Fermi National Accelerator Laboratory is involved in the development of a 60 MeV superconducting linac. This linac is part of the High Intensity Neutrino Source (HINS) R&D Program. The initial beam acceleration in the front end section of the linac is achieved using room temperature spoke cavities, each of which is combined with a superconducting focusing solenoid. These solenoid magnets are cooled with liquid helium at 4.5K, operate at 250 A and have a maximum magnetic field strength of 7.5 T. A prototype solenoid cryostat was built and tested at the Fermilab Magnet Test Facility. This paper discusses the test results of the prototype and compares the measured and estimated performance of the cryostat. We also present the methods and results for measuring and fiducializing the axis of the solenoid lens.

1LPC07

Test Results of Superconducting Helical Solenoid Model for Muon Beam Cooling

V.S.Kashikhin, N.Andreev, G.Chlachidze, Fermilab; R.Johnson, Muons, Inc.; V.V.Kashikhin, M.J.Lamm, M.L.Lopes, A.Makarov, G.Velev, K.Yonehara, M.Yu, A.V.Zlobin, Fermilab

Novel configurations of superconducting magnets for helical muon beam cooling channels and demonstration experiments are being designed at Fermilab. The magnet system for helical cooling channels has to generate longitudinal solenoidal and transverse helical dipole and helical quadrupole fields. The short model of Helical Solenoid was designed, built and tested at Fermilab. The model has 0.6 m diameter cold mass and consists of four superconducting coils. All coils wound from SSC NbTi inner cable and capable to carry 10 kA current. The model should prove the design concept, fabrication technology, and the magnet system performance. The results of magnetic and mechanical designs with the 3D analysis using TOSCA, ANSYS and COMSOL are presented. The model quench performance is reported and discussed. *Work is supported by the U.S. Department of Energy

1LPC08

The Design Study of Superconducting Solenoid Coil System for Acceleration of Variable Carbon Ion

B.S.Lee, D.L.Kim, Y.S.Choi, H.S.Yang, Korea Basic Science Institute; Y.S.Kim, Korea Institute of Radiological and Medical Sciences

The KIRAMS (Korea Institute of Radiological and Medical Sciences) has identified superconducting magnet system as main magnetic field generator of next cyclotron in korea. The KBSI (Korea Basic Science Institute) has contributed to development of indirectional cooled superconducting magnet system for acceleration of variable carbon ion (C2+,C4+,C6+). The coil design of this magnet system must have satisfied not only reduction of manufacturing cost but also consideration of adequate operation currents for each carbon ion. This paper presents these challenges with comments and solutions adopted for these magnets. Our efforts are expected to provide a NbTi magnet, corresponding to magnetic field above 3.13 T in a 1200 mm bore. Conductors requirements, magnetic, mechanical and quench protection issues for these magnet design will be presented and discussed. Also, the status of prototype magnet for design study are presented.

1LPC09

Quench Protection for the MICE Cooling Channel Coupling Magnet

X.L.Gou, Institute for Cryogenic and Superconducting Technology, HIT; M.A.Green, Lawrence Berkeley Lab; L.Wang, F.Y.Xu, L.X. Jia, Institute for Cryogenic and Superconducting Technology, HIT

This report describes the quench protection system selected for the MICE coupling magnet. Quench protection is designed to be completely passive. The coupling magnet will employ two methods of quench protection simultaneously. The most important method of quench protection in the coupling magnet is the sub-division of the coil. Cold diodes and resistors are put across the subdivisions to reduce both the internal voltages to ground and the hot spot temperature. The second method of quench protection is quench-back from the mandrel, which speeds up the spread the coil normal region. This paper explores the effect of quench propagation velocity within the coupling magnet on the quench process. The effect of the amount of resistance across a sub-division of the MICE coupling magnet on reducing the hot spot temperature and the voltage to ground will also be explored.

This work was supported by the Harbin Institute of Technology through funding to the Institute of Cryogenic and Superconductive Technology. This work was also supported by the Lawrence Berkeley Laboratory and the Office of Science, United States Department of Energy, under the DOE contract DE-AC03-76SF00098.

1LPC10

Quench Protection for the MICE Cooling Channel Tracker and Focusing Magnets

X.L.Gou, Institute for Cryogenic and Superconducting Technology, HIT; M.A.Green, Lawrence Berkeley Laboratory; L.Wang, F.Y.Xu, L.X.Jia, Institute for Cryogenic and Superconducting Technology, HIT

This report describes the quench protection system selected for the MICE tracker and focusing magnets. Quench protection is designed to be completely passive. Since the MICE tracker and focusing magnets will be connected in series, quench back is essential for spreading the quench from one magnet to the other magnets in the string. The MICE tracker magnets and focusing magnets will employ sub-division of the coil with resistors and diodes across each sub-division to reduce the voltage to ground within the coil. This paper explores the effect of quench propagation velocity within the magnet on the quench process. The effect of the amount of resistance across a sub-division of the MICE tracker or focusing magnet on reducing the hot spot temperature and the voltage to ground will also be discussed.

This work was supported by the Harbin Institute of Technology through funding to the Institute of Cryogenic and Superconductive Technology. This work was also supported by the Lawrence Berkeley Laboratory and the Office of Science, United States Department of Energy, under the DOE contract DE-AC03-76SF00098.

1LPD - Cable-in-Conduit Conductors – I 2:00pm - 4:00pm

1LPD01

Ic measurements on Nb3Sn strands extracted from ITER CICC prototypes

R.Herzog, R.Wesche, P.Bruzzone, CRPP/EPFL

The unexpectedly low critical current performance of some ITER cable-in-conduit prototype conductors (CICC) tested in the SULTAN test facility during the last two years led to the question whether it arises from a transverse strain in the strands caused by the transverse Lorentz force or from a damage of filaments in the strands. Since the former process is in principle a reversible effect while the latter is not, measurements of the critical current of ~10 cm long strand sections extracted systematically from prototype samples were performed to see if and by how much the critical current dropped relative to the one of the witness sample. Strand witness samples had been mounted on ITER reference barrels, heat treated together with the conductor samples for the SULTAN tests and their Ic measured. The comparison between the critical current of extracted strands exposed to the strong Lorentz forces in high magnetic fields (more than 12 T) during the conductor test campaign and of extracted strands which had not experienced any significant Lorentz force revealed additional information. The n-values of the three classes of strands, characterizing the sharpness of the superconducting transitions, served as complementary indicators of the strand quality, in addition to the critical current values.

1LPD02

Non linear analysis of the cable layout influence on the stiffness of a ITER full size conductor

D.P.Boso, University of Padua, Italy; M.Lefik, Technical University of Lodz, Poland; A.Di Zenobio, ENEA, Italy; B.A.Schrefler, University of Padua, Italy

During the last decade an extensive Research and Development program has been performed to demonstrate the feasibility of ITER magnet system. The testing of real scale coils has provided valuable information to finalize their design. However the behaviour of Nb3Sn based cables was not as good as expected on the basis of the characteristics evaluated for the uncabled strands. This degradation in Nb3Sn performance seems to be due to various factors, among which the strain state of the filaments due to bending and contact phenomena inside the cable. Therefore the conductor degradation seems to be linked to the loads on the strands within the cable, and to the extent to which the wires are supported by each other, therefore to the cabling pattern. The objective of this work is to develop some finite element models, to analyse the influence of the cable layout on the overall stiffness of a cable. Non-linear behaviour of the material and contact phenomena occurring inside the strand bundle will be taken into consideration. The possibility of using advanced numerical techniques such as artificial intelligence (e.g. Artificial Neural Networks) to develop a fast and predictive tool is also discussed.

This work is partly supported by EFDA-ENEA, SULMOD contract.

1LPD03

3D Strain State Analysis in Nb3Sn Multifilamentary Strand Bundles Using Neutron Diffraction

F.Fiori, Università Politecnica delle Marche, Italy; D.P.Boso, Università di Padova, Italy; V.Calbucci, A.Manescu, F.Rustichelli, Università Politecnica delle Marche, Italy; B.A.Schrefler, Università di Padova, Italy

In the present concept of ITER fusion reactor most of the coils are made of Nb3Sn based strands with the cable-in-conduit-conductor technology. However Nb3Sn sensitivity to strain leads to considerable problems in accurate performance prediction for large multistrand conductors at high field. Besides complex stress–strain fields within the cable due to pulsing magnetic forces, the different thermal contraction coefficients and the helicoidal geometry of the strands inside the cable must be considered. The strain state is supposed to play a fundamental role on the performances of the cable in working conditions. On this basis, neutron diffraction tests were carried out to measure the residual strain state in specimens made of Nb3Sn superconducting strands. Two sessions of measurements were performed at ILL – Grenoble and LLB – Saclay on specimens made of 9 and 48 strands. In both experiments the strain state along the principal directions in each single component was measured, and some tests under applied uniaxial tensile load are also foreseen. In this paper, the elastic strain state obtained at room temperature in the different phases of Nb3Sn wires is presented and discussed.

This work was carried out in the framework of the EU Project KMM-NoE,contract no. NMP3-CT-2004–502243.

1LPD05

Impact of cabling pattern, magnet field profile and joint properties on short sample qualification tests of ITER conductors

E.P.A.van Lanen, Y.Miyoshi, M.Dhalle, H.H.J.ten Kate, A.Nijhuis, University of Twente

The data reduction associated with short sample tests on ITER Nb3Sn CICCs gives some scope for different interpretation. Therefore, a simple but above all genuine model is required to describe the involved phenomena and explain the measured voltage tap signals. We present a numerical model that allows calculating the voltage temperature traces of a short sample Nb3Sn CICC, exposed to a relatively short length of high field as in SULTAN. The model simulates the electrical behaviour of the superconducting strands, coupled with resistor networks that represent the sample joints and accordingly computes the map of the jacket potential (JackPot) distribution. An important feature of the model is that the magnetic field B varies along each strand following its specific trajectory depending on the selected cabling pattern, build up with a relevant number of strands and sub-stages. The local electrical properties of each strand are approximated by power laws, with B-, T-, and ε - dependent Ic and n values derived from the measured strand properties and described by a scaling relation. The calculations are compared with the experimental results of the EU TFPRO-2 and JATF-2 prototype TF conductors, showing a good agreement and validating the model. The model identifies useful guidelines for optimal data reduction from short sample tests and provides an extrapolation to the expected TF-coil performance.

This work is supported by the ITER Organisation.

1LPD06

Test results of a Nb3Sn Cable-in-conduit Conductor with variable pitch sequence

P.Bruzzone, B.Stepanov, R.Wesche, EPFL-CRPP; A.della Corte, L.Affinito, M.Napolitano, ENEA; A.Vostner, Fusion for Energy

The performance degradation under electromagnetic, transverse load has grown to a key issue for the design of Nb3Sn cable-in-conduit conductors (CICC). Beside the tolerance to bending strain of the basic Nb3Sn strand and the void fraction of the CICC, a relevant parameter is thought to be the cable pattern. A sequence of “long” twist pitches (pitch > 40 x cable size) in the early stages of a multi-stage cable is credited to mitigate the performance degradation compared to “short” pitches (pitch < 25 x cable size). To assess quantitatively the effect of long/short pitches maintaining constant all other conductor parameters, a short length of four stages CICC is prepared, where the first half length has long pitches (83/140/192 mm) in the first three cable stages and the second half length has short pitches (34/95/139 mm). The last stage pitch is 213 mm for both lengths. The cable is made of Cr plated copper and Nb3Sn strands with a diameter of 0.81 mm. The conductor is assembled into a SULTAN hairpin sample where the two branches have respectively long and short pitches. The DC performance, AC loss and pressure drop are measured in both conductor sections. The results are reported and the balance of advantages and drawbacks of long vs. short pitches are discussed.

1LPE - Cable-in-Conduit Conductors – II 2:00pm - 4:00pm

1LPE01

Interstrand Resistance and current redistribution in a Cable-In-Conduit Conductor (CICC) termination

F.Cau, EPFL-CRPP,CH-5232 Villigen PSI, Switzerland; M.Bagnasco, P.Bruzzone, M.Calvi, F.Roth,

The non-homogeneity of the contact resistance distribution in the terminations of large CICC leads necessarily in DC operation to a certain level of current imbalance among the strands. The overloading of a strand or a group of strands hit first the critical surface at the high field region, and a current re-distribution process is thus driven by the initial current sharing voltage to minimize the energy of the system. This process takes place preferably at the electrical connection where the inter-strand resistance is lower. In order to study this phenomenon, a new interstrand resistance experiment is carried out at CRPP on CICC termination of a NbTi sample. The sample was formerly prepared and tested to determine the contact resistance distribution in the JORDI test facility and it is now re-arranged for this test. Two elements at a time (strands or group of strands) are selected and fed with a current of the order of 50 A. The voltage between them is sensed and the resistance derived. The results of this sample, together with those related to the Nb3Sn termination previously tested, allow to evaluate the effectiveness of the current re-distribution in the joints. The comparison of the results of the two terminations allows to judge the impact of the conductor characteristics (e.g. material, coating, layout) on the interstrand resistance and therefore on the current distribution. The effect of the current redistribution on the voltage-current and voltage-temperature characteristics in short length conductor tests is also discussed.

1LPE02

Electromagnetic Analysis of ITER NbTi Cable-In-Conduit Conductors Including a Thermal Model

W.Zamboni, G.Rubinacci, F.Villone, Ass. EURATOM/ENEA/CREATE

In order to investigate the electromagnetic behaviour of ITER cable-in-conduit conductors (CICCs), computer codes are required in the design and in the interpretation of experimental data. The intrinsically 3D structures, such as of cables and the coupled thermo-electromagnetic phenomena call for a detailed and self-consistent 3D modelling, especially when peculiar behavior induced by electrical transients and self magnetic fields have to be described. To do this, we use a 3D integral formulation of magneto-quasistatic Maxwell's equations in terms of edge elements shape functions, coupled to a simple thermal model representing the heat exchange between superconducting elements and helium. This approach can be seen as a generalization of a 1D distributed electric parameters/resistive network model. Superconductors (described by a power law) are separated by resistive barriers (subcable wraps or strand coating) and electrically connected by resistive joints, modelled with details. Suitable feeding or measuring electrodes simulate the presence of external feeding and measuring circuits. The model is used to analyze ITER NbTi Poloidal Field CICCs.

This work is supported by the Italian MIUR and the EURATOM/ENEA/CREATE Association.

1LPE03

Parametric analysis of the ITER TF conductor samples in SULTAN with the THELMA code

F.Bellina, Universita` di Udine; M.Breschi, P.L.Ribani, Universita` di Bologna; L.Savoldi Richard, R.Zanino, Politecnico di Torino

To evaluate the validity of the design solutions for the ITER Nb3Sn cable-in-conduit TF coil conductors, many samples have been tested so far at the SULTAN facility at PSI in Villigen (CH), under conditions representative of the future operation in the reactor. These samples differed from each other as regards both the cabling geometrical parameters and the type of strand, and gave quite different performances, in some cases unsatisfactory. To better understand these experimental results, and to assess a possible acceptance test procedure to be used for the normal production conductor during the coil manufacturing, a deeper insight in the sample actual test conditions was considered necessary. The paper presents the results of a numerical analysis campaign carried out with the THELMA code in which the steady-state behaviour and the typical tests (current-sharing temperature and critical current measurements) foreseen for the SULTAN samples of the ITER TF reference conductor have been studied, with special reference to the current and the field distribution among and along the sub- cables. In this analysis, both the geometrical (twist pitch, joint/termination length) and the electrical sample parameters (joint, termination and inter-bundle resistance) are supposed to range in their design or their measured boundaries, in order to understand their individual effect on the conductor performances and test conditions.

1LPE04

Thermal Expansion and Modulus Measurements of Nb3Sn Cable-in-Conduit-Conductors

R.P.Walsh, FSU/NHMFL

The performance of a high field superconducting (Nb3Sn) cable in a magnetic field is highly dependent on the strain state of the superconductor. The CICC conductor is a relatively complex composite whose properties are difficult to predict and measure accurately. The cables tested here are applicable to the NHMFL 45 T Hybrid magnet and future Series Connected Hybrid magnets being built at the NHMFL. Tests have been conducted on prototype copper cables, and reacted Nb3Sn superconductor cables, to measure the residual strain state of the CICC caused by manufacturing variables and stress-strain response of cables when subjected to externally applied force. The residual strain state is measured with strain gages on short CICC samples specially designed to capture the thermal stress caused by differential thermal expansion in the composite conductor. The longitudinal and transverse compliance of cables are obtained from tensile and compressive tests of CICC samples. The tests results provide valuable data for the design and modeling of CICC superconducting magnets.

1LPE05

Interstrand contact resistance of a cable-in-conduit-conductor heat treated with oil on strand surface

J.Lu, V.Toplosky, K.Han, A.Bonito-Oliva, National High Magnetic Field Laboratory

The interstrand contact resistance (Rc) of a cable-in-conduit conductor (CICC) is intimately linked to its AC losses and stability. Applying oil on strands surface during cabling of a CICC is one way to prevent sintering between adjacent strands during the heat treatment and to obtain manageable Rc. To understand the effectiveness of the oil, it is important to measure the Rc of a CICC made in this way. In this work, an experimental setup is built to measure the Rc of ~ 300 mm long CICCs at 4.2 K. With this setup, large transverse loads can be applied during the measurement to simulate the Lorentz force in an operating CICC. Rc of a CICC for the NHMFL 45 T hybrid upgrade which was cabled with Mobile 1 oil is measured as functions of transverse loads and the numbers of load cycles. We found that the Rc of the virgin sample increases with transverse load up to 56.3 kN indicating the breaking of the slightly sintered strands under transverse loads. In contrast, after 10000 load cycles, Rc decreases with transverse load. Rc increases initially with the numbers of load cycles and saturates after about 100 cycles. Finally, a comparison is made between our results and the published results of the ITER CICC with chromium plated strands.

The financial support of the National Science Foundation under grant of DMR-0603042 and the Hahn-Meitner Institut is gratefully acknowledged.

1LPE06

Measurements of Critical Current and Current Sharing Temperature as a Function of Longitudinal Strain for the Medium and Low Field Cable-in-Conduit Conductors of the Series-Connected Hybrid Magnet

I.R.Dixon, M.D.Bird, R.P.Walsh, H.W.Weijers, J.Lu, National High Magnetic Field Laboratory

Representative cable-in-conduit conductor (CICC) for the Nb3Sn outsert coil of the Series-Connected Hybrid magnets are constructed for the purpose of measuring their performance. The hybrid magnets for the National High Magnetic Field Laboratory (NHMFL) and Hahn-Meitner Institiut (HMI) have common Nb3Sn superconducting coils but different resistive insert coils. The superconducting coils consist of three CICC configurations graded for the applied field. Two conductor grades, for the middle and low fields, are tested at the NHMFL in a split magnet that is equipped with a system that can apply up to 250 kN force in a direction longitudinal to the sample. The samples are hydraulically connected to a cryosystem to deliver temperature controlled supercritical helium. Measurements of current sharing temperature and critical current with respect to electromagnetic cycling and strain are performed and discussed.

1LPE07

Development of Nb3Sn Bronze TF Conductor Sample for Testing in SULTAN Facility

A.E.Vorobieva, A.K.Shikov, V.I.Pantsyrny, E.A.Dergunova, L.I.Vozhdaev, N.I.Kozlenkova, Bochvar Institute of Inorganic Materials; V.E.Sytnikov, A.V.Taran, A.V.Rychagov, Scientific Research and Development Cable Institute; P.Bruzzone, Ecole Polytechnique Federale de Lausanne Centre de Recherche en Physique des Plasma

The results are presented on research of the Nb3Sn bronze strand with increased value of Jc produced. The strand has been designed and fabricated for use in full scale ITER TF conductor sample for testing in the Sultan installation. The verification and qualification of strands have been done. The critical current measurements as a function of temperature in the range from 4.2 K to 15 K in magnetic fields up to 12 T have been performed. The results of testing of current sharing temperature Tcs of strand are discussed. The cable in conduit was manufactured in accordance with ITER recommended scheme option 2. Peculiarity of cable design, thickness of subcable wraps, void fraction and others characteristics of conductor for TF coil have been investigated.

1LPF - Power Transmission Cables – II 2:00pm - 4:00pm

1LPF01

The AC Loss Analysis in the 5m HTS Power Cable Model

K.A.Shutov, V.E.Sytnikov, V.S.Vysotsky, S.S.Fetisov, N.V.Polyakova, Russian Scientific R&D Cable Institute

In the framework of the Russian R&D Program for superconducting power devices, the 30 m HTS power cable has been developed. Before the full length cable production, as the first prototype the short 5 m cable model was produced and tested. The model consists of two layers of "Hermetic" HTS tapes from American Superconductor Co. The inner former is made of aluminum – copper composite and has the outer diameter ~35 mm. The details of the design of the cable model and test results are presented in [1]. To verify the calculations and designing principles the model was heavily instrumented by potential taps and sensors to measure current distribution among layers, voltage – current characteristics and other parameters. AC losses in this cable model have been analyzed by use of digital measurements of current and voltages along the cable. The details of AC losses measurements are discussed. Their analysis and comparison with calculations by standard theoretical models are presented. 1. V. E. Sytnikov et al, The 5m HTS Power Cable Development and Test, IEEE Trans on Appl Supercon. Vol. 17, N2, pp.1684-1687, 2007

1LPF02

Characteristics of AC loss after jointed High Temperature Superconducting tape and mini-model cable

H.Kim, K.Sim, J.Cho, S.Kim, Korea Electrotechnology Research Institute/Superconducting Device & Cryogenics Group; J.H.Kim, Chang-won National University

To obtain realistic data on the high temperature superconducting (HTS) power cable, 3-phase 100 m long, 22.9 kV class HTS power transmission cable system have been developed by Korea Electrotechnology Research Institute (KERI) and LS cable Ltd. that is one of 21st Century Frontier Project in Korea. This cable was installed at Go-chang testing site of Korea Electric Power Corporation (KEPCO). For the application of the HTS power cable joint is very important to ensure the performance. Therefore, this paper gives some investigation of AC loss, critical current and joint resistance in jointed HTS tape. We experimentally showed that the influence of joint resistance on AC loss by using several joint methods. Finally, we are measured critical current, AC loss and jointed resistance for the manufactured mini-model cable.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

1LPF03

Power Loss Mearsurement of 100m HTS Power Cable System by Calorimetry Method

J.H.Lim, S.H.Sohn, S.D.Hwang, KEPRI; H.S.Ryoo, KERI; H.O.Choi, H.S.Yang, D.L.Kim, Y.H.Ma, KBSI; K.Ryu, Chonnam National University

In order to meet the needs of economical and stable power supply and high current density cable with compact size, several countries carry out researches on High Temperature Superconducting(HTS) cables. Korea Electric Power Corporation(KEPCO) established the HTS cable test center and installed 22.9 kV, 1250 A, 50 MVA, 100 m class HTS cable system to investigate the performances and application possibility in real power grids. the HTS cable system went through 7 times cooling down and warming up cycles and also many kinds of performance tests for 3 years. Rated voltage-current tests, over voltage tests, and measurement of heat loss and AC loss with various currents have been examined. Moreover, DC critical current tests were performed for checking conductor degradation before warming up or after cooling down. Through the performance tests of the HTS cable system, the overall efficiency and loss factors are estimated and compared with conventional power cables in this paper.

This research was supported by a grant from Electric power Technology Evaluation & Planning center funded by Ministry of Commerce, Industry and Energy, Republic of Korea

1LPF04

AC Loss Characteristics of a Multi-layered Cylindrical High Temperature Superconductor

Y.H.Ma, Z.Y.Li, K.Ryu, Chonnam National University; S.D.Hwang, Korea Electric Power Research Institute

Recently, the greatly improved Jc of high temperature superconductor (HTS) is leading to the commercialization of superconductor power devices including power cable, fault current limiter, power storage, etc. Though the commercialization is not easy because of economic disadvantage of the system arising from the AC loss problem, demonstrative tests on cable is being actively performed worldwide. Especially, in the multi-layered structure with many HTS tapes as in cable application, the understanding on evaluation and characteristics of AC loss by electrical method is not clear because of non-uniform current distribution and different phase among the layer currents, hardly connect the voltage lead to pick-up loss flux completely in the inner layer, etc. Therefore, the cylindrical multi-layered HTS cable was prepared using Bi-2223 tapes to elucidate the AC loss characteristics of multi-layered HTS cable. In this work, magnitude and phase of layer currents were set completely equally by wiring the individual current leads in series and setup voltage leads on each layer to electrically evaluate the AC loss. In addition, AC losses were experimentally investigated for the each single layer and the each layers on layer currents with various directions. Finally, the resulting AC losses were theoretically reviewed by numerical analysis.

research was supported by a grant from Electric Power Industry.

1LPF05

Development of YBCO HTS Cable with Low AC Loss and HTS Joint with Low Electrical Resistance

M.Yagi, S.Mukoyama, Japan / Furukawa Electric; N.Amemiya, Japan / Yokohama National University; N.Kashima, S.Nagaya, Japan / Chubu Electric Power Company; Y.Shiohara, Japan / ISTEC-SRL

For an increasing electrical demand, we have developed high temperature superconducting (HTS) cables using YBCO tapes. YBCO tapes with 10 mm wide were divided into five strips using a YAG laser to reduce AC loss. We fabricated a 10 m HTS cable with a three-layer HTS conductor, electrical insulation, and a one-layer HTS shield. The AC loss in this 10 m HTS conductor was less than 0.1 W/m 1 kA and 50 Hz. In addition, it is important to develop an HTS joint with good mechanical properties and a low electrical resistance. The HTS joint that included 3-layer HTS conductor and 1-layer HTS shield was designed and fabricated. The HTS joint was compact and had enough mechanical properties and low electrical resistance. And we also confirmed the efficiency of the HTS joint construction. Moreover, the 20 m long HTS cable test was successfully demonstrated in January 2008. This HTS cable consisted of two-type 10 m HTS cables and the HTS joint. One 10 m HTS cable using HoBCO was made by SEI and the HTS joint and the other 10 m cable using IBAD YBCO was made by Furukawa and CEPCO. The electrical resistance of the HTS joint was less than 0.01 microOhm and the 20 m HTS cable including the HTS joint withstood the over-current condition of 31.5 kArms for 2 seconds.

This work was supported by NEDO as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

1LPF06

Invited

Study on the AC loss of 22.9kV/150MVA high-Tc superconducting power cable

S.J.Choi, S.J.Lee, Uiduk University/Electrical Engineering Department; K.D.Sim, J.W.Cho, KERI / Superconducting Devices and Cryogenics Research; S.K.Lee, LS Cable

By means of several loss factors (Hysteresis, Eddy current, Coupling Loss, etc), HTS shows AC losses under the AC systems. The AC loss in a HTS tapes is usually much lower than the resistive loss in a normal conductor under the same circumstances. Nevertheless, minimization of the AC loss is technically important because the energy is dissipated as heat in the low temperature. It is necessary that study theoretically and experimentally to analyze the AC losses. The HTS power cable is composed of 2 layers for transmission and 1 layer for shield. For the analysis of AC losses in an HTS power cable, 2-dimensional numerical calculation is carried out to figure out the magnetic field. We calculated the magnetization losses in HTS core for cable from these field. And we calculated the transmission losses using a monoblock equation. These calculated results are in accord with those of experiment.

1LPF07

Numerical Analysis of AC Loss Characteristics of Multi-Layer HTS Cable Assembled by Coated Conductors

S.Fukui, J.Ogawa, N.Suzuki, S.Watanabe, T.Oka, T.Sato, M.Yamaguchi, Niigata University; O.Tsukamoto, Yokohama National University

With the recent progress of fabrication technology of long length YBCO coated conductor, a high current YBCO cable must be a next candidate for the AC power transmission cables. Since the current capacity of a HTS tape is limited, the conductors for AC power transmission should be assembled by multiple HTS tapes to obtain the necessary current capacity. Generally, HTS cables are made by assembling HTS tapes around the circumference of the cylindrical former. In the cable conductor assembled by the HTS tapes, the AC loss characteristics are strongly depend on the structures of the cable. Therefore, to design it is important to precisely understand the AC loss characteristics of the cable conductor assembled by multiple HTS tapes. In our previous study1, we have developed the numerical model to analyze the AC losses in the HTS cable made by the thin coated conductor. In this study, we extend our numerical model to the multi-layer cable. Based on the model, the influences of tape gap length, tape width, former radius, tape number and layer gap on the AC loss characteristics are numerically studied and the recommended structure to achieve low AC loss is discussed. 1 S.Fukui, R.Kojima, J.Ogawa, M.Yamaguchi, T.Sato, O.Tsukamoto, IEEE Trans. on Appl. Supercond., vol.16, No.2, pp.143-146, 2006.

1LPG - Fault-Current Limiters – I 2:00pm - 4:00pm

1LPG01

Analysis and Short Circuit Test of Various Types of YBCO Bifilar Winding

Y.Zhou, Z.Zhang, Y.Wang, Y.Jia, X.Li, L.Xiao, Institute of electrical engineering, Chinese Academy of science

This paper deal with performance under short circuit test of bifilar windings using YBCO high temperature superconducting (HTS) wire. Due to its promising electromagnetic properties, YBCO HTS wire might considerably increase the feasibility of superconducting current limiters. The paper presents experimental quench result with three types of YBCO bifilar winding for different test conditions. The bifilar windings have different structure and stability respectively. These types of winding are solenoid cooled in single facet, solenoid cooled in double facets and pancake cooled in double facets. The windings were applied by controllable AC pulse with duration from 80ms to 320ms, voltage from 10V to 40V. In result of tests, the pancake cooled in double was more effective to limit a fault current. Both solenoid and pancake has outstanding characteristic of stability. The feasibility of the FCL using YBCO HTS wire was verified by this paper.

This work was supported by the National High Technology Research and Development Program of China(2006AA03Z210)

1LPG02

A Concept of control technique of starting level of current limiting of SN transition type fault current limiter

S.Torii, A.Ichinose, CRIEPI

The fault current limiter (FCL) is a new concept power apparatus that it does not appear impedance during normal operation of power system, and appears impedance rapidly just after fault occurrence and reduces the fault current. Applying the superconducting technology for FCL, it is possible to reduce loss for normal operation, to detect and to limit the fault current by itself just after fault occurrence. Especially, the SN transition type superconducting FCL is simple for both of concept and construction. But the characteristics of YBCO thin films still remain scattering for critical current, so it is difficult to construct the FCL with same capacity. It has already measured the strong temperature dependence of critical current of YBCO thin film. We focused on this property, and proposed the regulation method by the temperature control. We measured the temperature dependence both of critical current and starting current of limiting. They have similar relations against temperature. So, we considered that it has possibility to control the starting level of limiting current by the control of LN2 temperature.

1LPG03

Integrated current limiting effects of a matrix-type SFCL with Serial and Parallel Arrays.

J.H.Lee, H.S.Choi, Y.S.Cho, Chosun University; B.S.Han, Chonbuk University; B.I.Jung, H.M.Park, Chosun University

The matrix-type superconducting fault current limiter(SFCL) using YBCO thin film consists of the trigger and current-limiting parts. We fabricated the matrix-type SFCL with the integrated current limiting modules. A trigger part has a reactor to apply external magnetic field and a superconducting unit to sense the fault. The current limiting part has two superconducting units to limit the short-circuit current. To analyze the current limiting characteristics, we carried out the experiment of matrix-type SFCL with the integrated current limiting modules connected in serial or parallel connection. When the applied voltage was increased, the quenching characteristics of superconducting units were improved in the matrix-type SFCL with serial connection. This is because the difference of critical current between superconducting units was decreased by increment of current flowing into the reactor which applied the magnetic field into the superconducting units. As a result, we confirmed that the serial connection could improve the quenching characteristics by the integrated current limiting effects of a reactor, and the parallel connection could increase the capacity of the SFCL by the current distribution effect. In the meantime, the parallel arrays reduced the voltage gaps generated between superconducting units.

This work has been supported by KESRI(R-2005-7-066), which is funded by MOCIE(Ministry of commerce, industry and energy).

1LPG04

Experimental Analysis of Bifilar Pancake Type Fault Current Limiting Coil using Stabilizer-Free Coated Conductor

J.B.Na, D.K.Park, S.E.Yang, Y.J.Kim, K.S.Jang, T.K.Ko, J.W.Park, Yonsei University

YBCO coated conductor (CC) have been researched and manufactured actively these days. Equally, stabilizer-free (SF) CC with Hastelloy substrate was developed for superconducting fault current limiter (SFCL). The SF CC has higher resistivity than other existing CCs with thick metallic stabilizer. Higher voltage per unit length can be applicable to the SF CC at the same condition of temperature rise during fault. Thus, total amount of CC required for SFCL can be reduced. The bifilar pancake coil using SF CC was manufactured and characteristic tests of the coil for SFCL were performed in this research. Though the bifilar coil is supposed to have no impedance during normal operation, the transport current loss will be produced due to AC current flowing through the SF CC. AC loss was measured and short-circuit test was performed in liquid nitrogen. In order to develop large scale SFCL, it is indispensable to consider the dielectric characteristics of pancake module. Dielectric breakdown tests were carried out to find applicable maximum voltages in one pancake module. These results were provided to suitable design parameters and to show technical feasibility of pancake type module as an SFCL.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

1LPG05

Power Hardware-in-the-Loop Testing of a YBCO Coated Conductor Fault Current Limiting Module

C.Schacherer, Forschungszentrum Karlsruhe, Institute for Technical Physics; M.Steurer, Florida State University, Center of Advanced Power Systems; M.Noe, Forschungszentrum Karlsruhe, Institute for Technical Physics

The quality and quantity of YBCO coated conductor manufacturing process has made good progress in the recent years. The availability of long length coated conductors with constant quality has started miscellaneous activities in material characterisations as well as developments and tests of electrical power applications like motors, transformers and fault current limiters (SCFCL). It is clear that for medium and high voltage levels resistive SCFCL applications consists of several modules connected in serial and parallel to adapt the required voltage and current. The limited length of such an SCFCL module simplifies the configuration, manufacturing, maintenance and enables testing under laboratory conditions at reduced power levels. In order to test SCFCL modules under conditions they will experience in electrical high voltage networks, advanced test methods such as power hardware-in-the-loop (PHIL) can offer significant advantages. This test method allows studying conditions such as voltage stability and severe system perturbations with the actual SCFCL module in the loop. Therefore, the quench behaviour of the SCFCL module can be tested under conditions of real electrical power networks. This paper presents results from PHIL experiments with a SCFCL module consisting of a 10m coated conductor. For comparison, test results obtained with the same module under conventional laboratory conditions are shown.

1LPG06

Experimental Investigation of Parallel Connected YBCO Coated Conductors for Resistive Fault Current Limiter

A.Kudymow, C.Schacherer, M.Noe, W.Goldacker, Forschungszentrum Karlsruhe, Institute for Technical Physics

The rapid development of critical current density, homogeneity and manufacturing process of YBCO coated conductors (CC) opens up new fields for power applications. The feasibility of superconducting fault current limiter (SCFCL) at medium und high voltage levels or for high current applications would be unimaginable without modular assembling. This means that CC have to be connected in series according to voltage condition and in parallel according to specific current requirements. The limiting behaviour and the AC-losses of such a module can be defined by purposeful selecting components with different physical properties. This work presents the experimental results of parallel connected CC with equal and different physical properties like stabilisation and critical current (Ic). The tests are performed under different over-currents from minor overloads to fault currents and demonstrate the limiting behaviour of a single CC and of the bundled CC in liquid nitrogen bath under ambient pressure.

1LPG07

Fault Current Limiter Using YBCO Coated Conductor – Limiting Factor and its Recovery Characteristics

C.A.Baldan, EEL/USP and FEG/UNESP; J.S.Lamas, C.Y.Shigue, EEL/USP; E.Ruppert Filho, FEEC/UNICAMP

A Fault Current Limiter (FCL) based on non-inductive high temperature superconducting coils were designed and tested in 220V line for a fault current peak between 1 kA to 4 kA. The coils employed second generation (2G) HTS tapes of YBCO coated conductor reinforced with stainless steel. Four tapes were electrically connected in parallel with effective length of 0.4 m per element (12 elements connected in series) constituting a single-phase unit. The FCL performance was evaluated through over-current tests and its recovery characteristics were analyzed in order to design the shunt protection. The projected limiting ratio achieved a factor higher than 4 during fault of 5 cycles without degradation. Construction details and further test results will be shown in the paper.

Work supported by Companhia Paulista de Força e Luz - CPFL and CAPES

1LPG08

Experimental and Theoretical Analysis on Magnetic Field Distribution and Maximum Transport Current of Two Non-Inductively Stacked YBCO Coated Conductor

Y.J.Kim, D.K.Park, K.S.Chang, S.E.Yang, T.K.Ko, Yonsei University; Y.S.Yoon, Ansan College of Technology; M.C.Ahn, MIT

This paper presents experiments and theoretical analysis on characteristics of multi-stacked YBCO coated conductors (CC) with non-inductive stacking method. When CC is applied to resistive superconducting fault current limiter (SFCL), adopting non-inductively winding method for the CC is necessary to reduce the AC loss of SFCL. The SFCL which has high current rating needs more parallel connected HTS tapes in limited space and stacking HTS tapes is a profitable option to make higher current rated SFCL. In this paper, we investigated characteristics of two different stacked CC tapes which have different substrate. We expected that the differences between two CC tapes can affect magnetic field distribution and available transport current of the stacked CC tapes. We measured critical current of each CCs and transport current of the stacked CC sample was compared with them. In addition, we re-ordered the stacks of CC to investigate the change of available current. The experimental observations have been compared with the theoretical predictions through finite element method (FEM) to investigate which CC tape and stacking order were suitable to stack the CC tapes for SFCL.

This work was supported by MOCIE through EIRC program with Yonsei Electric Power Research Center (YEPRC) at Yonsei University, Seoul, Korea.

1LPG09

Thermal, Electrical, and Mechanical Characteristics of Bifilar Coils using Coated Conductor for Resistive FCL during Short Circuit Condition

D.K.Park, S.E.Yang, Y.J.Kim, K.S.Chang, T.K.Ko, Yonsei University; Y.S.Yoon, Ansan College of Technology

Demand on fault current limiter (FCL) has been occurred as the fault level increases above the rating of existing circuit breakers in the power system. The purpose of this paper is to present a simulation and experimental results of the behavior of resistive FCL coils using coated conductor (CC) during short circuit duration. The study of thermal, electrical and mechanical phenomena of bifilar CC coils during fault condition is required for design of stable operating FCL. Two kinds of coils were dealt in this paper; pancake type and solenoid type non-inductively wound coil. Generated resistance curve and temperature distribution of each bifilar coil were simulated by thermal and electrical analysis, and mechanical stress analysis was also conducted. The analyses were performed by finite element method. Also, two kinds of bifilar coil were fabricated using CC and short circuit tests were performed in the liquid nitrogen. Experimental results were compared with simulations. These results are expected to be a basis design for stable operation of resistive FCLs.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

1LPG10

Characteristics of Simultaneous Quenches in Series-Connected Coated Conductor Coils of SFCL

E.R.Lee, D.K.Park, S.E.Yang, Y.J.Kim, K.S.Chang, T.K.Ko, Yonsei University; M.C.Ahn, MIT

This paper deals with characteristics of Simultaneous Quenches in Series-Connected Coated Conductor Coils to gain design parameters of non-inductive SFCL. We have investigated effective method of simultaneous quenches in series-connected coated conductor (CC) coils. The extremely rapid superconductor-normal transition causes the uneven quenches in series-connected CC coils. Consequently, an appropriate method for simultaneous quenches is needed for stable quench operation of CC operation in fault condition. In this paper, we adopted shunt resistors in parallel with each CC coil and external magnetic field by copper windings to achieve synchronized quenching time of all CC coils, respectively. The experimental results which include quench and electrical characteristics of each CC coil have been compared with the theoretical predictions by using finite element method (FEM).

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

1LPG11

Characteristics of Resistive-type Fault Current Limiting Elements using YBCO Superconducting Thin Film with Meander-shaped Metal Layer

H.Ohsaki, M.Sekino, S.Nonaka, The University of Tokyo

We have studied current limiting characteristics of resistive-type fault current limiting (FCL) elements having superconducting thin film by a numerical analysis method, and designed FCL elements having superconducting film deposited on almost whole area of the substrate and a gold layer deposited in the shape of meander on the superconductor. The FCL element used in the experiment had YBCO thin film superconductor, which had been fabricated by the MOD (Metal Organic Deposition) method and was about 40 mm wide and about 50 mm long. The gold layer was about 2 mm wide and about 170 mm long. The S-N transition phenomena of YBCO thin film superconductor and the normal-zone propagation were studied from the measured voltage and current waveforms, and also the steady-state characteristics of the FCL element was investigated. These experimental results were compared with the results of finite element analysis based on the thin-plate approximation and current vector potentials. The results have verified our FCL design concept, but indicated that further improvement in the patterning and fabrication of the meander-shaped metal layer was needed.

We would like to thank Dr. T. Kumagai of National Institute of Advanced Industrial Science and Technology for providing the YBCO thin film superconductor.

1LPH - Maglev, Bearings and Flywheels - II 2:00pm - 4:00pm

1LPH03

Tests and simulation of superconducting magnetic bearings

G.G.Sotelo, R.de Andrade Jr., A.C.Ferreira, UFRJ

This work presents a study of superconducting magnetic bearings (SMB). Three SMB prototypes were made using Nd-Fe-B magnets in the rotors (each one having approximately 80mm of external diameter) and a 75mm diameter YBCO disc. The magnetic rotors of these SMB prototypes were manufactured in two different topologies: flux shaper or axially magnetized rings. Bean critical state model was applied to simulate the levitation force of the SMBs. The simulation model was implemented using finite element method magnetostatic simulations (to solve the problem in the space) and finite difference method (to solve the problem in the time). This model calculates the SMB levitation force based on its critical current density, that was obtained by variation of external magnetic field. The model calculates the critical current density by finding the minimal energy state into the superconducting region. One system to measure the levitation force was developed to test the SMB prototypes. It was automatized by an acquisition board, that controls the SMB relative position (using a stepper motor) and acquire the force obtained from a load cell. Simulated and measured SMB levitation force results were very similar, showing that the applied simulation model is efficient for new SMB projects.

This work was supported by the Brazilian agency CNPq.

1LPH04

Analysis on the Levitation Characteristics of the Superconducting Sphere

S.W.Zhao, Q.L.Wang, C.Y.Cui, Q.Zhang, Institute of Electrical Engineering, Chinese Academy of Sciences

In this paper we study the distribution characteristics of the magnetic field in the levitation system, which consists of exciting coils, shaping niobium rings and the superconducting sphere, and the vibration properties of the levitated niobium sphere when it is perturbed. We calculate the magnetic flux density out of the sphere with FEM method. The results show the shaping niobium rings can effectively change the distribution of the magnetic field. We analyze the change rule of the levitation force and the velocity, and obtain the levitation stiffness of the superconducting sphere and the maximum vibration velocity that the sphere can tolerate in order to keep in the Meissner state. After that we calculate the electromagnetic field and the ac loss in the sphere and analyze the levitation stability of the system.

1LPH05

Assessment of the energy loss for SFES with rotational core type PMSM/G

J.P.Lee, N.H.Jeong, Y.H.Han, S.C.Han, S.Y.Jung, B.J.Park, T.H.Sung, Korea Electric Power Research Institute

The energy loss of the superconductor flywheel energy storage system (SFES) is mainly generated in the part of magnetic field such as superconductor bearing and the core with permanent magnet rotor of PM type synchronous motor/generator (PMSM/G). In this paper, to minimize the energy loss, the new type PMSM/G is developed. The new type PMSM/G is the rotational core type PMSM/G that both the core and the permanent magnet rotor rotate simultaneously at same speed. And the effect of the energy losses by conventional PMSM/G, the new type PMSM/G and the superconductor bearing are assessed. To do this, we manufactured the vertical axial type superconductor flywheel energy storage system with journal type superconductor bearing. Both the conventional PMSM/G and the new type PMSM/G can be installed in lower part of flywheel axis of this system. To quantitatively assess the energy loss for SFES, after measuring the energy losses by only superconductor bearing without any PMSM/G, the energy losses by the conventional PMSM/G and the new rotational core type PMSM/G with permanent magnet rotor empirically is measured. From the results, it is confirmed that the energy loss can be reduced considerably by means of new rotational core type PMSM/G.

1LPH06

Improvement of Energy Storage Flywheel System with SMB and PMB and Its Performances

H.Mitsuda, A.Inoue, B.Nakaya, M.Komori, Kyushu Institute of Technology

__INTRODUCTION__We have already developed an energy storage flywheel system using a superconducting magnetic bearing (SMB) and a permanent magnet bearing (PMB). The energy storage flywheel system is composed of a rotor with a flywheel, a superconducting bearing (SMB), a permanent magnet bearing (PMB) and a brushless type motor/generator. __SYSTEM__The superconducting magnetic bearing (SMB) is composed of a doughnut-shaped YBa2Cu3Ox superconductor (OD45mm x ID25mm) and four ring SmCo magnets (OD24mm x H4mm). By improving the structure of the permanent magnet bearing (PMB), the stiffness of the permanent magnet bearing (PMB) is larger than the previous PMB. __EXPERIMENTS__Spin down tests were performed in order to investigate the vibrations of the rotor. The results show natural rotation decay curves are observed which continue for about 60 s. The system has a resonant rotation speed. The displacement except for the resonant rotation speed is about 0.1-0.2 mm over a wide time range. Instantaneous voltage drop test was performed for confirming the flywheel energy storage system. Just after the instantaneous voltage drop, flywheel power supply rapidly increases from zero to 0.012 W. However, resistance load voltage keeps constant. __SUMMARY__We have developed and improved an energy storage flywheel system using a superconducting magnetic bearing (SMB) and a permanent magnet bearing (PMB). The energy storage flywheel system works well for the instantaneous voltage drop.

1LPH07

Test results of a compact radially layered superconducting flywheel energy storage with disk-type, permanent magnet motor/generator unit

Z.Kohari, Budapest University of Technology and Economics

A compact, radially layered flywheel was developed and manufactured at our department, which integrates driving magnets (PM part of the motor generator (M/G) unit) and bearing magnet (PM part of the SC bearing). Main goal of this development was to verify achievable power and energy density with the proposed permanent magnets disc-type M/G unit, and also to test mechanical calculations of the structure, the balancing features of the rotor and the achievable coefficient of friction. Test results of no-load (spin-down) and full-load operation are presented.

1LPH08

Effects of Spin-up Rate on Internal Resonance in a High-Tc Superconducting Bearing System

T.Suda, T.Tange, T.Sugiura, M.Yoshizawa, Mechanical Engineering, Keio University

Multi-degree-of-freedom nonlinear systems can show complicated dynamical behaviors, because energy transfer between multiple modes can occur through their nonlinear coupling. For example, in internal resonance, once one mode starts its natural oscillation, it causes to excite and to resonate another mode through nonlinear coupling, and this resonance also brings resonance of the mode first showing natural oscillation. This internal resonance can occur, if a system has two or more commensurable or nearly commensurable natural frequencies. We previously reported that a rotor magnet levitated over a high-Tc supercounducting bulk can show internal resonance between its vertical and horizontal oscillations while it spins, if the ratio of the two natural frequencies is two to one. This research investigates the rotor's transient behaviors passing through resonance by numerical analyses and experiments. Effects of spin-up rate on the internal resonance of the rotor have been examined and clarified by changing the rate of increasing voltage applied to the D.C. motor for rotating the rotor.

1LPH09

Double-evaporator Thermosiphon for Cooling 100 kWh Superconducting Flywheel Energy Storage system

S.Jeong, KAIST

This paper presents an idea of thermosiphon that peculiarly implements two integrated evaporators to cool both HTS (High Temperature Superconductor) bulks in different locations simultaneously. A so-called double-evaporator thermosiphon was designed, fabricated and tested using nitrogen as the working fluid under sub-atmospheric pressure condition. The operating temperature is approximately 70 K. To confirm the feasibility of double-evaporator thermosiphon, the experiment on cool-down process and steady-state operation was extensively conducted by a small-sized mock-up double-evaporator thermosiphon (Ltot = 231 mm, do = 50 mm). The double-evaporator thermosiphon worked successfully at steady-state operation. The results showed that its had the total temperature difference of 1.59 K and the temperature difference between two evaporators of 0.64 K at the heat flow of 10.6 W. Based on the preceding results of small-sized double-evaporator thermosiphon and additional experiments, a large-sized double-evaporator thermosiphon (Ltot = 1050 mm, do = 160 mm) was designed for the actual 100 kWh SFES (Superconducting Flywheel Energy Storage) application. The potential impact of superior heat transfer characteristic of the double-evaporator thermosiphon is discussed in the paper.

1LPH10

Improvement of Magnetically Levitated Superconducting Conveyer using PMB

T.Uchiyama, B.Nakaya, A.Inoue, M.Komori, Kyushu Institute of Technology

---INTRODUCTION---We have already developed a magnetically levitated superconducting conveyer. The conveyer is composed of a levitated stage with permanent magnets, a conveying stage with superconductors and permanent magnets, electromagnets, and Hall sensors. ---SYSTEM---The levitated stage has two permanent magnets (PMs) (Φ50 x 10mm). The conveying stage has also two superconductors (OD45mm x ID25mm x T20mm) and two permanent magnets. The superconductor with a permanent magnet, and the permanent magnet are facing each other. Thus, the two permanent magnets yield a permanent magnet bearing (PMB). The levitated stage is supported by the pinning force and the repulsive force. ---EXPERIMENTS---In order to confirm the effect of the permanent magnet bearing (PMB), the gap between the levitated stage and the conveying stage was measured. From the results, it is found that the levitated stage keeps a constant gap compared with the previous system without permanent magnet bearing (PMB). Impulse responses for levitated stage without control show that there are some vibration modes and that vibrations decrease exponentially. When PD control is applied to the system, the vibrations of the levitated stage are suppressed well. This shows that the effect of the PD control is obvious for the levitated stage. ---CONCLUSIONS---We have improved the magnetically levitated superconducting conveyer and controlled the levitated stage. The system shows the better performances than the previous system.

1LPJ - Measurement Techniques and Instrumentation
2:00pm - 4:00pm

1LPJ01

Index Loss Effect in n-value Measurements of Commercial Superconductors

Y.Lvovsky, GE Healthcare

In persistent applications such as NMR and MRI, the n-value of superconductor is one of the major design parameters and a cost driver. Determining the actual n-value accurately is critical to the magnet design. In conduction-cooled HTS coils with low n-value, the heat generated by index loss causes stability crisis and reduces stable parametric design space well below the critical current [1]. It was shown recently for the adiabatic MgB2 superconductors [2] that the substantial overheating from the index loss produces misleading, artificially high measured n-values. To reduce the heating effect, fast dynamic pulse measurements were suggested for MgB2 adiabatic conductors. This paper presents analysis that shows that in the helium-cooled commercial NbTi and Nb3Sn wires (as well as in cooled MgB2 and HTS conductors), the index loss can noticeably affect the measured n-values, even when obtained in the helium bath. The overheat of a few tens mK or less is sufficient to artificially increase the measured n-value; the error is increasing for conductors with higher n. Analytical correlation is given between the apparent steady-state-measured and the actual n-values. Effect of Ec-criterion, heat transfer and current sharing is discussed. [1] Y. Lvovsky. IEEE Trans. Appl. Supercond., 2001, v. 11, pp.1840-1843. [2] A. Stenvall, A. Korpela, J. Lehtonen and R. Mikkonen. Supercond. Sci. Technol., 2007, v.20, pp.859-864.

1LPJ02

Strain Measurement in Low Temperature Superconducting Magnet through Fiber Bragg Grating

H.J.Zhang, Q.L.Wang, Institute of Electrical Engineering, Chinese Academy of Sciences; G.J.Huang, Z.H.Jiang, J.Xiao, Institute of Mechanics, Chinese Academy of Sciences

Abstract—The strain response of Fiber Bragg grating (FBG) sensors at 4.2 K has been studied. The function between the strain and the central wavelength shift of FBG was achieved. Based on the result, the strain measurement in superconducting magnet cooled by liquid helium was carried out. A high magnetic field superconducting magnet was designed and fabricated, and FBG sensors array were attached along circumferential and axial direction of the magnet, which could monitor the hoop strain and the axial strain respectively. The finite method (FEM) was used to simulate the magnet strain, and the experimental value is close to the calculated result. Then the FBG can be used in liquid helium and high magnetic field environment for strain measurement. A novel technology using FBG strain sensor to monitor strain in a LTS high magnetic superconducting magnet is developed.

1LPJ03

Splice Resistance Measurements in 2G YBCO Coated Conductor

C.M.Rey, R.C.Duckworth, Oak Ridge National Laboratory

The Oak Ridge National Laboratory has been investigating the electrical splice resistance of second-generation (2G) YBCO coated conductor. The purpose of the experimental investigation is to study the splice resistance of 2G YBCO coated conductor as a function of: a) surface preparation condition, b) flux type, c) solder type, d) sheath materials, e) operating temperature, f) thermal cycle, and g) magnetic field. Understanding the splice resistance with its corresponding variation as a function of surface preparation and operating conditions are essential to the practical implementation of electric utility devices e.g. motors, generators, transformers, cables, and fault-current limiters, etc. Preliminary test results indicate that the barring any physical that the 2G YBCO tapes show little degradation as a function of thermal cycle. Furthermore, test results on 2G YBCO indicate that the splice resistance is influenced by the operating fraction of the critical current (i= I op/Ic). This clearly demonstrates the importance of the superconducting properties (i.e. so called n-value) in determining the absolute value of the splice resistance. Surface preparation conditions, flux, type and solder type test results are also discussed.

Research sponsored by the U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, Superconductivity Program for Electric Power Systems under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, managed and operated by UT-Battelle, LLC.

1LPJ04

Design of a cryogenic calorimeter for synchrotron light source beam-based heating

F.Trillaud, S.Prestemon, R.D.Sclueter, S.Marks, LBNL

Superconducting insertion devices using Nb3Sn conductors offer the potential of higher brightness photon beams and enhanced spectral range over existing permanent magnet technology. However, Nb3Sn is a low temperature superconductor that must be operated at temperatures near 4.2 K. At these temperatures, any small heat dissipation can potentially be sufficient to lose the superconducting state of a section of a superconducting electromagnet. To quantify the amount of power deposited on the winding emanating from beam-induced heating on a storage ring, we propose a calorimeter that will be integrated into the synchrotron ring. The design of the calorimeter is discussed and the various heat input sources, expected to disturb the operation of a superconducting electromagnet, are reviewed. The calorimeter design attempts to provide sufficient data to isolate the different sources. A modular design will allow the calorimeter to be used on different synchrotron rings, providing further data of correlations between heat load and diverse beam parameters.

1LPJ05

Development of Testing Device for Critical Current Measurements for HTS/LTS

Q.Wang, Y.Dai, Z.Zhao, S.S.Song, IEE, CAS; S.Chen, Z.Cao, L.Yan, Y.Lei, H.Wang, IEE,CAS

The development of full cryofree test device is a very important technology, where allows high field superconducting magnets and high sample current to be operated without use of liquid helium and nitrogen to test the critical characteristics for the Bi2223 and YBCO tapes. For goal of superconducting magnet applications in the advanced testing of HTS wire and sample coils, a wide bore conduction-cooled superconducting magnet with available warm bore of 186 mm and center field of 6T for background magnetic field applications was designed and will be fabricated and tested. The Sample cryostat system consists of removable sample device and sample cryostat and other accessories. To meet the requirements of easy mounting/change of the sample, removable sample device is independent from sample cryostat. So sample with one cryocooler and all other accessories can insert from the top of cryostat. Four guide rods will be mounted on the top of cryostat so that removable sample device goes in and out easily and quickly. This allows measurements to be performed in a repeatable and reliable fashion. To support the high stress in magnet, the detailed finite element analysis with electro-plastic model is proposed. The sample cryostat is designed with cryofree. It includes two GM cryocoolers. The detailed design, fabrication and thermal analysis are presented in the paper.

**The work was supported by high technology project in part and NSFC No. 50577063*

1LPJ06

Magnetic field measurements of superconductive undulator mock-up coils

E.Mashkina, B.Kostka, E.Steffens, University of Erlangen-Nürnberg; A.Grau, T.Baumbach, S.Casalbuoni, M.Hagelstein, R.Rossmanith, ISS/ANKA, Research Center Karlsruhe; A.Bernhard, D.Wollmann, University of Karlsruhe

Accurate magnetic field measurements are a prerequisite for the characterization and optimization of insertion devices. At the synchrotron light source ANKA there is an ongoing R&D program for superconducting insertion devices. Within this program a device for precise magnetic field measurements of superconductive coils was designed, built and installed at the Forschungszentrum Karlsruhe. The magnetic field is measured by Hall probes along the mock up axis with a longitudinal precision of 10 µm. The data are acquired on the fly. In this contribution we present the measuring system and the first magnetic field measurements.

1LPJ07

Cryogen–free magnetic field measurement system for superconducting undulator coils

A.Grau, S.Casalbuoni, M.Hagelstein, R.Rossmanith, T.Baumbach, Institute for Synchrotron Radiation, Research Center Karlsruhe, Germany; E.Mashkina, B.Kostka, E.Steffens, University of Erlangen-Nürnberg, Germany; A.Bernhard, D.Wollmann, University of Karlsruhe, Germany

Superconducting cold-bore undulators are electrically tunable and have - for a given gap and period length - a higher field strength than permanent magnet undulators. The performance of superconducting devices depends strongly on the field quality, e.g. the homogeneity should be as good as possible. To characterize the magnetic field one needs a highly accurate field measurement system. At the Research Center Karlsruhe a test facility for superconducting coils up to a length of 1.5m is under construction. This design allows to measure both local fields with Hall probes and field integrals in a 4.2 K cryogen-free vacuum environment. In this contribution we focus on the description of the equipment, technical cryostat design and the measurement setup for local and integral field measurements.

1LPJ08

Cryogenic Low-Voltage/High-Current DC Power Source using Multi-Parallel-Connected MOSFETs

Y.Kondo, S.Fukano, T.Ishigohka, A.Ninomiya, Seikei University

The authors have proposed a cryogenic low-voltage/high-current DC power source using multi-parallel-connected MOSFETs for an excitation power source of superconducting coils. It has been confirmed that the power source can operate at 77 K in liquid nitrogen bath. The fundamental idea and some experimental results are presented. The experiment using 400 MOSFETs connected in parallel are carried out. The forward-direction voltage drop at 77 K has been measured. The excitation current of the superconducting coil can be increased and decreased arbitrarily. The experimental results show good prospect of this type of DC power source not only for the excitation of superconducting coils but also for the forced discharging of the coils.

1LPJ09

A Quench Monitoring System of Superconducting Coils by Using the Poynting's Vector Method

F.Sumiyoshi, A.Kawagoe, M.Tokuda, Kagoshima University

A new quench monitoring system by using the Poynting's Vector method was proposed to detect sudden local normal transition during an operation of superconducting coils. In this system, the superconducting coil is surrounded by the metallic thin cylinder composed of some pieces, where the cylinder is electrically insulated from the coil; potential leads to measure local electric fields are directly attached to this cylinder surface and pickup coils to measure local magnetic fields are put on the surface. The Poynting's vector distribution around the coil can be obtained by using many sets of both the potential lead and the pickup coil. Since sudden changes of energy flow profiles around the superconducting coil is induced in the event of occurrence of local normal transitions in the coil winding, such an unusual event in coils can be detected as the change of Poynting's vector distribution. This system has no risk of the destructive voltage breakdown which may happen in case of the existing balance voltage method, because it needs not the direct connection with the coil windings. And this method is expected to be higher reliability and responsibility than the acoustic emission method. The demonstration test was carried out to confirm whether the present method can detect the quench induced by the heater for the Bi-2223 coil immersed in liquid nitrogen, and a sign of the quench was successfully detected by the present method.

1LPJ10

High Resolution Data Acquisition System for Fast Voltage Transients in Superconducting Magnets

J.Lizarazo, D.Doering, L.Doolittle, J.Galvin, J.Joseph, A.F.Lietzke, A.Ratti, G.L.Sabbi, X.Wang, S.Zimmerman, Lawrence Berkeley National Laboratory

A novel system to monitor voltage transients in superconducting coils has been developed at LBNL. This new Magnet Voltage Monitoring System (MVMS) includes 160 monitoring channels capable of measuring differential voltages of up to 1.5 kV with 120 kHz bandwidth and 500 kS/s digitizing rate. This paper presents the system design and examines voltage-spike transients captured during testing of the high field dipole HD2. We discuss the signal characteristics for different processes occurring in the magnet and how the MVMS enhances our capability to determine the quench origins.

Research supported by the U. S. Department of Energy, under Contract No. DE-AC02-05CH11231.

1LPJ11

Characteristic Analysis and Design of the Heater Triggered Switch for High-Tc Power Supply of YBCO Insert Magnet in Various Helium Condition

Y.J.Kim, S.E.Yang, K.S.Chang, D.K.Park, T.K.Ko, Yonsei University; Y.S.Yoon, Ansan College of Technology; J.B.Song, H.Lee, Korea University

This paper presents experiment and characteristic analysis of high-Tc heater triggered switch using coated conductor (CC) in various helium environment. HTS power supply has been studied only focusing on proving the operational concept rather than applying to real superconducting magnet load. HTS insert which can be installed in a LTS magnet has been proposed and researched to generate higher magnetic field for NMR. Since CC could be an attractive option for HTS insert, it is important to research the characteristics of heater-triggered switch employing CC. HTS power supply consists of two switches and one of key design parameters is to make a timing sequential chart. We investigated, experimentally and theoretically, the quench and recovery time of the switch with respect to transport current. The maximum permissible transport current of the switch with the heater current was also investigated. The basic data of the heater-triggered switch for design of the HTS power supply was obtained; correlations among heater current, transport current, and quench/recovery time.

This work was supported by the Korea Science and Engineering Foundation(KOSEF) through the National Research Lab. Program funded by the Ministry of Science and Technology. (R0A-2007-000-20063-0).

1LPJ13

Optimal Processing Parameters of Piezoelectric Materials for Acoustic Emission Sensor for High Temperature Superconducting Power Application Systems

J.H.Kim, J.H.Lee, Korea Univ., Seoul, Korea; H.M.Kim, KERI, Changwon, Korea; W.S.Kim, C.Park, Seoul National Univ., Seoul, Korea; K.D.Choi, Korea Polytechnic Univ., Siheung, Korea; H.G.Lee, Korea Univ., Seoul, Korea

The acoustic emission (AE) technique is used as a complement to facilitate early detection of the presence of a "hot spot" in a superconductor and thus help to protect the power application system. The high temperature superconductor in the power application system can have micro-cracks and thermal/electrical shock by quench. Acoustic emission (AE) sensor detects mechanical vibration, induced by quench of superconductor, and directly converts AE signals to the electrical voltage peaks. It consists of two half moon piezoelectric materials such as Pb(Zr,Ti)O3–Pb(Fe2/3W1/3)O3–Pb(Mn1/3Nb2/3)O3 (PZT–PFW–PMN) ceramics. In this paper, we discuss the optimal processing parameters of piezoelectric materials to improve the resolution of AE sensor and its performance results in the bath of the liquid nitrogen (LN2).

This work was supported in part by a grant from the CAST of the 21st Century Frontier R&D Program and Electric Power Industry Technology Evaluation and Planning, and also was partially supported by MOCIE through EIRC program with YEPRC at Yonsei University, Seoul, Korea.

MONDAY LATE AFTERNOON ORAL SESSIONS 4:00am - 6:00pm

1LX - Accelerator Magnets I – Memorial to Hiromi Hirabayashi
4:00pm - 5:45pm

4:00pm
Invited

1LX01 - Status of Superconducting Magnet System for the J-PARC Neutrino Beam Line

***T.Ogitsu**, Y.Ajima, Y.Fujii, N.Higashi, N.Kimura, T.Kobayashi, Y.Makida, T.Nakamoto, H.Ohhata, T.Okamura, K.Sasaki, K.Tanaka, A.Terashima, T.Tomaru, A.Yamamoto, KEK*

A superconducting magnet system for the J-PARC neutrino beam line has been constructed since 2004. The system consists 14 doublet cryostats. Each cryostat contains 2 combined function magnets (SCFMs) of which required magnetic fields are 2.6 T dipole and 19 T/m quadrupole with 3.3 m magnetic length. The system also contains 13 inter-connect components, 3 corrector magnets, 5 beam monitors, 4 quench relief valves, and one vacant. The SCFMs had been developed by 2004 and mass-produced since 2005. The production of SCFM will be completed in summer 2008. The installation of the system will starts in Feb. 2008 and planed to be completed by the end of 2008. The paper summarizes the production of the SCFMs as well as the inter-connect components. The status of the installation will be reported also.

4:30pm

1LX02 - Quench performance of the Main Superconducting Magnets during commissioning of the LHC

***A.Siemko**, A.Ballarino, N.Catalan Lasheras, K.Dahlerup-Petersen, R.Denz, CERN; S.Feher, R.Flora, G.Kirby, FNAL; M.Modena, S.le Naour, M.Pojer, D.Richter, G.de Rijk, R.Saban, R.Schmidt, CERN*

The LHC is a complex machine requiring more than 1700 main superconducting dipole and quadrupole magnets distributed along a circumference of 26.7 km. All main magnets are wound from two types of cables with Nb-Ti strands. Thye contain protection diodes to by-pass the current in case of the transition to the normal conducting state in case of a quench, and hence reduce the hot spot temperature. These magnets are powered in 24 main electrical circuits with nominal current of 11850 A. Besides reaching magnetic fields with substantial margins above the required nominal range, all of the main LHC magnets must meet stringent requirements for their protection and electrical integrity. Like most large scale superconducting magnets, the LHC main dipoles exhibit premature training quenches, causing a progressive increase of the current level being reached after repeated quenching. In this paper the performance of the main LHC magnet circuits is presented, focusing on the quench training and magnet to magnet quench propagation behaviour. The results as measured on the entire circuits will be compared to the test results obtained during the reception tests of the individual magnets.

4:45pm

1LX03 - Fast Ramped Superferric Prototypes and Conclusions for the Final Design of the SIS 100 Main Magnets

***E.Fischer**, GSI; W.Gaertner, Babcock Noell GmbH; H.Khodzhibagiyan, A.Kovaelenko, JINR; G.Moritz, GSI; G.Sickler, Babcock Noell GmbH; A.Stafiniak, W.Walter, GSI*

The 100 Tm synchotron SIS 100 is the core component of the Facility of Antiproton and Ion Research (FAIR). An intensive R&D allowed considerably reducing the cryogenic losses as well as improving the field quality. Prototype magnets were built last year with the first dipole magnet completed by Babcock Noell GmbH and currently being tested. After a brief description of the main components and of the key production-steps, focus will be on the manufacturing of the new SIS100-superconducting coil and on the fabrication of the magnet's yoke. In order to monitor the magnet behaviour during the test phase and to yield the large set of experimental data, which is necessary to support the layout of the future series of 108 dipoles, a large array of sensors and instrumentation devices has been implemented. We present the experimentally measured loss to the one obtained by FEM calculation. This result is then extended on the foreseen operation cycles of SIS 100 and outlined which modifications are required for the series.

This work is supported by EU FP6 Design study (contract 515873 – DIRACsecondary-Beams)

5:00pm

1LX04 - Magnetic Testing of a Superferric Dipole that uses Metal-Oxide Insulated CICC Coils

*J.DeLauter, J.C.DeKamp, **A.F.Zeller**, NSCL/MSU; C.Gung, J.Minervini, PSFC/MIT*

A small superferric dipole has been constructed that uses metal-oxide insulated CICC (MO-CICC) coils in place of standard potted coils. The MO-CICC coils are constructed with inorganic materials and are therefore radiation resistant. The initial results from feasibility studies reported [1] tests at engineering current densities of 12 A/mm^2. The magnet is designed for 100 A/mm^2. Initial testing done at the MIT PSFC resulted in measured densities of more than 40 A/mm^2. Changes in current lead supports were required for higher currents. The test results are reported and extension of this technology to larger devices is discussed. [1] J. DeLauter, J.C DeKamp and A.F. Zeller, IEEE TAS 17, 1087 (2007)

Supported in part by grants from the NSF, PHY-0606007, and GSI. A portion of this work was supported by the U.S. Department of Energy, Grant No. DE-FC02-93ER54186

5:15pm

1LX05 - Operational experiences of superperconducting quadrupoles for BigRIPS in-flight separator at RIKEN

***K.Kusaka**, M.Ohtake, T.Kubo, Y.Yano, RIKEN; M.Nobutoki, Taiyo-Nippon-Sanso; H.Ito, N.Kakutani, T.Tsuchihashi, K.Sato, Toshiba*

The BigRIPS fragment separator in the RIKEN RIBF project is characterized by the fourteen superconducting triplet quadrupoles (STQ's). Each STQ contains three superconducting quadrupoles with effective lengths of 500mm-800mm/1000mm-500mm, in a single cryostat. The nominal field gradient of these quadrupoles is 14T/m and the warm bore diameter of the cryostat is 240mm. While the five STQ's on the first stage of the BigRIPS are cooled by a liquid-helium cryogenic plant, the nine STQ's on the second stage are cooled by small cryocoolers on their cryostat. The main components of the first stage cryogenic plant are a Linde TCF50S refrigerator, a 315kW Maekawa compressor, and a 50-m-long transfer line along the beam line. The total cold mass of the plant system weighs about 42 tons. The STQ's of the second stage are stand-alone superconducting magnets. About 8 tons of the cold mass is kept at 4.3 K in the helium bath and evaporating gas is re-condensed by a 2.5W 4K-GM/JT cooler, which is mounted on the cryostat together with a 90W GM cooler for the shield and the HTSC power leads. Commissioning operations of these cryogenic systems are reported.

5:30pm

1LX06 - Medium Field HTS Magnets for Accelerator

***R.Gupta**, Brookhaven National Laboratory*

Application of high temperature superconductors (HTS) is looking promising in many medium field HTS magnets. The HTS option is becoming particularly attractive for those future accelerators and beam line magnets where either the energy deposition is too large for conventional low temperature superconducting magnets or the cost of electrical power consumption is too high for water-cooled copper magnets. In last few years, a significant number of HTS coils (about 30) and several medium super-ferric R&D magnets have been successfully built for the proposed Facility for Rare Isotope Beams (FRIB). The consistently good performance of these coils and the successful test of them in various magnet configurations (cold iron mirror, warm iron mirror and full short R&D quadrupole) demonstrates that the technology has now matured enough to be considered in real applications. Most of above coils and magnets were built with the first generation HTS. However, the more recent coils were (and are being) built with the second generation HTS. Second generation HTS is expected to cost less and offers much superior performance in many areas. A set of unique experiments was also recently carried out at Brookhaven National Laboratory, where the coils were subjected to unprecedented heat deposition. These experiments demonstrated that HTS magnets can operate in presence of large energy deposition. The test results and their implications to future applications will be reviewed. In another major developments, a number of samples of the second generation HTS were subjected to very high level of radiation dose. The change in critical current and the change in critical temperature were observed. Preparation for similar radiation testing for the first generation HTS is now underway as well. This talk will describe the progress in the field (both in terms of the R&D magnets that have been recently built and tested and those under design) and examine their use in various applications in future. It will also review the cost of ownership (construction plus operation) and compare HTS magnet options with (a) water-cooled copper magnet option and (b) with normal superconductor magnet option, as applicable.

1LY - HTS Motors and Generators – I 4:00pm - 6:00pm

4:00pm
Invited
1LY01 - HTS Coil with Transposed Cable and 3D HTS Coils for Rotating Machines: Test Results at 30K
M.P.Oomen, *M.Leghissa, N.Proelss, H.W.Neumueller, Siemens AG, CT PS3*
We have manufactured and tested new HTS coil configurations in order to extend the range of rotating machines to which HTS tapes can be applied. The rotors of large utility generators require operating currents of several kA, which can be achieved by connecting several HTS tapes in parallel in a transposed cable. Design of a generator poses questions on winding technique for the coils, cooling technique at the required operating temperatures around 30K, and VI-relation and stability of such coils. These questions were addressed by winding a test coil using 40m of transposed cable comprising 500m of BSCCO tape and testing it at 30K. Smaller generators coupled to gas turbines have to work at many thousands of rpm. The high g-forces and need for compactness make it necessary to place the rotor coils as close as possible to the shaft, which requires coils with 3D-bent heads, like in accelerator dipoles. We have produced this type of coils with BSCCO tapes for the first time. After developing a winding technique using simple tooling, 700m of BSCCO tapes were used to manufacture two 3D demonstrator coils, which were tested at 30K as well. We describe winding methods, cooling technique and test results for both types of coils.
This work was funded by the German BMBF under #13N8519

4:30pm
1LY02 - Design and Simulation of a HTS Flux Pump for High Current Rotor Application
S.A.Ishmael, *Advanced Magnet Lab, Melbourne, FL; H.Gutiérrez, Florida Institute of Technology, Melbourne, FL; P.J.Masson, Center for Advanced Power Systems, Tallahassee, FL; R.B.Meinke, Advanced Magnet Lab, Melbourne, FL; R.L.Sullivan, Florida Institute of Technology, Melbourne, FL*
The use of superconductors enable the generation of very high flux density magnets. In rotating electrical machinery, current leads that connect the rotor to an external power supply represent the main heat load of the cryogenic system. Operating the rotor in a persistent mode and charging it with the help of a flux pump would decrease the heat load therefore enabling large rotor currents. While flux pumps based on low temperature superconductors are well established, the concept still needs to be developed for high temperature superconductors. MgB2 offers several advantages in this respect; it is rather inexpensive and facilitates manufacturing of superconducting splice joints which are essential for flux pump operation. MgB2 used in certain conditions of temperature and current density could be switched magnetically. This paper describes the design of a rectifier-type flux pump based on superconducting switching modes using MgB2 conductor. Design of the switches is not trivial and will be described and tentatively experimentally validated. A superconducting transformer consisting of double-helix coils is used to charge an inductive load connected to the secondary side. Results from model calculations as well as test first results are being presented.

4:45pm
1LY03 - HTS Squirrel-cage Induction/Synchronous Machine for Low Speed Generator Application
T.Nakamura, *K.Matsumura, T.Nishimura, K.Nagao, Y.Hirotani, Kyoto University; N.Kashima, S.Nagaya, Chubu Electric Power Co., Inc*
Current status of development of high temperature superconducting induction/synchronous machine (HTS-ISM) is presented in this paper. The Kyoto University group has already shown based on the analysis as well as the experiment, that simple replacement of secondary windings in the squirrel-cage induction machine with HTS realizes the exciting characteristics such as co-existence of slip and synchronous rotation, robustness against the over-load, etc. Our present target is the operation of the above-mentioned exciting HTS-ISM as a low speed generator. In this case, the HTS-ISM is surely operated as a synchronous generator at steady state condition, even the structure of such machine is that of the squirrel-cage induction one. Fundamental experiment as well as the analysis results will be reported. Furthermore, the low speed test results for the fully superconducting HTS-ISM are also to be presented and discussed.

5:00pm
1LY04 - HTS "Supersat" for application in airborne high speed turbo-generators
P.J.Masson, *CAPS/ Florida A&M University, USA; A.Rezzoug, D.Netter, J.Leveque, GREEN-Nancy, France; C.A.Luongo, NHMFL/FSU, USA*
Aircraft technology is going towards more electrical systems. As electrical loads are multiplied, onboard power generation needs to increase. Military aircraft can require power levels of several MWs that would have to be generated by high power density systems. Such power plants can be developed using high RPM turbines driving generators. Superconducting generators could potentially lead to higher compactness benefiting airborne applications. However, wound rotors cannot withstand accelerations stemming from high RPM, therefore other configurations have to be considered. We propose to use an axial field topology using rotors composed of over-saturated magnetic teeth by a stationary superconducting coil. This concept known as "supersat" has lead to a prototype using LTS materials built and successfully tested. The bulk nature of the rotating part allows for high rotation speeds, the variation of the air gap flux density can reach 3T. This paper presents an optimized design of a "Supersat" type generator using HTS material. A FEA model is presented along with simulation results for a multi-MW - 16 kRPM machine.
This research was partially supported by the NASA Vehicle Systems Program and the Department of Defense Research and Engineering (DDR&E) division under the URETI on Aeropropulsion and Power

5:15pm
1LY05 - Working magnetic field around the rotating YBCO disk of a low-power 2-phase bipolar motor entirely based on bulks
***A.Alvarez**, P.Suarez, J.M.Ceballos, B.Perez, University of Extremadura*
Superconducting electrical motors represent one of the least developed applications in the field of superconductivity. The profitability of this type of machine is only reached when the power is very high, and so their development requires large budgets, and they have always been based on superconducting tape coils. However, the design of a bipolar single-turn coil made from a YBCO bulk was proposed by the group of Electrical Application of Superconductors, at the University of Extremadura, to be an element for the design of a modular low-power two-phase axial-flux motor. The magnetic field is created by several of these elements strategically located in an arrangement that makes the field rotate in the space where a disk-shaped rotor made from YBCO is going to work. Such a motor permits us to understand other aspects of superconductivity and the electro-mechanical interactions between superconducting elements. In previous works we have shown how part of the pulling mechanism is due to the trapped magnetic field in the rotating disk and another part is due to the variation of the magnetic field on the surface of the disk, and how the magnetic field is screened by the disk. In this work we study the magnetic field map in the space where the rotor works, before and after its placement, and quantify the trapped magnetic field in the disk. The results permit us to present a first mathematical model of the pulling process.

5:30pm
1LY06 - Magnetic and cryogenic parameters of a low power superconducting servomotormotor.
***J.Lopez**, UPC; X.Granados, ICMAB-CSIC; R.Torres, UPC; J.Lloberas, ICMAB-CSIC; R.Maynou, UPC; J.Grau, CEIB-UPC; R.Bosch, X.Obradors, UPC*
In this work, we discuss about the main magnetic parameters of a low power superconducting toothless servomotor with four radial poles. Magnetization process of the superconducting pellets and the achievable values is investigated in terms of the copper coils and the toothless iron shielding of the external stator. Requiered cooling for pellets and coils is also investigated in order to obtain the maximun opperative magnetic field.

5:45pm
1LY07 - Design and control of a superconducting permanent magnet synchronous motor
***Y.Jiang**, R.Pei, W.Xian, Z.Hong, T.A.Coombs, Cambridge University*
This paper gives a detailed description of a high temperature superconducting (HTS) permanent magnet synchronous motor (PMSM). The stator of the motor consists of six air cored HTS racetrack windings, together with an iron shield. The rotor is made of 60 superconducting YBCO pucks. Two additional copper windings are built to magnetize the rotor, and pulse field magnetization (PFM) method is considered to magnetize the rotor as a four-pole permanent magnet. The magnetization process and the results will be presented. The average magnetic field produced by the magnetized rotor is 0.4 T. When actuated with a 35 A rms currents, the total power of the motor is 8.4 kW. This paper concentrates on the torque ripple and harmonics of the stator currents which are induced by the rotor field. In order to suppress the torque ripple, iterative learning control (ILC) algorithm is used additional to the former field oriented control method. The results show the ILC algorithm can largely reduce the torque ripple, which lead to the reduction of the AC losses of the motor.

TUESDAY, AUGUST 19, 2008

TUESDAY MORNING POSTER SESSIONS 10:00am - 12:00pm

2LPA - Accelerator Magnets - II 10:00am - 12:00pm

2LPA01
Invited
Reproducibility of the coil positioning in Nb3Sn magnet models through magnetic measurements
E.Todesco, F.Borgnolutti, CERN; G.Velev, S.Zlobin, V.Kashikin, FNAL; G.L.Sabbi, P.Ferracin, S.Caspi, LBL
The variation of the harmonics along the longitudinal axis has been successfully used in the past to identify the reproducibility of the coil positioning in the LHC main dipoles. Using a magnetic model and a MonteCarlo approach, coil blocks are randomly moved with a given amplitude and the amplitude that best fits the measured data is interpreted as the reproducibility of the coil positioning. Previous values for Nb-Ti magnets are around 0.020 mm. In this paper we use this approach to estimating the coil position for Nb3Sn short models that have been built in the framework of the LARP program and of the FNAL core program. Our analysis shows larger values with respect to the Nb-Ti results.

2LPA03
Invited
Fabrication and Test of a 3.7 m Long Support Structure for the LARP Nb3Sn Quadrupole Magnet LQS01
P.Ferracin, LBNL; G.Ambrosio, FNAL; M.Anerella, BNL; S.Caspi, D.W.Cheng, H.Felice, A.R.Hafalia, C.R.Hannaford, LBNL; F.Nobrega, FNAL; S.Prestemon, G.L.Sabbi, LBNL; J.Schmalzle, P.J.Wanderer, BNL; A.V.Zolbin, FNAL
The 3.7 m long quadrupole magnet LQS01 represents a major step of the US LHC Accelerator Research Program (LARP) towards the development of long Nb3Sn accelerator quadrupole magnets for a LHC Luminosity upgrade. The magnet support structure is a scale up of the 1 m long Technology Quadrupole TQS design with some modifications suggested by TQS model test results. It includes an aluminum shell pre-tensioned over iron yokes using pressurized bladders and locking keys (bladder and key technology). The axial support is provided by two stainless steel plates compressed against the coil ends by four stainless steel rods. The structure, instrumented with strain gauges, has been fabricated and assembled around four aluminum “dummy coils” in order to determine pre-load homogeneity and mechanical response during cool-down. After presenting the main magnetic and mechanical parameters of LQS01, we report in this paper on design, assembly, and test of the support structure, with a comparison between strain gauges results and 3D numerical predictions.

2LPA04
Invited
Development of high current Nb3Sn Rutherford cables*
D.R.Dietderich, A.Godeke, H.C.Higley, Lawrence Berkeley National Laboratory
The Superconducting Magnet Program of LBNL has been fabricating Rutherford cables for superconducting magnet. The cabling parameters (wire diameter, cable thickness, cable width, pitch length, and keystone angle) that are acceptable for various strands (MJR, RRP, and PIT) with different internal structure, composition, and fabrication methods are discussed in the context of cables for LHC-US Accelerator Research Program, Next European Dipole, and LBNL's high field dipole HD2 magnets. An empirical model is presented to guide in the cabling process to minimize or eliminate strand damage. The cable parameter limits for LARP prototype and production cables are presented. The cabling behavior for strands with different Cu content and different internal layout are also discussed. First generation LARP quadrupole magnets will require cables with widths of 10-15mm and thickness of 1.25-1.45mm for strands with diameters of 0.70-0.80mm and a keystone angle of up to 1.0 degree. Efforts to increase the keystone for this range of cable widths will be discussed. The results provide guidelines for making cable with minimal strand damage.
**Supported by the U.S. Department of Energy under Contract No DE-AC02-05CH11231.*

2LPA05
Development of pre-bent high-strength Nb3Sn cable with stainless-steel reinforcement strands
G.Nishijima, H.Oguro, S.Awaji, K.Watanabe, Tohoku University; H.Tsubouchi, Furukawa Electric; S.Hanai, Toshiba Corporation
The reinforcement effect of stainless-steel (SS) strands in a (6+1) cable was tested to develop a high- strength large-current superconducting cable. The (6+1) cable, which consists of three pre-bent CuNb/Nb3Sn high-strength superconducting strands and four SS strands, was fabricated. The reacted 0.6-mm diameter CuNb/Nb3Sn strands were pre-bent by 10 fixed pulleys. Three CuNb/Nb3Sn and three 0.6-mm diameter SS strands were arranged alternately around the SS center strand. The cable was wound on a GFRP bobbin and was tested at 4.2 K, 11 T. A triplet consisting of three pre-bent CuNb/Nb3Sn strands was also tested for comparison. The critical current (Ic) at 11 T for the (6+1) cable was 197 A, whereas the triplet Ic was 270 A. The Ic deterioration can be explained by an additional compressive strain, which caused by the difference of the thermal contraction coefficient between the Nb3Sn strands and the SS strands. In contrast, the (6+1) cable showed the maximum transport current of 308 A under the hoop stress, whereas the triplet showed 209 A. Furthermore, the (6+1) cable Ic did not deteriorate after the hoop stress test. The SS strands possibly decreased the hoop stress in the Nb3Sn strands. The tensile strain, caused by the hoop stress, increases the Nb3Sn strand Ic. The result suggests that the SS reinforced pre-bent Nb3Sn (6+1) cable is applicable for superconducting magnet windings.

2LPA06
Quench Tests and FEM Analysis of Nb3Al Rutherford cables and Small Racetrack Magnets
R.Yamada, Fermilab; A.Kikuchi, NIMS, Japan; E.Barzi, G.Chlachidze, M.Lamm, I.Novitski, Fermilab; T.Takeuchi, M.Tartaglia, NIMS, Japan; D.Turrioni, Fermilab; M.Wake, KEK, Japan; A.V.Zlobin, Fermilab
In collaboration between NIMS and Fermilab, we have made a couple of different copper stabilized Nb3Al Rutherford cables, using Nb-matrixed and Ta-matrixed strands. The characteristics of these cables are investigated at high current in low self field using a flux pump, and their test data are reported. Using these Rutherford cables, we built and tested small racetrack magnets. The magnet made with the Nb-matrixed strand showed the low field instability. The FEM simulation was done successfully to explain this behavior. It is shown that the interfilamentary coupling current in the outer layer of multi-filaments is running through the Nb matrix. This current is causing shielding effect inside the strand. Thus the strand is withstanding to higher external field, and eventually collapsing with a bigger flux jump. The small racetrack magnet wound with the Ta-matrixed Nb3Al Rutherford cable was stable at 4.5 K operation, because the Tc of Ta is 4.5 K. With the successful operation of the small racetrack magnet up to its short sample data, the feasibility of the Nb3Al strand and its Rutherford cable for their application to high field magnets is established. The characteristics of Nb3Al Rutherford cable is compared with that of the Nb3Sn Rutherford cable, and the advantages of Nb3Al Rutherford cable are discussed.
** Supported by U.S. Department of Energy*

2LPA07
Field Quality of LARP Nb3Sn TQ Series Quadrupole Models
G.V.Velev, R.Bossert, J.DiMarco, V.V.Kashikhin, M.J.Lamm, J.C.Tompkins, A.V.Zlobin, S.Caspi, FNAL; P.Ferracin, G.L.Sabbi, LBNL
Fermilab, in collaboration with LBNL and BNL, developed and tested a series of Nb3Sn 1-m long technological quadrupole (TQ) models with a 90 mm bore diameter and field gradient of 200 T/m. These models, which are based on similar coils and two different mechanical structures, were designed and built as part of the US-LHC accelerator research program (LARP) with a primary goal to demonstrate the Nb3Sn accelerator magnet technology for the planned luminosity upgrade of LHC Interaction Regions (IR). In this paper, we present the field quality measurements in both TQ models including magnet transfer function and field harmonics. The results are compared to the expectations from the magnet geometry and magnetic properties of coils and iron yoke. Additionally, we present the comparison between the field harmonics of the models with the corresponding ones from 18 NbTi quadruples, produced by Fermilab for the present LHC IRs.
Work supported by the U.S. Department of Energy.

2LPA08
Pre-load of Accelerator Magnets with Non-linear Coil Mechanical Properties.
I.Novitski, A.V.Zlobin, FNAL
To minimize the variation of field harmonics in the operating field range and to reduce the probability of spontaneous quenches caused by turn motion, superconducting coils in accelerator magnets are pre-loaded during assembly. The required value of coil pre-load is determined by the magnet design, nominal operating field (field gradient) and thermo-mechanical properties of the structural materials. The pre-load applied to the magnet coils at room temperature has to be sufficient to compensate for the pre-load reduction due to structure spring back, coil creep, difference in thermal contraction between the coil and structural elements, and Lorentz forces during magnet excitation. This paper discusses the issues related to the pre-load of superconducting accelerator magnets with non-linear coil mechanical properties. Mechanical analysis was performed on NbTi and Nb3Sn large-aperture quadrupole models developed for the LHC Interaction Regions.
This work supported by the U.S. Department of Energy.

2LPA09

Manufacturing and test of a short Nb3Sn quadrupole magnet model at CEA/Saclay

M.Durante, L.Quettier, M.Segreti, CEA; F.Simon, ITER; D.Leboeuf, Y.Le Noa, CEA; K.Sugita, GSI

DSM/IRFU/SACM at CEA/Saclay has undertaken an R&D program on Nb3Sn aimed at designing and building a 1-m-long, 56-mm-single-aperture quadrupole magnet model. The main goal of the program is to learn about Nb3Sn technology and evaluate fabrication techniques relative to the use of this superconductor. Model design is based on the design of LHC arc quadrupole magnets, without iron yoke. It is expected to reach a nominal field gradient of 211 T/m at 11,870 A. Coils are wound from Nb3Sn Rutherford-type cables insulated with glass fiber tape, before being heat-treated and vacuum-impregnated with epoxy resin.. Laminated, austenitic collars are locked around the coil assembly by means of keys in order to restrain Lorentz forces. Coils manufacturing and magnet assembly have been achieved in 2007. After a recall of the conceptual design, the paper reviews the manufacturing of the coils and of the magnet assembly and presents the results of warm magnetic field measurements.

2LPB - HTS Bulk - Large Scale 10:00am - 12:00pm

2LPB01

Invited

Superconductors: The Next Generation of Permanent Magnets

T.A.Coombs, Cambridge University

Magnets made from bulk YBCO are as small and as compact as the rare earth magnets but potentially have magnetic flux densities orders of magnitude greater than those of the rare earths. In this paper a simple technique is proposed for magnetising the superconductors. This technique involves repeatedly applying a small magnetic field which gets trapped in the superconductor and thus builds up and up. Thus a very small magnetic field such as one available from a rare earth magnet can be used to create a very large magnetic field. This technique which is applied using no moving parts is implemented by generating a travelling magnetic wave which moves across the superconductor. As it travels across the superconductor it trails flux lines behind it which get caught inside the superconductor. With each successive wave more flux lines get caught and the field builds up and up. The wave could be generated in many different ways but the preferred way is simply to heat a material whose permeability changes with temperature at its edge. As the heat travels across the material so the permeability changes and a magnetic wave is generated. It is in effect the first novel heat pump in a very long time and one which will enable the enormous potential available from these unique and highly versatile superconducting magnets to be fully realised. Within this paper we present results showing the superconductor being progressivelt magnetised by sequentially applied “heat” pulses. We also demonstrate that the sign of the magnetisation is reversed if “cold” pulses are applied instead of heat pulses. These experimental results are supported by modelling.

2LPB02

Invited

Small-scale Strong Magnetic Field Generators with Cryo-cooled High Temperature Bulk Superconducting Magnets and Their Performances

T.Oka, Y.Hirose, T.Inomata, J.Imai, H.Yamazaki, S.Fukui, J.Ogawa, T.Sato, M.Yamaguchi, Niigata University

Various types of strong magnetic field generators have been constructed with use of HTS bulk magnets and small-scale cryo-coolers. Since the handling of cryogen requires special techniques and does not suit widespread industries, we have been emphasizing the importance of adopting cryo-coolers instead of cryogen such as liquid nitrogen to keep the superconductivity. The magnetic flux density in the open space between the face-to-face magnetic poles that contain bulk magnets have been estimated as over 3 T and 4 T when they were activated by applying the pulsed fields and static fields, respectively. In the paper, a couple of novel and small-scale HTS bulk magnet systems with use of compact pulse tube cryo-coolers and GM cryo-coolers are discussed with respect to the magnetic field distributions in the open space where the magnetic field is used in practical. The generating field of HTS bulk magnet with use of the pulse tube cryo-cooler reached 2.76 T on the magnetic pole surface when activated at 59 K by 5 T static field generated by a superconducting solenoid. The most characteristic feature of HTS bulk magnet is defined as a small-scale and strong magnetic field generator. Various kinds of the equipments must be successively proposed even in the very early stage of R&D of the equipments.

2LPB03

Magnetic Flux Concentrator Using Gd-Ba-Cu-O Bulk Superconductors

T.Kiyoshi, S.Choi, D.Uglietti, S.Matsumoto, T.Asano, National Institute for Materials Science

Magnetic flux concentration is a very important technique for the effective generation of high magnetic fields. Although ferromagnetic materials are commonly used, their contribution is limited by their saturation magnetization. We have demonstrated several magnetic flux enhancement methods using HTS bulk cylinders. The shape of the bulk superconductors was changed to increase the concentration efficiency. Two Gd-Ba-Cu-O bulk cylinders made by Nippon Steel Corporation were used. The diameter and height were 29 mm and 30 mm, respectively. From each cylinder, a truncated cone with an upper diameter, lower diameter, and height of 7 mm, 29 mm, and 30 mm, respectively, was removed. Two of the bulk superconductors were arranged face-to-face in the smaller inner radius with a gap of 0.3 mm. In order to suppress the circulating current that shields the magnetic flux along the vertical direction, the bulk superconductors were vertically separated with a gap of 0.5 mm. The bulk superconductors were fixed with epoxy resin in a stainless steel tube. By inserting this magnetic flux concentrator in the external field, a three-time higher flux density is expected in the center of the concentrator, while the bulk superconductors maintain a superconducting state. Experimental results in liquid helium and numerical results by FEM analysis are discussed.

2LPB04

A strong magnetic field generation by superconducting bulk magnets with the same pole arrangement

K.Yokoyama, Ashikaga institute of technology; T.Oka, Niigata university; K.Noto, Iwate university

We study on the construction of superconducting permanent magnets by RE123 bulk materials and the investigation of these industrial applications such as a magnetic separation. The bulk magnets can generate strong magnetic field in comparison with common permanent magnets and electromagnets. When two Sm123 bulk materials of 45 mm in diameter were magnetized with a different pole arrangement by using a face-to-face type superconducting bulk magnet system, the highest magnetic field of 3.15 T in the axial direction was achieved in the open space between the magnetic poles. On the other hand, it is also interesting that two magnetic poles are arranged in a same pole because a magnetic field in the radial direction is increased though that in the axial direction weakens. In an application to magnetic separations, for instance, the separation performance improves by making the direction of magnetic field parallel to that of the flow of samples. In this paper, two Gd123 bulk materials of 65 mm in diameter are magnetized with a same pole arrangement by using a face-to-face superconducting bulk magnet system. The radial component of magnetic field, Bx, is measured in the open space between the magnetic poles with changing the gap from 20 mm to 50 mm, and |Bx|>1.0 T is achieved in the wide area.

2LPB05

Qualification of the machining and fitting precision of YBCO bulks and rings joined together with the examination of the flux trapped together

J.Kosa, I.Vajda, L.Farkas, Budapest University of Technology and Economics

The quality of the drilled YBCO bulks and rings and the precision of the fitting of the YBCO rings joined together can be decuded with the elaborated method. In the case of concerted magnetization of tightly fitted rings and bulk the measured maximum flux density is approximately the same as it was prior to machining unless the material got damaged during machining. It is a convenient method to test the material before the application of bulks and rings.

The authors thank the German collegaues IPHT at Jena for YBCO superconductor bulk.

2LPB06

Transformation of the DC and AC magnetic field with novel application of the YBCO HTS ring

J.Kosa, I.Vajda, Budapest University of Technology and Economics

With the new arrangement to be presented we can transfer the magnetic energy of DC or AC magnetic fields between two independent iron cores inductively from one closed iron core to the other one. It means, DC magnetic field can be transformed in a controlled way. This method can result in new applications in the field of transferring both the energy of DC magnetic field and AC electrical energy.

The authors thank the German collegaues IPHT at Jena for YBCO superconductor bulks.

2LPC - HTS Motors and Generators – II 10:00am - 12:00pm

2LPC01

Production and Test of a 7.5kW REBCO Superconducting Synchronous Motor

M.Iwakuma, Kyushu University; Y.Hase, T.Satou, Japan Motor & Generator Co. Ltd.; A.Tomioka, Fuji Electric Advanced Technology Co. Ltd.; Y.Iijima, T.Saitoh, Fujikura Ltd.; Y.Yamada, T.Izumi, Y.Shiohara, Superconductivity Research Laboratory

We are developing a 7.5kW-360rpm synchronous motor with a REBCO superconducting rotor. The rotor is 6-pole type. The armature winding is wound with copper. We finished the winding of the 6 pieces of superconducting field coils. One field coil is a 62-layer solenoidal one. The YBCO and GdBCO superconducting tapes were fabricated by IBAD-PLD method. The total length of 5 mm wide tapes was 2.4 km. The rotor will be cooled by forced-flowed helium gas. The designed operating temperature is 40 K and the operating field current is 50 A. The magnetic field in the field winding is about 0.4 T at maximum. In advance of the assembly to a rotor, we investigated the I-V properties of the individual field coil and verified the stable operation up to 80 A at 40 K. In addition we finished to investigate the properties of the cryogenic rotor system installing dummy copper coils instead of superconducting coils. We verified the satisfactory good mechanical and thermal operation. We will complete the 7.5kW motor by next March and will make a full test.

This work was supported in part by the New Energy and Industrial Technology Development Organization (NEDO) as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

2LPC02

Fabrication and Test of the HTS Homopolar Motor Field Coil using Bi-2223 Wire

J.-D.Lee, Changwon Nat`l Univ; S.-H.Lee, Hanyang Univ; H.M.Kim, S.-K.Baik, E.-Y.Lee, Y.-K.Kwon, KERI; Y.-S.Jo, J.-P.Hong, CAST; M.Park, I.K.Yu, Changwon Nat`l Univ

In general, in most case of high temperature superconducting (HTS) rotating machinery, HTS field coil is rotated. HTS homopolar motor field coil is not necessary to be rotated and the torque of motor is not strongly related with the field coil. Therefore, HTS homopolar motor has a superior mechanical stability comparing with other HTS rotating machines. These advantages can make the design of HTS field coil and cryostat much more simple. In this paper, HTS field coil and cryostat were fabricated and tested. Before test, authors have estimated the critical current of HTS field coil at 77K by simulation using FEA (Finite Element Analysis) software and power law equation. The operating current of field coil was decided, consequently. The experiment details and results are presented in this paper, and discussed.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPC03

Performance Test of a 100kW HTS Generator Operating at 77K

H.M.Wen, School of Engineering, University of Southampton; K.Goddard, School of Electronics and Computer Sciences, University of Southampton; W.Bailey, M.K.Al-Mosawi, C.Beduz, Y.Yang, School of Engineering, University of Southampton

A systematic test program has been in progress to fully characterise a 100 kW HTS synchronous generator which was successfully constructed in 2004. The machine was one of the first HTS synchronous generator/motors to operate at liquid nitrogen temperatures while achieving a power rating relevant to practical application. The 3-phase machine has a conventional stator and the cold superconducting rotor consisting of 10 HTS Bi2223 pancake coils separated by magnetic flux diverters and a magnetic core. The test program includes a series of tests at various speeds, field currents and temperatures (65-77K) with the machine in (1) open circuit to determine the machine waveform and harmonic characteristics at different levels of iron saturation, and (2) short circuit tests to determine the synchronous reactance. The inductance of the HTS rotor is measured at different frequency to examine the effectiveness of the copper rotor screen. In addition, stationary measurements of the rotor critical current are carried out using dc current in the stator windings to quantify the influence of stator field on the performance of superconductor. The spatial distribution of rotor voltage and temperature are measured using a radio frequency telemetry system.

2LPC04

Development of 1MW HTS Motor for Industrial Application

Y.K.Kwon, H.M.Kim, E.Y.Lee, S.K.Baik, Korea Electrotechnology Research Institute; J.D.Kim, Korea Electrotechnology Research Institute,; Y.C.Kim, Research & Development Center, Doosan Heavy Industries & Construction Co., LTD.; S.H.Lee, J.P.Hong, Hanyang University; Y.S.Cho, Center for Applied Superconductivity Technology

This paper describes the development results of the high temperature superconducting motor which consists of HTS rotor and air-core stator. The machine was designed for the rated power of 1MW hp at 3600 rpm. The HTS field windings are composed of the double-pancake coils wound with Bi-2223 tape conductor. These were assembled on the support structure and fixed by a bandage of glass-fiber composite. The rotor assembly was tested independently at the stationary state and combined with stator. Characteristic parameters such as reactance, inductance, and time constants were determined to obtain a consistent overview of the machine operation properties. This paper presents the design and experimental test results of 1MW HTS motor at Korea Electrotechnology Research Institute and Doosan Heavy Industry in Korea.

This work was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPC05

Electromagnetic and Test Result Analysis of a 1 MW HTS Synchronous Machine

S.K.Baik, Y.K.Kwon, H.M.Kim, E.Y.Lee, J.D.Lee, Korea Electrotechnology Research Institute; Y.C.Kim, T.S.Moon, H.J.Park, W.S.Kwon, Doosan Heavy Industries Co.

A 1 MW class superconducting motor with HTS(High-Temperature Superconducting) field coil is analyzed and tested. This machine is a prototype to make sure applicability aimed for generation and industrial motor applications such as blowers, pumps and compressors installed in large plants. This machine has HTS field coils made with Bi-2223 HTS wire and conventional copper coils cooled by water. It is analyzed by 3-dimensional electromagnetic FEM(Finite Element Method) to get magnetic field distribution, inductance, electromagnetic stress and so forth. Open and short circuit tests were conducted in generator mode while a 1.1 MW rated induction machine was rotating the HTS machine. Electrical parameters such as mutual inductance and synchronous inductance are deduced from these tests. Load test was done upto rating torque during motor mode and efficiency was measured at each load torque. Test results are analyzed based on measured losses according to IEEE standard 115.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPC06

Experimental Validation of a Conduction Cooled HTS Motor

J.E.Pienkos, P.J.Masson, C.A.Luongo, CAPS-FSU/FAMU College of Engineering

A compact HTS motor was developed for use in electric aircraft propulsion. The motor is based on BSCCO coils and YBCO bulk plates acting as permanent magnets (flux trapping). This requires a novel approach to cooling, where not only steady-state operation is important, but also the scheme for a two-stage cooldown to trap flux in the YBCO. The motor inductor is conduction cooled and must provide adequate heat transfer paths between a cryocooler head and the HTS elements in the motor. The size and weight of the motor and cooling system are minimized due to the aeropropulsion objective. Experimental validation of the conduction cooling method was achieved by using a full size thermal mock-up of the HTS inductor. The mock-up inductor is constructed and tested under similar heat loads experienced during normal motor operation. The experiments are performed using a G-M cryocooler, cryostat with liquid nitrogen jacket, vacuum pump, and the mock-up inductor. Experimental results are shown and compared to previous modeling results, validating the previous work and proving the viability of conduction cooling during steady state operation, the ability to implement a two-step cooling schedule to trap flux in the YBCO elements, and the overall thermal feasibility of the compact HTS motor design.

This research was partially supported by the NASA Vehicle Systems Program and the Department of Defense Research and Engineering (DDR&E) division under the URETI on Aeropropulsion and Power.

2LPC07

Development of Cryogenic System for High Speed Superconducting Generator Applications

T.Zhang, K.Sivasubramaniam, E.T.Laskaris, J.Bray, K.Amm, GE Global Research Center

Under the contract with Air Force Research Lab (AFRL), General Electric has successfully tested a high speed, superconducting generator for a Multimegawatt Electric Power System (MEPS) aimed for military applications. As the first successful full-power test of a superconducting generator for the Air Force, the demonstration tested the generator's load up to 1.3 MW and over 10,000 rpm. A key component of the generator system is a closed loop cryo-refrigeration system to cool the field excitation coil at liquid neon temperature (around 30 K). This paper reports the design and tests of the cryogenic system, including the liquid neon dewar, cryogenic cooling loop for the high temperature superconducting (HTS) field coil and the cryostat. Performance data during both short-term load run and long-term non-load run are presented. Key challenges with design and operation of a reliable cryogenic system for a superconducting generator are discussed. We also describe the development of an improved version.

2LPC08

Invited

A High Speed and High Power Density HTS Superconducting Generator for Airborne Application

K.Sivasubramaniam, T.Zhang, E.T.Laskaris, J.Bray, B.Brunell, K.Amm, GE Global Research Center

General Electric, under contract with the Air Force Research Labs (AFRL), has successfully developed and tested a high speed, multimegawatt superconducting generator. The generator was built to demonstrate high temperature superconducting (HTS) generator technology for application in a high power density Multimegawatt Electric Power System (MEPS) for the Air Force. The demonstration tested the generator under load conditions up to 1.3 MW at over 10,000 rpm. The new MEPS generator achieved 97% efficiency including cryocooler losses. All test results indicate that the generator has a significant margin over the test points and that its performance is consistent with program specifications. This demonstration is the first successful full-load test of a superconducting generator for the Air Force. In this paper we describe the development of the generator and present some key test results used to validate the design. Extrapolation to a higher power density generator is also discussed.

2LPD – Transformers 10:00am - 12:00pm

2LPD01

The uses of superconducting transformer in a 1kW Fly back power supply

F.Weinachter, B.Douine, J.Leveque, University of Nancy GREEN

The field of applications of Fly-back power supplies with low voltage and high current is very important; we can cite, by example, electrochemistry or fuel cell …. We propose to decrease the size and the weight of these systems by the use of superconducting wires. With superconducting cable, we can avoid an iron magnetic circuit and we have a high current density. The feasibility of this kind of power supply was proved in a previous paper (ASC 2004), with the realisation of a small size prototype. In this paper, we present the design and tests of a brand new structure which avoid the use of a snubber which is a protection device for the semi conductor component. The first step of the design consists in the optimization of the superconducting coils of the transformer. The goal is to minimize the leakage inductance in order to limit over voltage on the terminals of the transistors. Then, we have built the Fly Back supply. The nominal power of this supply is 4 kW (input 400V/10A - output 10V/400A). The shape of the transformer is cylindrical, its diameter is 180mm and its high is 150mm. We use IGBT Transistor 75A and 120V by Semikron and a schottky diode 1200 A and 1800 V by Semikron. We compare experimental measurements with theoretical results including losses calculations and waveforms analysis.

2LPD02

Design method for optimized superconducting transformers

A.Berger, M.Noe, Institute for Technical Physics, Forschungszentrum Karlsruhe, Germany; N.Hayakawa, Department of Electrical Engineering and Computer Science, Nagoya University, Japan

The design of conventional transformers is partially based on experience, which is not applicable for the design of High Temperature Superconducting Transformers (HTST). Therefore, a method for designing optimized HTST has been developed and is presented in this paper. The design method is an iterative process, whereby volume, weight or costs of the transformer becomes minimized by adjusting the winding voltage (volt per turn ratio). In every step of the iteration a complete design of the transformer has to be done. Hence all design parameters are specified, whereby the optimal winding voltage for the next step can be calculated. This allows an approximation to achieve minimal volume, weight or costs. This paper describes the order of design steps and the calculation of the optimal winding voltage. Examples are given to verify the optimization method.

2LPD03

Insulation Design of an HTS Transformer and OLTC

H.G.Cheon, J.W.Choi, S.H.Kim, Gyeongsang National Univ. and Eng. Research institute

HTS transformer is promising one of HTS power applications to be commercialized in the near future. Among the auxiliary functions of transformers, voltage regulating is the most important one. For the voltage regulation, transformers are equipped with on load tap changers (OLTCs). TO development of HTS transformer and OLTC, insulation technology at cryogenic temperature should be established. So breakdown characteristics should be considered at insulation components; turn-to-turn, layer-to-layer, winding-to-winding, drive shaft-to-drive shaft, tab connecting
terminal and others were investigated. This paper describes the electric insulation design, fabrication and expermental results for a mini model of HTS transformer and OLTC.

This research was supported by a grant from the Center for Applied Superconductivity Technology of the 21s Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPD04

Tests of the Operational Modes of an HTS Current Limiting Transformer

I.Vajda, A.Gyore, Budapest University of Technology and Economics; A.E.Baker, F.J.Mumford, A.Hyde, AREVA T&D Technology Center; R.Dommerque, H.Walter, A.Hasenhuetl, Nexans Superconductors GmbH; T.Arndt, European High Temperature Superconductors GmbH; G.Marot, L`Air Liquide; G.Nador, Ganz Transelektro Electric Co Ltd; V.Meerovich, V.Sokolvsky, Ben Gurion University of the Negev

The current limiting or self-limiting transformer (SLIMFORMER, CLT) is a multifunction device which combines the functions of a usual power transformer with the functions of a current limiter. The investigated CLT is to consist of a room temperature primary winding and a secondary high temperature superconductor (HTS) winding (BSCCO 2223) divided into two parts located on different limbs and an HTS ring (BSCCO 2212). The primary winding is connected to the network, the secondary winding supplies an HTS cable. As a result the CLT is an inductive terminal too between the room temperature network and the HTS cable. For investigation of the CLT a 20kVA experimental device with copper secondary winding was designed, built and tested. The principle of the design and the optimization aspects are presented. The CLT were investigated experimentally for both sudden short circuit and stationary (transformer) operation mode in cases of several selected configurations, which are provided for various limitation levels according to the limited and the nominal current. The activation currents were determined in cases of sudden short circuit and transformer operation modes with various secondary winding turn ratios. The behaviour of a thin wall HTS was investigated in a small scale device. SLIMFORMER work is being performed as part of an EC funded project.

2LPE - System Studies for SC Devices 10:00am - 12:00pm

2LPE01

Study on Optimal Location of a Resistive SFCL Applied to an Electric Power Grid

B.C.Sung, D.K.Park, T.K.Ko, J.W.Park, Yonsei University

This paper describes the study on optimal location of a resistive superconducting fault current limiter (SFCL) applied to an electric power grid. The resistive SFCL, which is designed to provide the quick system protection during a fault, can have the different effects on operation and planning of a power system depending on its location. To select optimal location of the SFCL, the sensitivity analysis of power changes and power losses of the system with respect to its resistive value occurred in series with a transmission line during a fault is introduced. Moreover, the optimal location determined by the proposed method is coordinated with the corresponding optimal resistive value of the SFCL to improve low-frequency oscillation damping performance. The IEEE benchmarked 4-machine 2-area test system is used to evaluate the effectiveness of the proposed method with the power systems computer aided design/electromagnetic transients including DC (PSCAD/EMTDC) based time-domain simulation and the real-time digital simulator (RTDS) based experimental results.

This work was supported by MOCIE through EIRC program with Yonsei Electric Power Research Center (YEPRC) at Yonsei University, Seoul, Korea.

2LPE02

Power System Voltage Stabilizer using LC Resonance Circuit with Superconducting Coil and Capacitor

S.Kawashima, T.Ishigoka, A.Ninomiya, Seikei University; K.Arai, AIST

In recent days, the voltage stability of the power system is very important particularly in semiconductor industries. So, the development of a device suppressing voltage dips in power system is expected. In this article, the authors propose a new voltage stabilizing device using a LC resonance circuit composed of superconducting coil and capacitor connected in parallel. This power system voltage stabilizer acts automatically against an instantaneous voltage dip or a steep voltage change, and it suppress the voltage drop for several cycles by releasing its stored energy. The authors have confirmed this principle experimentally using a small model system using a LC resonance circuit with a superconducting coil and a capacitor. The experimental results and some theoretical analyses are presented.

2LPE03

Cooperation of HTSFCL with protection devices in power systems

Z.Zhifeng, Z.Caihong, D.Shaotao, X.Liye, L.Liangzhen, Dept. Applied Superconducting Technology,Institute of Electrical Engineering,Chinese Academy of Sciences

High temperature superconducting fault current limiter (HTSFCL) and breakers are connected in series in power system, which puts into effects of limit and break the short current. During short circuit fault, HTSFCL restricts the fault current immediately and also inserts the impedance in power system, which effects on the operation of the breaker. In this paper, the HTSFCL and the breaker models are built respectively, and the cooperate strategy are studied. At same time, the typical power system numeric model with breaker and HTSFCL is built. The system simulation is implemented in MATLAB. The research results further validate the cooperation method, and make the breaker more portably.

This work was supported by K.C.WONG Education Foundation,and Technology of China, Chinese Academy of Sciences.

2LPE04

Closed-loop Testing of Protective Relay in Distribution Power System with 22.9kV SFCL Using Real Time Digital Simulator

S.Lee, J.Yoon, KERI(Korea Electrotechnology Research Institute); J.Kim, Changwon National University; B.Lee, Korea University

Protective relay system study is one of the important technical issues on the power system application of SFCL(Superconducting Fault Current Limiter). We used RTDS(Real Time Digital Simulator) to study the true interaction of the protection system with the power system. RTDS modeling of SFCL is necessary to the detailed protective relay tests. In this paper, we developed an analysis model using RTDS(Real Time Digital Simulator) for studying the transient behavior of 22.9kV SFCL and carried out closed-loop testing of protective relays in distribution power system with the developed SFCL model. The SFCL model has the operation mechanism of 22.9kV hybrid SFCL being developed by LSIS and KEPRI in Korea. The parameters of the model are based on the test data of the real SFCL. Power system planners and operators can solve the expected problems in power system application of SFCL using protective relay testing results.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPE05

Concept Design of Superconducting Power System Applying Distributed Switching Stations for The Metropolitan Area

S.Lee, J.Yoon, KERI(Korea Electrotechnology Research Institute); B.Lee, Korea University

This paper proposes a future power system structure of new concept by applying superconducting power devices such as superconducting cables, transformers and FCLs(Fault Current limiters). The proposed system, which utilizes the large-capacity and environment-friendly characteristics of superconducting power equipments, aims to resolve problems in expanding power facilities in metropolitan areas where power load is concentrated and to maximize economic, environmental and social benefits. We carried out basic study on the basic concept of the superconductive power system, examined its system structure and technical and economic aspects, and determined its applicability.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPE06

Micro Power Grid System with SMES and Superconducting Cable Modules Cooled by Liquid Hydrogen

T.Nakayama, T.Yagai, M.Tsuda, T.Hamajima, Tohoku University

It is proposed that a micro power grid system is mainly composed of several power modules, such as superconducting cable module, SMES system, hydrogen system, fuel cell system, renewable energy modules, and power converter module connecting to a utility power system. The hydrogen is mainly generated by the renewable energy and excessive nocturnal utility power. It is liquefied to cool down the superconducting cable and SMES modules, and is stored in a tank to generate the electric power through the FC. Since the SMES module is able to response quickly and the fuel cell is able to supply the electric power for longer time, the combination of the SMES and the FC modules can make high quality electric power from short time to long time for the micro grid. The cable can simultaneously transfer both electric power and hydrogen fuel. The refrigerant energy is also moved through the cable. We study on functions of main power modules and simulate the power balance of the micro grid to estimate the power efficiency. It is found that the proposed micro grid can reduce the total energy loss under some modes, and has attractive added values such as good power quality, dual energy transfer, and full use of the renewable energy.

2LPE07

Reactive Compensation Needs for Superconducting Transmission Systems

B.K.Johnson, J.M.Appikonda, University of Idaho; G.Venkataramanan, University of Wisconsin-Madison

Replacing conventional ac transmission lines with superconducting cables provides many potential advantages, including strengthening the dynamic coupling of the power system since superconducting cables have much lower series inductance than overhead lines in addition to the greatly reduced resistance. This will make the transmission lines appear electrically shorter and can eliminate the need to install shunt capacitors for transmission voltage support or the need to install series capacitors to make lines appear electrically shorter to improve system performance. However, the superconducting cable performance characteristics will be dominated by shunt parasitic capacitance charging affects, much as is the case with conventional underground cables. As a result, ac superconducting cables will face distance limits unless reactive compensation is added to correct for the effects of this capacitance. In addition, superconducting systems have less inherent damping for electromechanical disturbances. The compensation scheme will need to address these needs as well. Dynamic reactive compensation will provide the best overall system performance improvements. This paper develops a dynamic reactive compensation schemes to work in superconducting transmission systems to improve dynamic performance of both the superconducting cables and nearby conventional transmission lines.

2LPF - Magnetic Separation 10:00am - 12:00pm

2LPF01

Characteristics of magnetic separation for magnetic particle and ion by magnetic chromatography with novel magnetic column

S.B.Kim, Y.Okimoto, R.Iwamoto, S.Murase, Okayama University; H.Okada, NIMS; S.Noguchi, Hokkaido University

The magnetic chromatography (MC) is very useful system for an ion and/or fine magnetic particle separations. It can be used on the strong magnetic field gradients for separating magnetic particles with different magnetic susceptibilities in a colloidal mixture. In our study, the simple experiments using superconducting magnet with a large room temperature bore and micro-scale magnetic column consisted of ferromagnetic wires were carried out to understand the magnetic particles separating and experimental results were compared with the numerical analytical results by the developed numerical analysis computer program. And we studied the design issues for magnetic column consisted with ferromagnetic wires and flow channel to separate the magnetic particles and/or ions. In this paper, the influences of the flow velocity, the magnetic susceptibility and the channel height of magnetic column will be described. In addition, we confirmed that there is something like an interaction when the magnetic particles mixed with the ions. So, we examined the behavior of the interaction when the ratio of the density of ion and magnetic particle were changed.

2LPF02

Design and Test of Filter of High Gradient Magnetic Separation System for Trapping Immunoglobulin in Serum

H.Ueda, Waseda University; K.Agatsuma, AIST; K.Kajikawa, Kyushu University; S.Fuchino, AIST; A.Ishiyama, Waseda University

Recently affinity magnetic beads have made a rapid remarkable progress in immunomagnetic cell sorting (IMCS) technology. Today we can easily sort and analyze DNA and antibody (immunoglobulin) using many various kinds of affinity magnetic beads supplied on the market. The sizes of these affinity magnetic beads in immunomagnetic cell sorting are limited over about 1 micron of diameter because of the low magnetic field induced by permanent magnet. Now much smaller nano sized affinity magnetic beads are strongly desired to get more high resolution. We have been studying and trying to develop high gradient magnetic separation (HGMS) system by using superconducting magnet to induce much higher magnetic field than a permanent magnet in order to trap the smaller nano sized affinity magnetic beads by a filter made of fine stainless steel wool. In this study, we constructed the prototype of desktop-type HGMS system using the cryocooler-cooled LTS magnet and carried out the preliminary experiments on trapping the nano sized magnetic particles. Furthermore, we investigated the magnetic field distribution and magnetic force around a magnetic wire in a filter by means of a numerical simulation.

2LPF03

Removal of uranium and radium ions from solution by high-gradient magnetic separation with schwertmannite adsorbent

K.Nishimura, O.Miura, D.Ito, Tokyo Metropolitan University; Y.Wada, Japan Atomic Energy Agency OB

Schwertmannite, i.e. iron oxyhydroxysulfate, particles are excellent adsorbents for uranium ions. The magnetic separation characteristics for removal of radioactive ions, i.e. uranium and radium ions, from solution with the adsorbents of synthesized schwertmannite particles have been studied. By a 10 Tesla superconducting high gradient magnetic separator, —10 ppb uranium ions in sample solution could be reduced to less than 1 ppb level successfully with the 100 ppm adsorbent addition. Adsorption time dependence for the uranium ions at pH=7 suggests that the effective adsorption sites are located on the particle surface. Adsorption characteristic decreasing at pH=3 also suggests that schwertmannite adsorbent can be recycled by the pH control of solution.

2LPF04

High-speed magnetic filtration system using HTS bulk magnet for used wash water of drum

T.Terada, F.Mishima, Graduate school of engineering,Osaka University; T.Ohnish, Chuo Sangyo CO., LTD.; K.Iino, H.Ueda, Nippon Sheet Glass Engineering CO., LTD. ; S.Nishijima, Graduate school of engineering,Osaka University

Fundamental study of a high speed filtration system using HTS magnet for purifying the used wash water of drum has been made. This system consists of a magnetic seeding system and a magnetic filtration system. Since the wastewater is a mixture of various used wash water, the wastewater treatment is attended with the difficulty. For that reason, the wastewater is processed as industrial waste products. In the purification system the waste component in the wastewater is made into the flock containing magnetite in the magnetic seeding system. The wastewater is run by near HTS bulk magnet and the flock is filtered by magnetic force. It was found that the system shows the extensibility and is low price because the system consists of simple equipments.

2LPF05

Purification of wastewater from paper factory by superconducting HGMS

D.W.Ha, T.H.Kim, R.K.Ko, K.J.Song, S.S.Oh, H.S.Ha, H.S.Kim, Y.H.Kim, Korea Electrotechnology Research Institute; T.W.Ha, Daegu Science College

Paper factories use a large amount of water and same amount of wastewater is generated. It is important to recycle the wastewater because of water shortages and water pollution. Large-scale equipment is necessary to process the wastewater. Reciprocal superconducting high gradient magnetic separation (HGMS) system that had a purpose to purify the wastewater was assembled. Cryo-cooled Nb-Ti superconducting magnet was used for magnetic separator. This system can operate continuously because contaminated filters can keep on returning after cleaning. The various magnetic seeding reactions were investigated to increase the reactivity of coagulation.

This research was supported by a grant from Korea Electrotechnology Research Institute, Republic of Korea.

2LPF06

Phosphorus removal and recovery from treated water of large sewage disposal plants with zirconium ferrite adsorbent by high gradient magnetic separation

D.Ito, K.Nishimura, O.Miura, Tokyo Metropolitan University

Zirconium ferrite particles are good adsorbent for phosphate ion. The magnetic separation characteristics for removal of phosphate from treated water of sewage disposal plants with the adsorbent have been studied to prevent eutrophication of closed bay and pond. Based on the ferromagnetic properties of the zirconium ferrite adsorbent and high gradient magnetic separation method, magnetic velocity for the treated water flow with using superconducting magnet was discussed. Very rapid magnetic filtration velocity, i.e., 106 times larger than that of percolation method, regeneration properties of the adsorbent and zero emission of excess sludge indicate that the zirconium ferrite is the excellent adsorbent for phosphorus removal and recycle from the treated water of large scale sewage disposal plants with the superconducting high gradient magnetic separation.

2LPG - Maglev, Bearings and Flywheels – III 10:00am - 12:00pm

2LPG01

Discussions About Measurement Results of Levitation Force and its Time Relaxation between GdBCO Bulk Superconductors and Superconducting Magnet with a High Magnetic Field Gradient

S.Araki, Keio University; K.Nagashima, H.Seino, Y.Miyazaki, Railway Technical Research Institute; T.Suzuki, T.Murakami, K.Sawa, Keio University; K.Takeuchi, M.Murakami, Shibaura Institute of Technology

High temperature bulk superconductors have significant potential for various engineering applications such as a flywheel energy storage system. This system is expected to decrease the energy loss by using bulk superconductors for the bearing. Recently, the authors have developed a new superconducting magnet to realize the large levitation force. The magnet has two coils on the same axis and each coil's current flows to the opposite direction. In this system, the axial component of magnetic field is canceled each other but the radial component of magnetic field expects to be enhanced. In this paper, the authors measured the levitation force and its time relaxation at different bulk positions in both cases of one and two bulks by using this new magnet. From the results, it was made clear that the levitation force of two bulks was twice as large as that of one bulk and its time relaxation was decreased. In addition, hall sensors were attached on the sample surface to measure the surface magnetic field distribution. The behavior of the magnetic field was discussed.

Levitation force, Bulk superconductor, GdBCO, Flywheel

2LPG02

Interaction between HTSC Levitation Magnet and Ground Conductors with Static EDS Simulator

D.K.Bae, Chung National University; K.Sim, J.H.Bae, KERI; N.Jang, Dept. of Electrical and Electroinics Engineering, Korea Maritime University

High-Tc superconducting (HTSC) electrodynamic suspension (EDS) system basically consists of HTSC levitation magnet and ground conductor and the levitation force is made from the interaction of the moving HTSC magnet and the ground conductor. A conducting plate and a circle type conductor can be a ground conductor for EDS system. Although a plate type ground conductor can produce more levitation power than circle type ground conductor, a plate conductor is less efficient in the cost. In this paper, the analysis on the interaction between the HTSC levitation magnet and the ground conductors, which are plates having various thickness and circle type conductors having various size, was implemented. The static EDS simulator comprise of HTSC magnet, force measuring devices and standing structure. 3-D finite element method was used in the numerical simulation of the interaction and compared with the experimental results.

work was supported by MOCIE through EIRC program with Yonsei Power Research Center (YPRC) at Yonsei University, Seoul, Korea. This work has been supported by KESRI (R-2005-7-068), which is funded by MOCIE (Ministry of commerce, industry and energy).

2LPG03

An analysis on the heat loss of the superconduction magnet journal bearing in the superconductor flywheel energy storage system

H. M.Park, H. S.Choi, Y. S.Cho, The Department of Electrical Engineering, Chosun University; T. H.Sung, Y. H.Han, S. C.Han, Korea Electric Power Research Institute

We analyzed the heat lose of a superconducting magnet journal bearing in the superconducting flywheel energy storage system (SFES). To analyze the heat loss in the SFES, we designed the bulk style YBCO superconductor located in the inside of the bearing and the NbFe-30 permanent magnet located in the outside of the bearing. The interval between the superconductor and the permanent magnet is 3.5mm. In this paper, we investigated the heat loss by the comparison of eddy current generated in the superconducting magnet journal bearing and the magnet journal bearing through the Maxwell 3D program. The heat loss generated in the magnet journal bearing was occurred by the storing of heat because of vacuum state in the bearing system. Therefore, the special design is necessary for the elimination of heat. However, by the simulation of an SFES, we confirmed that the superconducting magnet journal bearing did store the heat, and the heat generated by eddy current was very small. Consequently, the behavior of heat loss of the superconducting magnet bearing was superior to those of the magnet journal bearing.

This work has been supported by KESRI(R-2005-1-393), which is funded by MOCIE(Ministry of commerce, industry and energy).

2LPG04

Simulations and tests of superconducting linear bearings for a MAGLEV prototype

D.H.N.Dias, G.G.Sotelo, R.de Andrade, Jr., R.M.Stephan, UFRJ Rio de Janeiro; L.Kuehn, O.de Haas, L.Schultz, IFW Dresden

The complex microstructure of melt grown YBCO bulk material and their non-linear electromagnetic behavior makes it difficult to determine their thermal, electrical and magnetic properties. The knowledge of these parameters is essential to design superconducting magnetic bearings (SMB's) for various applications. The main characteristic of a SMB's is the levitation force that arises between the superconductor and the magnetic source. The availability of simulation tools can greatly simplify the design of new prototypes. An algorithm based on the critical state model and the finite element method (FEM) was developed. This method is based on the determination of the current density profile within the superconductor due to the penetration of the flux lines. This algorithm showed satisfactory to simulate the levitation force for a rotational magnetic bearing used in a flywheel prototype. In the present paper, this method is used to simulate a linear bearing and to design the optimal geometries for a magnetic rail that is being developed for a MAGLEV vehicle prototype. The linear bearing consists of two parts: a rail assembled with Nd-Fe-B magnets and YBCO blocks mounted inside a cryostat. Some simulated bearings were mounted and tested. The simulation results show a good agreement with the measurements.

This work was partially supported by CAPES/DAAD/PROBRAL.

2LPG05

Preliminary study on high temperature superconducting magnets using 2G wires for the maglev train

K.Nagashima, M.Ogata, Y.Miyazaki, T.Sasakawa, M.Iwamatsu, Railway Technical Research Institute

There are several advantages by applying a high temperature superconducting wire to an on-board superconducting magnet for the maglev train. At first, the thermal capacity of superconducting coils increases and the stability of the superconducting magnet improve drastically. In addition, reliability improves by simplification of the magnet structure. The weight of the superconducting magnet and the energy consumed by the on-board cryocooler will decrease. Therefore, we examined the application possibility of a 2G wire with a high critical current density in a high magnetic field. We performed numerical analysis about the weight of a superconducting magnet and the energy consumption of an on-board cryocooler in consideration of the characteristics of the 2G wire. Furthermore, we have carried out the critical current measurement of the 2G wire by varying experimental conditions such as temperature, magnetic field and bending stress and so on. We also performed the trial manufacture of the small race track-shaped superconducting coil.

This study is financially supported by the Ministry of Land, Infrastructure and Transport, Japan.

2LPG06

Experimental and Numerical Investigation of the levitation force between bulk permanent magnet and MgB2 disk

E.Perini, G.Giunchi, M. Geri, EDISON SpA

The interaction of bulk MgB2 with permanent magnets (PM), at various temperatures, has been measured by conductively cooling the superconductor with a two stage cryocooler . The levitation forces and the stiffness have been measured moving the PM in two directions above the superconducting disc. To realize FC conditions the MgB2 disc was connected to a switch able heating element. The levitating characteristics of the very dense MgB2, obtained by Mg-Reactive Liquid Infiltration process, are very stable during the time, with no measurable flux creep up to 28K. At 33K the measured relaxation rate, S= - 1/Fo dF/d(lnt), in a time scale of 105 sec, was 0.009, a very low value, also with respect to the YBCO type superconductors at equivalent T/Tc. The measured levitation characteristics shows that the MgB2 material, either conductively cooled or pool cooled by liquid Ne, at about 27K, can be consider a real alternative to the YBCO melt textured levitators.

2LPG07

Increase of levitation force on magnetic levitation system using magnetic shielding effect of HTS bulks

T.Takao, S.Saito, T.Kobayashi, Sophia University; H.Kamijo, Railway Technical Research Institute

We have experimentally and numerically studied a magnetic levitation system using magnetic shielding effect of HTS bulks. In our former work, levitation force in the system was not large and insufficient to lift up a moving part. To increase the levitation force, we have improved the system; some ferromagnetic bars were added to make adequate flux path. In the paper, details of system settings including the added ferromagnetic bars are explained. And effect of the added bars are quantitatively discussed.

2LPG08

A superconducting magnetic bearing for astrophysical polarimetry

J.M.Klein, S.Hanany, University of Minnesota; T.Matsumura, California Institute of Technology

We report on our application of a superconducting magnetic bearing (SMB) for use in astrophysical polarimetry. This work is a follow up on earlier publications about this project (Hanany et. al., 2003, Hull et. al., 2005, Matsumura et. al., 2005). The SMB is used to rotate a half wave plate, which is an optical element used for polarimetry, in a 4 Kelvin environment. A SMB is essential in this application because mechanical bearings produce excessive heat dissipation. The rotor of the SMB has a diameter of 34 cm, a mass of 5 kg and the target rotational speed is 6 Hz. We present results from an end-to-end implementation including warm support provided by a cryogenic actuator, rotational drive with a Kevlar belt, and angular encoding with a cryogenic laser.

2LPH - Other Novel Applications 10:00am - 12:00pm

2LPH01

Shear stress generated by a superconducting system on a fluid flow

L.Heyrendt, D.Netter, University of Nancy - GREEN; K.Bekkour, University of Strasbourg - IMFS; J.Leveque, University of Nancy - GREEN

The aim of our research project is to create magnetic forces on a flow of bentonite suspensions in order to get a rheological characterization of the fluid. The magnetic forces, linked to the gradient of the square magnetic induction, must be sufficient to modify the radial speed profile of the flow. Bentonite suspensions are non-Newtonian fluids which have unique rheological properties. Relatively small quantities of bentonite suspended in water form a viscous, shear thinning gel. Moreover, bentonite suspensions are thixotropic, exhibiting a stable form at rest but becoming fluid when agitated. Much of bentonite`s usefulness is in the drilling and geotechnical engineering industry and the cosmetic industry. The crucial issue of the study is to obtain a high magnetic field and a non-uniform gradient (contrary to magnetic levitation). We intend to develop a system based on one or more superconducting coils. We present the optimal configuration of the superconducting system required to obtain the maximum of gradient of the square magnetic induction and a non-uniform gradient in the working area. We performed numerical investigations with different configurations: a multi-coil one and another one with a comparison of different shape of coils. We managed to calculate the modification of the speed profile for a water flow. The results show the feasibility of this project of great interest for the rheological characterization of complex fluids.

2LPH02

Polarization Characteristics in RF Magnetic Shielding Effects of the BPSCCO Plate

T.Nishikubo, H.Endo, M.Itoh, Grad. School of Kinki Univ.

A high-critical temperature superconductor (HTS) is an ideal material for use as a radio frequency (RF) electromagnetic shield. As one of the basic areas of research for the improvement of the electromagnetic environment by the use of a bulk HTS as an electromagnetic shield, the present paper has developed a Bi-Pb-Sr-Ca-Cu-O (BPSCCO) plate having the polarization characteristics. To achieve the polarization characteristics, a slit (1 mm width, 46 mm length) was cut into the surface of BPSCCO plate (50 mm square, 4 mm thickness); termed the slit BPSCCO plate. The value of the RF magnetic shielding degree SDHP when holding the slit of the BPSCCO plate perpendicular to the ground, in the frequency region of 1 MHz (20 dB) to 30 MHz (40 dB), increased with frequency, and reminded approximately constant in the region of 30 MHz to 3 GHz (40 dB). The value of the RF magnetic shielding degree SDHH for holding the slit horizontally indicated an average value of 15 dB in the region of 1 MHz to 3 GHz. Namely, the difference of RF magnetic shielding degree, SDHP - SDHH, to the orientation of the slit represents polarization characteristics. It is anticipated that those polarization characteristics can be used to apply the filter for radio frequency band, the RF magnetic shields with the directional characteristics, the switch for microwave guide, among others, as new applications. Experimental results revealed several characteristics of the slit BPSCCO plate that include the dependences of polarization characteristics on the slit length, slit width, and slit number.

2LPH03

Vibration Transmission Characteristics against Vertical Vibration in Magnetic Levitation Type HTS Seismic Isolation Device

M.TSUDA, T.KAWASAKI, T.YAGAI, T.HAMAJIMA, Tohoku University; T.YAMADA, K.YASUI, Okumura Corporation

We have devised a magnetic levitation type HTS seismic isolation device that can theoretically eliminate any horizontal vibration transmission completely. The HTS seismic isolation device has three layers; the bottom, middle, and top layers are composed of permanent magnet, HTS bulk and permanent magnet, and HTS bulk, respectively. During earthquake, the damage in structures and instruments is mainly affected by horizontal vibration. Seismic isolation effect against the vertical vibration, however, should be improved to prevent as much damage as possible from the earthquake. Therefore, using the middle and bottom layers in the HTS seismic isolation device, we investigated the characteristics of vertical vibration transmission from the bottom layer fixed on an excitation device to the middle layer. Dependence of vibration frequency and amplitude, load weight on the middle layer, and air gap between the middle and bottom layers on the vertical vibration transmission were experimentally investigated. Especially, ratio of vibration amplitude of the middle layer to that of the bottom layer decreased with the load weight. To clarify mechanism of the vertical vibration transmission from the bottom layer to the middle layer and the dissipation of vibration energy, we investigated electromagnetic behavior within the levitating bulk using our developed analytical method and simulated the levitating bulk motion in the vertical direction.

2LPH04

Magnetic Design of a Bi2223 Cusp-type Superconducting Magnet for Propulsion Experiment

Y.M.Dai, Institute of Electrical Engineering, Chinese Academy of Sciences

A cusp-type HTS superconducting magnet is designed to simulate the magnetic field configurations for propulsion application. The magnet is composed of two Bi2223 superconducting coils and has an inner diameter of 80 mm and outer diameter of 220 mm. The magnetic field configurations are simulated for different separations between the two coils. Optimization on the Bi2223 superconducting tapes are carried out to obtain the 0.5T radial field for the axial propulsion coils. Mechanical considerations for the magnet construction and cryogenic supports are also presented in this paper.

2LPJ - Stability and Protection I – HTS and CIC 10:00am 12:00pm

2LPJ01

Periodicy of Contacts Between Subcables in Multistage Cable-in-Conduit Conductors and its Effect on Computation of AC Losses and Supercoupling Currents

S.A.Egorov, M.S.Astrov, S.B.Fedotova, Scientific Research Institute of Electrophysical Apparatus (NIIEFA)

The paper refines the lumped net-work technique for computation the coupling AC losses and magnetically induced supercoupling currents in multistage cable-in-conduit conductors (CICC) used in superconducting magnetic energy storages (SMES), tokamak reactors, etc. Surfaces of the subcables in CICC are not "smooth", but "corrigated". As the result the contacts between the subcables are featured with certain periodicy which depends on the pitches of the sequential cabling stages. The paper presents an expression for such periodicy and the results of computation of AC loss and supercoupling currents with and without taking into account the envisaged periodicy of contacts between subcables in multistage CICC, showing the significance of the effect.

2LPJ02

AC Loss Measurements in CICC with Different Aspect Ratio

F.Cau, P.Bruzzone, EPFL-CRPP,CH-5232 Villigen PSI, Switzerland

The coupling loss in a Cable in Conduit conductor (CICC) is strongly influenced by the cable geometry. Beside the cable pattern, twist pitch, wrapping and void fraction, also the aspect ratio has a not negligible role in the loss. In fact, it defines the area crossed by the flux variation and it determines therefore the entity of the coupling current between strands. An AC loss experiment on two Nb3Sn CICC samples (PITSAM II and PITSAM III) is carried out with a calorimetric method in the SULTAN test facility, in order to investigate the impact of the conductor aspect ratio on the loss. The two conductors, identical for cable pattern, void fraction and characteristics of both superconducting and copper strands, differ only in the aspect ratio, having PITSAM II and PITSAM III a square and a rectangular cross-section respectively. After the DC measurements scheduled in the SULTAN test-procedure (including cycling load), each sample is tested in a sinusoidal field perpendicular both to the background field and to the conductor axis, and generated by a pair of saddle shape coils. The background field during the tests is 2 T while the peak to peak amplitude of the sinusoidal signal is ± 0.3 T, with a frequency in the range between 0.2 and 6 Hz. The rectangular PITSAM III is tested with a sinusoidal magnetic field perpendicular first to the wide then to the narrow side of the conductor, so that the loss relative to three different aspect ratios is compared. The relation between loss and aspect ratio is also investigated with reference to the time constants τ and to the shape factor n.

2LPJ03

Experimental investigation of the CICC "matrix" specific resistance depends on transversal pressure.

S.A.Lelekhov, A.V.Krivykh, RRC "Kurchatov Institute"

There are different mechanisms of losses: eddy current loss, coupling loss, hysteretic loss and mechanical loss. The Lorentz force causes moving of the strands in the conduit and may result in plastic deformation of the cable. In our previous investigation was observed that the mechanical losses in CICC decrease in the process of the load-unload cycling if plastic deformation of the cable takes place. The transversal compression of the cable can decrease resistance of the contacts between strands. This leads to decreasing of matrix resistance and increasing of the eddy current and coupling losses. One of the goals was to measure the evolution of matrix specific resistance versus number of load cycles. Another goal was to investigate the dependence of matrix specific resistance on maximal pressure. Investigations were carried out in two conditions: in liquid nitrogen and in air at room temperature. The method and results of investigation are presented in this work.

We would like to thank Prof. V. Keilin, and Dr. N. Martovetsky for useful discussions and for the proof reading of this paper.

2LPJ04

Irregular Flux Linkage for Coupling Current Loops in Different Type CIC Conductors.

T.Yagai, Y.Shibata, J.Ohmura, M.Tsuda, T.Hamajima, Tohoku University; Y.Nunoya, K.Okuno, K.Takahata, JAEA

It is hard to estimate the AC losses in large Cable-In-Conduit (CIC) Conductors, especially for those with long time constant, because lengths of the formed coupling current loops are completely irregular. In order to investigate the mechanism of forming loops, we measured actual strand traces in two CIC conductors, one has 81 strands with circle cross-section and the other has 486 strands with rectangular cross-section and then, made clear formed loops by using measured results. One more important parameter for investigating causes of the losses is the flux linkage of those loops which can drive the coupling current flowing through the loops. If the flux linkage is canceled out by other loops, it should be in an ideal conductor whose strand traces are completely symmetry, the coupling current would not flow and hence, the losses would not be observed. In actual conductors, as we measured, the traces are not quite symmetry. We also investigated the difference of flux linkage between two conductors mentioned above. It seemed that the flux linkage compensation is better in the circular-shape conductor than in the rectangular-shape conductor. This result should be remarkable for devices which uses rectangular-shape CIC conductor.

This work was supported in part by Grant-in Aid for basic research, the Ministry of Education, Culture, Sports, Science and Technology, Japan.

2LPJ05

Accuracy of AC transport current loss in HTS tape measurements using a pick-up loop

J.Ogawa, S.Fukui, T.Oka, T.Sato, A.Maruko, H.Tanaka, Niigata University

AC transport current loss in high temperature superconducting (HTS) tapes can be measured without a direct electrical connection by using a pick-up loop method. This method requires a correction factor, which is related to the ratio of the linkage magnetic flux determined by the distribution of the transport current in the HTS tape and pick-up loop. We reported previously that the ideal shape of a pick-up loop is spiral, its radius is not important, and the distance from tape face to the pick-up loop return should be as small as possible. In this study, we determined the accuracy of the AC transport current loss measurement using a pick-up loop method in Bi2223/Ag tapes with the critical current distribution in the tape axis. We found the pick-up loop voltage of the deteriorated part of the HTS tape to be higher than the normal part with the same transport current. We conclude that the accuracy of the pick-up loop method is sufficient to measure the AC transport current loss in the HTS tape.

2LPJ06

Noncontact measurement of current distribution in filaments of a coated conductor

S.H.Park, Korea Polytechnic Univ. / Graduate school of Energy; M.J.Park, KEESRI / EECS Research Division; S.B.Byun, Korea Polytechnic Univ. / Graduate school of Energy; W.S.Kim, Seoul National Univ. / Dept. of Materials Sci. & Eng.; J.K.Lee, Woosuk Univ. / Dept. of Electrical Eng.; C.Park, Seoul National Univ. / Dept. of Materials Sci. & Eng.; J.B.Song, H.G.Lee, Korea Univ. / Dept. of Materials Sci. & Eng.; K.Choi, Korea Polytechnic Univ. / Graduate school of Energy

The AC loss in a coated conductor due to a perpendicular magnetic field is high because of its aspect ratio. To reduce the AC loss, the width of the coated conductor should be narrow with the order of its thickness. Or we have to make filaments on the conductor as many as possible and twist it. Because twisting an HTS tape is not useful for winding, continuous transposed coated conductors such as Roebel assembled coated conductors are tried for the AC application. We have proposed that striations on a Roebel strand made some effect for AC loss reduction. And we have also showed it was possible to measure current distribution in parallel conductors by hall sensors without contact. In this paper we measured the individual currents in filaments on Roebel strands. The Roebel strand with the width of 6 mm is made from a 12 mm coated conductor. We made several samples of continuous transposed coated conductors with different number of strands. We also made variation on the number of striations on a single strand.

This work has been supported by KESRI(R-2005-7-090), which is funded by MOCIE(Ministry of commerce, industry and energy).

2LPJ07

Losses in 2G tapes wound close together: Comparison with similar 1G tape configurations

P.Suarez, A.Alvarez, J.M.Ceballos, B.Perez, Universidad de Extremadura

In multilayer and magnetically coupled coils made from tape, the loss in each segment of tape in a coil depends on the parallel segments in the adjacent layers. In the case of coils, the current in all the layers is the same, but in other cases the current in the adjacent layer can be different both in amplitude and phase. In previous work, we have studied the influence of the proximity between tapes by considering the total loss in a segment as the sum of three components: the transport current in it, the global magnetic field due to the complete coil (or coils), and the local magnetic field due to the current in the tape wound just over or under the segment in question. To measure the last component, an experimental method has been proposed and carried out with Bi-2223 tape, showing that the loss in the tape can be increased or reduced by the proximity of another tape, depending on the current in the latter. We have shown how the variation of transport currents (and, therefore, of the associated magnetic fields) influences the practical critical current of the tape under test. Advances in YBCO tape (2G tape) fabrication have led to increases in the field tolerance of the tape, and the dependences of loss and practical critical current on the proximity of an adjacent tape needed to be revised. In the present work, we study the behaviour of the loss and practical critical current in 2G tapes under the influence of other tapes carrying zero or different currents. A comparison between Bi-2223 and YBCO tapes is shown.

2LPJ08

AC Loss measurement of polygonal assembly of coated conductors by thermo-couple method

M.Liu, Z.Jiang, Yokohama National University; N.Amemiya, Kyoto University; T.Kato, M.Ueyama, Sumitomo Electric Industries, Ltd.; Y.Shiohara, ISTEC-SRL

We attempt to measure the AC losses of assembly of coated conductors (CCs) for power transmission cables by the thermo-couple method, in which thermo-couples are used to determine the AC loss by measuring the local temperature rises of CCs. As the gap between CCs in cables is small, the influence of heat conduction between CCs must be considered for AC loss measurement of cables using thermo-couples, especially in cables composed of CCs with different electric properties such as critical current. We fabricate a mono-layer polygonal assembly of CCs with different critical currents and small gaps and measure their AC losses by thermo-couple method. A DC current around the critical current is supplied to one CC, and the temperature rises in all CCs in the assembly are measured. This is repeated for all CCs, we can obtain a system of equations which provides us the relation between the heat dissipations and temperature rises in CCs. When we supply an AC current, the AC losses in CCs can be determined from their temperature rises using this system of equations. AC losses measured by the thermo-couple method are compared with ones measured by electrical method.

This work was supported by NEDO as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

2LPJ09

Quench Analysis of the KSTAR TF Magnet and Busline for the first Campain

H.J.Lee, Y.Chou, D.K.Oh, S.H.Park, Y.K.Oh, National Fusion Research Institute

The operation region of a forced flow cooling superconducting(SC) magnet of CICC (Cable in Conduit Conductor) type is limited by the temperature, the magnetic field, the current density and so on. In order to extend the operation region, not only a development of superconducting material and CICC design but also an improvement of operating condition is being done. The KSTAR (Korea Superconducting Tokamak Advanced Research) TF(Toroidal Field) coils had been fabricated by Nb3Sn SC strands of the high critical field (Bc2) and the high critical temperature (Tc). It will be operating under the supercritical helium area and supplied 35.2kA (Bpeak 7.2T) for DC operation. During the first campaign, the heat generation of the coil comes from the strands movement or other physical reason would not exceed the cooling power due to the reduced current operation (15kA). And the conductor will be able to recover from any temperature excursion in this current operation field. If the quench of the TF coils is being developed, a mount should be discharged into the external dump resister of 80mohm. And the time constant of the fast discharge is 7 sec. In this paper, we have analyzed the thermo-hydraulic phenomena of the TF coil with the protection delay after quench from 5 sec to 2sec using the 1-D thermo-hydraulic analysis code (GANDALF).

This work is supported by the Korean Ministry of Science and Technology under the KSTAR project contract.

2LPK - SC Magnet Design, Tools, and Simulation 10:00am -12:00pm

2LPK01

A Micro HTS System for Simultaneous Energy Storage and Attitude Control of Picosatellites: Design Optimization and Control

E.Lee, MIT

This paper deals with the design optimization and control of the micro HTS system for three-axis stabilized picosatellites. The system uses three pairs of counter-rotating micro HTS wheels to achieve attitude control and energy storage simultaneously. A compact servo amplifier for the integrated HTS system is developed. To play and combine different functions of attitude control and energy storage with one unit, the design and control should be unified at the early stage of system development. With this motivation, this paper investigates control strategies to realize integrated attitude control and energy storage systems. First, nonlinear dynamics of spacecraft using the HTS systems are studied. A control approach is then proposed both to track desired attitude and to keep desired energy level while avoiding singularities in energy and attitude. The nonlinear control method compensates for disturbances as well as unmodelled and uncertain dynamics such as varying spacecraft inertia. Finally, in order to achieve more efficient and simpler micro HTS systems design guidelines, such as wheel configuration, are suggested based on this spacecraft dynamics and control study, and necessary changes have been made. This micro HTS system will be developed using micro fabrication technology.

2LPK02

A conceptual design of a conduction-cooled magnet for a superconducting property measurement system

S.J.Choi, Korea Polytechnic Univ./ Knowledge-Based Technology&Energy; J.H.Bae, M.H.Sohn, KERI / Superconducting Devices and Cryogenics Research ; W.S.Kim, C.Park, Seoul National Univ. / Materials Science and Eng.; J.K.Lee, Woosuk Univ. / Electrical Eng.; K.Choi, Korea Polytechnic Univ./ Knowledge-Based Technology&Energy

A superconducting property measurement system is being developed in Korea. Its purpose is to measure the characteristics of short HTS single and multiple tape samples. It can measure the properties of short samples of small superconducting cables which are made with parallel HTS tapes. This system is consisted of two parts; a conduction cooled HTS magnet and sample positioning part which is able to rotate the sample at various angles. In this paper we designed the HTS magnet with a shape of racetrack. Its maximum magnetic field is 3 T and has the homogeneity of 1 % at the center cylindrical space where its axial length is 20 cm and the radius is 3 cm. The magnet is separately cooled by cryo-cooler from the sample positioning part. So the temperature of the sample is independently controlled from 10 K to 77 K.

This work was supported by Electric Power Industry Technology Evaluation and Planning

2LPK03

Increment of the central magnetic field of a YBCO magnet by using multiple power sources

M.Kang, M.Koo, H.Lee, G.Cha, Soonchunhyang University

In the HTS magnet consisting of pancake windings, all pancake windings have been connected in series and excited by a single power source. In that case, currents of the whole pancake windings were limited by the minimum current of the top and the bottom pancake windings where maximum perpendicular magnetic field was applied. This paper presented the results of the excitation of an HTS magnet consisting of pancake windings by using multiple power sources.Currents of each pancake winding were determined by using optimization technique. Objective function of the optimization was the central magnetic field. Calculation and test was carried out using the YBCO magnet with 8 pancake winding. Results of calculation and test show that excitation of the YBCO magnet by using multiple power source is able to generate higher magnetic field comparing with a conventional single power excitation.

2LPK04

Determination of the critical magnetic field in an HTS pancake winding

M.Koo, M.Kang, H.Lee, G.Cha, Soonchunhyang University

The critical current of a pancake winding is limited by the critical current of a wire in the magnet whose magnetic field is maximum. To evaluate the critical current of the pancake winding, it is crucial to determine properly the magnetic field. In a pancake winding, the direction and magnitude of the magnetic field which is applied to the HTS winding are different from points to points. Even in an HTS wire, those can be quite different. It makes difficult to determine the magnetic field of a pancake winding. This paper assumed four types of the magnetic field as the magnetic field of a pancake winding, that is, maximum B, mean of maximum B and minimum B, arithmetic mean of B and quadratic mean of B. Critical current of the pancake winding was calculated by using above magnetic fields. Measurements of the critical current were carried out by using two BSCCO pancake windings which had different turns.

2LPK05

Analysis of MgB2 Linear-Type Magnetic Flux Pump for Persistent Current Mode HTS Magnet

Y.Fujii, T.Nakamura, Kyoto University

Novel performance of magnetic flux pump with the use of MgB2 sheet was analyzed in this paper. The target of the application is for the compensation of the small amount of current decay in HTS magnets, which are operated at persistent current mode. Although HTS magnets can be operated at higher temperature compared to LTS counterparts, such coils suffer from the current decay even in the persistent current mode. The reasons for the decay originate from the intrinsic property of HTS such as flux creep phenomenon and finite resistance due to immature technology of superconducting joints. In order to overcome the above-mentioned problem for practical applications of such magnets, our group has already proposed a new type of superconducting power supply called Linear-Type Magnetic Flux Pump (LTMFP). In our previous study, however, the fabricated LTMFP possesses the superconducting Nb foils, and then such compensator has to be operated in liquid helium correspondingly. Then, we move on to investigate the MgB2 LTMFP as a candidate to be operated at 20K. As a first step, the pumping performance of MgB2 LTMFP is analyzed based upon the 3-D Finite Element Method(FEM) that takes into account the nonlinear current transport characteristics as well as magnetic diffusion. The analysis results will be presented. The preliminary test results are also to be reported and discussed.

We would like to thank Dr.YoonDo Chung for valuable discussions.

2LPK06

Optimisation of the mechanical and superconducting properties of wires and tapes for high field solenoid magnets

D.Uglietti, ICYS-NIMS; T.Kiyoshi, Superconducting Materials Center - NIMS

Conductors for high field magnets should have high mechanical strength and high Young modulus to withstand large electromagnetic forces as well as high critical current density in order to generate higher fields. The optimisation of those properties is very important in the design of a magnet and its conductors. An overview of the limits to the mechanical and superconducting properties of low temperature superconductors (LTS) and high temperature superconductors (HTS) is presented in this paper. In case of large solenoids made with HTS and LTS, the main factor limiting the coil current in is the mechanical properties of the conductors. A new optimisation procedure for conductors is introduced, starting from the competition between the transport properties (large superconducting cross section) and the mechanical properties (large cross section of the reinforcement material). Mechanical and transport properties are balanced, depending on the coil diameter and on the applied magnetic field, and examples of applications to Bi2223 tapes and Nb3Sn wires are presented.

2LPK07

Numerical Analysis of the Operation Parametres of Fast Cycling Superconducing Magnets

E.Fischer, GSI; R.Kurnyshov, Electroplant; P.Schnizer, GSI; P.Shcherbakov, IHEP

The 100 Tm synchrotron SIS 100 is the core component of the Facility of Antiproton and Ion Research (FAIR). Prototype magnets were built last year with the first dipole magnet completed and tested. Thorough R&D resulted in FEM models which allow calculating the magnetic field of the magnet during static and dynamic mode. We illustrate the R&D steps required for the FEM calculation next to the development of the magnetic measurement system. We illustrate its accuracy and compare the results of the simulation to the measurements. We analyse the field quality and compare it with the spezification.

This work is supported by EU FP6 Design study (contract 515873 – DIRACsecondary-Beams)

2LPK08

Validation of Quench Simulation Software with Measurement Data of LHC Magnets under Operation Conditions

N.Schwerg, B.Auchmann, R.Denz, S.Russenschuck, CERN

During the recent phase of hardware commissioning of the LHC main ring, quenches of superconducting main magnets and corrector magnets have been recorded for the first time under operation conditions. The recorded “post mortem” data at different excitation levels can now serve for the validation and gauging of the quench analysis routines recently implemented in the CERN field computation program ROXIE. Quench simulation depends strongly on a number of input parameters such as thermal and electrical material parameters, magnet protection schemes, quench detection and heater delays, among others. In addition, these input parameters are known in advance only in a certain range due to the manufacturing processes and operational conditions at cryogenic temperatures. Voltage and current signals are the only reliable measurement data of quenching magnets in an accelerator. Quench processes can be better understood considering also results from numerical simulations. This requires a complete model of the thermo electrical phenomena as well a careful choice of physically meaningful model parameters. Our goal is to gauge our tools by the reproduction of measurement data, in order to predict the quench behavior during the design of future magnets.

2LPK09

Accurate computation of superconducting coil parameters using 3-D integral model

W.Zamboni, G.Rubinacci, Ass. EURATOM/ENEA/CREATE

Electric circuit models of superconducting coils are widely literature to represent their interaction with external power systems. Often, static approximation of Maxwell’s equations are applied to simplified geometries of coils to derive the circuit parameters, such as inductance and capacitance. This approach allows the use of the analytical formulae widely used in the literature for different kind of superconducting coils. This approach is not satisfactory for the design of the entire superconducting coil system, especially when very rapid response capabilities are required. For instance, this is the case of SMES systems, which are designed for the exchange of energies of the order of MWs in few milliseconds. The relatively fast transients to be simulated calls for a self-consistent and broad band electromagnetic modelling of the coil, including the full set of Maxwell’s equation although in the electromagnetic-quasistatic limit. This improves the approximations related to the simplified electrostatic models allowing to represent in a self-consistent way the capacitive couplings taking place during fast transients. In this work, we evaluate the admittance parameter of superconducting coil using a 3-D integral formulation of the full Maxwell’s equations. The frequency-domain admittance parameters are used to derive an N-port time-domain equivalent circuit of the system.

This work is supported in part by Italian MIUR and EURATOM/ENEA/CREATE Association.

2LPK10

Design of Adjustable magnetic field Homogeneous Region Superconducting Magnet System

Q.Wang, Y.Dai, B.Zhao, S.Song, S.Cheng, Z.Cao, L.Yan, Y.Bai, Institute of Electrical Engineering, CAS

We have designed and fabricated a superconducting magnet with center field of 1.3 ~4 T and warm bore of Φ 100 mm based on the hybrid method with genetic optimal method. The superconducting magnet has the adjustable length of homogeneity regions with the lengths for 150mm to 200 mm. Also the superconducting magnet can generated the multi-homogeneous regions with the length of 200, 250 and 320mm. The homogeneity of magnetic field is about ±0.5% with constant homogenous length and ±1.0% for adjusting homogenous length. All the homogeneous regions are with the same starting point and the field is decayed to 1/15-1/20 from the front point of homogeneous region to 200 mm. The superconducting magnet is cooled by 1.5Watt 4 K GM refrigerator. In the paper, the design and fabrication of the superconducting magnet are presented.

**The work was supported by NSFC*

2LPK11

Design of a Superconducting Magnet for Trapping Antihydrogen-Atoms at CERN

F.M.Esser, G.Hansen, J.Schillings, H.Soltner, M.Schmitt, Forschungszentrum Juelich GmbH

The ATRAP collaboration at CERN operates an experiment at the antiproton decelerator AD. The intention is to create and catch Antihydrogen-Atoms at a very low temperature in order to perform a precise comparison of the 1s-2s spectroscopy of Antihydrogen and Hydrogen. For trapping of neutral Antihydrogen-Atoms a strong magnetic field gradient is required. The design for such a superconducting magnetic trap has been accomplished in close co-operation with the ATRAP collaboration. It has been manufactured and tested together with the industry partner ACCEL. The main design criterion was a very compact construction of a superconducting racetrack-type quadrupole combined with two solenoids. Beside the geometrical design of the magnet system, this paper will focus particularly on the finite element calculations of the assembly including the cooling to the operating temperature of the magnet. An overview of the manufacturing and mounting procedure will be given and first test results will be presented.

We thank G. Gabrielse and his colleagues from the Harvard Physics Department as well as W. Oelert and D. Grzonka from the Institute of Nuclear Physics and all other members of the ATRAP collaboration used in the

for their support and the great discussions. We gratefully thank ACCEL for their support and the good job they did.

2LPK12

An Optimization Design Method of Actively Shielded MRI Superconducting Magnets with Robustness Analysis

J.Q.Liang, W.Guo, X.X.Wei, X.H.Jiang, Dept. of Electrical Engr., Tsinghua University

An optimization design method is proposed for electromagnetic design of actively shielded MRI superconducting magnets. Central field strength, uniformity over FOV, stray field regulation, and uniformity robustness against manufacturing errors are combined as an optimization goal. A cost-effective solution is guaranteed by constraining the magnet dimensions and pre-estimating the operating current upper limit. Design of a 7T animal MRI superconducting magnet is provided as an example of the proposed method.

2LPL - Novel Insulation Materials for Special Applications
10:00am - 12:00pm

2LPL01

Nanodielectrics for superconducting power applications at cryogenic temperatures

E.Tuncer, I.Sauers, D.R.James, A.R.Ellis, Oak Ridge National Laboratory

Thermal compatibility of dielectric and structural materials and their electrical insulation performance influences the size of the power equipment. Just as in conventional equipment, cryogenic applications also require well-characterized electrical insulation materials to be used by apparatus designers. In this study we review the current materials used in the superconducting power applications at cryogenic temperatures, and introduce novel materials based on nanoparticle-filled polymers for cryogenic electrical insulation. These new materials are composed of ex-situ or in-situ synthesized nanoparticles. These materials exhibit improvements in the dielectric breakdown strength compared to that of the base polymers. Several different nanocomposite systems are investigated and their electrical properties are summarized.

Research sponsored by the U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, Superconductivity Program for Electric Power Systems under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, managed and operated by UT-Battelle, LLC.

2LPL02

Electrical insulation characteristics of glass fiber reinforced resins

E.Tuncer, I.Sauers, D.R.James, A.R.Ellis, Oak Ridge National Laboratory

Non-metallic structural materials that act as an electrical insulation are needed for cryogenic power applications. One of the extensively utilized materials is glass fiber reinforced resins (GFRR) and may also be known as GFRP and FRP. They are created from glass fiber cloth sections that are impregnated with an epoxy resin under pressure and heat. Although the materials based on GFRR have been employed extensively, reports about their dielectric properties at cryogenic temperatures and in larger thicknesses (> 6 mm???) are generally lacking in the literature. Therefore to guide electrical apparatus designers for cryogenic applications, GFRR samples with different thicknesses are tested in a liquid nitrogen bath. A scaling relation between the dielectric breakdown strength and the GFFR thickness is established. Almost no data exists for partial discharge inception in GFRR materials as a function of thickness and geometery; initial PD results will be summarized. Loss tangents are also reported as a function of temperature at various frequencies.

Research sponsored by the U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, Superconductivity Program for Electric Power Systems under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, managed and operated by UT-Battelle, LLC.

2LPL03

Nanomaterial-Reinforced Dielectrics for use in HTS Systems

J.K.Walsh, M.W.Hooker, M.J.Lizotte, Composite Technology Development; E.Tuncer, I.Sauers, Oak Ridge National Laboratory

Recent advances in nanomaterials technology offer the capability to tailor the dielectric performance of electrical insulation materials for HTS power applications. In this work, POSS nanomaterials were incorporated into candidate insulation systems and the dielectric constant and high-voltage performance of the materials were characterized at cryogenic temperatures. The processing characteristics and dielectric performance of the various nanomaterial-reinforced materials will be discussed relative to that of conventional materials such as G10.

2LPL04

Industrialization of Radiation-Resistant Cyanate Ester Magnet Insulation

M.W.Hooker, M.W.Stewart, S.D.Grandlienard, S.A.Arzberger, N.A.Munshi, Composite Technology Development

Cyanate ester resins have been shown to exhibit excellent radiation resistance, high mechanical strength, and processing characteristics suitable for the vacuum-pressure impregnation of large, high-performance magnets. To industrialize this technology, various tests have been performed to demonstrate the processing and use of these materials in magnet-specific configurations. The results of these tests, and their implications for future magnet systems, will be presented.

2LPL05

Thermal Expansion of Filled Cyanate ester and Epoxy Resins

J.A.Rice, MultiPhase Composites, LLC

During the winding of high field superconducting magnet coils, small gaps inevitably form between the wire and the supports. These gaps must be filled with a material that will fully support the superconductor and prevent cracking of the epoxy or cyanate ester resin. Many times the simplest solution is to manually chop some glass fiber and pack it into the space hoping it will be uniformly infiltrated with epoxy. But what are the properties of this filler? This paper will present data on the thermal expansion of three filled organic resin systems and discuss potential formulations that will most closely match the expansion of the superconductor.

Supported by the U.S. Department of Energy under SBIR Grant # DE-FG02-04ER84014

2LPL06

Characterization of Dielectric Materials Under Cryogenic Conditions

H.Rodrigo, Center for Advanced Power Systems, Florida State University

Electrical characterization of dielectric materials used in devices such as motors, transformers, magnets and cables are presented. The performance of newly developed materials which are composites of polymer resins with nano-particle additives are compared with those that have been in usage before. Aspects of the materials such as breakdown voltages under AC, DC and impulse are presented. Loss measurements at room temperature and cryogenic temperatures are presented.Partial discharge measurements over a wide temperature range are presented and their significance to design and operation of electrical equipment are also given.

This research has been funded by the US Department of Energy and the Office of Naval Research.

2LPL07

Characterizations of Sol-Gel Ceramic Insulation Coatings on Stainless-Steel Tapes under Various Pressures and Temperatures

O.Cakiroglu, Istanbul Uni., Hasan Ali Yucel Education Faculty; L.Arda, Bahcesehir Univerity, Art and Science Faculty ; O.Bulut, Istanbul Technical University

The insulation coatings were coated on Stainless-Steel-304 (SS) tapes by reel-to-reel sol-gel process for investigation of characterizations under various pressure at room temperature (298 K) and liquid nitrogen temperature (77 K) for HTS/LTS high field insert coil. Solutions were prepared by using Mg, Y, Al and Zr based precursors, solvent and chelating agent, then the insulations was coated on long-length SS substrate. The film thickness was controlled by number of coating, withdrawal speed and solution chemistry. High voltage breakdown, electrical strengths, and dielectric constants were tested of these samples by using standardization equipment. Thermogravimetric (TGA) analyzes in air and in nitrogen, and the effect of corrosion test according to the standardization of ASTM B 117 was studied. Surface morphology of micrographs of high voltage breakdown and corrosion test samples were examined using ESEM.

2LPM - Small Test Coils – I 10:00am - 12:00pm

2LPM01

Thermal and Electromagnetic Analysis of Conduction-Cooled HTS Magnet

H.Y.Park, Changwon National University; M.H.Shon, K.D.Sim, S.Kim, E.Y.Lee, H.M.Kim, KERI; A.R.Kim, M.Park, I.K.Yu, Changwon National University

Generally the decreasing rate of critical current under magnet field is very sloped in case of 1st generation (1G) superconducting wires more than 2nd generation (2G) superconducting wires. Therefore, it is strongly necessary to consider the thermal and electromagnetic characteristics for HTS magnet design stage. In this paper authors measured and analyzed the thermal and electromagnetic characteristics with actually fabricated 8 conduction-cooled HTS magnet and have compared with the analysis result using analysis tool. As well known, the conduction-cooled superconducting coil can reduce its size in the constant operating current, and has a merit of simple use. The inner diameter of fabricated double-pancake coil is 110mm and the outer diameter is 195mm. The HTS magnet is cooled via two-stage GM cryocooler and, cooling capacity of the first stage is 37W at 40K and the second stage is 1W at 4.2K. The fabricated HTS magnet showed good operating characteristic and good agreement to the analysis result.

This work was supported by Electric Power Industry Technology Evaluation and Planning

2LPM02

Conduction-Cooled Superconducting Magnet for Material Control Application

Y.S.Choi, D.L.Kim, B.S.Lee, H.S.Yang, W.M.Jung, KBSI; T.A.Painter, NHMFL

A conduction-cooled superconducting magnet with operating current of 210 A is designed, fabricated, and tested for material control application. The superconducting magnet has the effective warm bore of 52 mm and the maximum central field of 5 T. Since magnetic field gradient should be larger at the end rather than at the center of the magnet for material control, we developed design method to optimize magnet for this purpose. The safety of superconducting magnet is evaluated, taking into account the electro-magnetic field, heat and structure, and the superconducting coil is successfully wound by the wet-winding method. The superconducting coil is installed in the cryostat maintaining high vacuum and cooled by a two-stage GM cryocooler. The superconducting magnet reached the designed central field and stably operated more than a week at a normal operating temperature of 4.5 K within +/- 0.3 K variation.

2LPM03

Performance test and design of module coil for cryogen free HTS magnet

H.M.Kim, M.H.Sohn, H.Y.Park, K.Sim, KERI; H.S.Kim, H.G.Lee, Korea Univ.; Y.G.Kown, KERI

This paper deals with the performance test and design of module coil for cryogen free High Temperature Superconducting (HTS) magnet. This coil generated the center field with 2 T totally consists of 8 Double Pancake (DP) coils by using Di-BSCCO 2223 HTS wire by Sumitomo Electric Inc. A model coil among 8 DP coils firstly fabricated to observe the electro-magnetic property of the coils wingding with Di-BSCCO HTS wire. The operating temperature and current of a module coil are 20 K and 150 A, respectively. It measured magnetic field and temperature distribution of DP coil with respect to operating current variation of the module and the test result agreed with computational result very well.

This work was supported by a grant from Basic Science Research Program of Korea Electrotechnology Research Institute funded by the Korea Council for Industrial Science and Technology (KOCI), Korea.

2LPM04

Development of 2 T Cryogen Free HTS Magnet

M.H.Sohn, S.Kim, K.D.Sim, H.M.Kim, E.Y.Lee, K.C.Seong, H.Y.Park, Korea Electrotechnology Research Institute

A laboratory-scale cryogen free high temperature superconducting (HTS) magnet are fabricated and tested. This HTS magnet was designed in order to generate 2 T at center of room bore in operating current 120 A. It consisted of eight double-pancake sub-coils, two HTS (High temperature superconducting) current leads, a GM cryocooler and a cryostat without a radiation shield vessel. Sub-coils were wound with DI-BSCCO tapes fabricated by Sumitomo Electric Industries, Ltd. using react and wet-winding method. The inner diameter of coil is 110 mm and the outer diameter is 195mm. Room bore diameter of this magnet was 66 mm. Each bobbin of double-pancake coils was of GFRP. Upper and lower supporting plates of coils was of Al in order to improve thermal conduction. In this paper, fabrication and test results of HTS magnet system will be presented.

This work was supported by a grant from Basic Science Research Program of Korea Electrotechnology Research Institute funded by the Korea Council for Industrial Science and Technology (KOCI), Korea.

2LPM06

Development of coiling technique using YBCO tape for power applications

K.Shikimachi, N.Hirano, N.Kashima, T.Watanabe, S.Nagaya, Chubu Electric Power Co., Inc.; T.Izumi, K.Nakao, Y.Shiohara, ISTEC

IBAD/ CVD-YBCO coated conductor has not only much higher transport properties at high temperatures in high magnetic fields but also much higher mechanical properties than conventional metallic superconductors and other HTS conductors. Although it has these high characteristics, coiling using YBCO coated conductor tape requires different skills compared with conventional superconducting wire. So, coiling technique such as winding, electrode formation, impregnation, reinforcing was developed for power applications such as SMES, and various types of double-pancake coils were manufactured using IBAD/ CVD-YBCO tape. The basic tests of the coils were conducted in conduction-cooling systems, and the effects of copper tape and resin impregnation to improve their thermal conduction and stability were estimated.

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO), under the Research and Development of Superconducting Magnetic Energy Storage System sponsored by Agency of Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI). In addition, YBCO coated conductors used in this work were produced by Chubu Electric Power Co., supported by NEDO through ISTEC, as the Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

2LPM08

Magnetic field stability of a small YBCO magnet in persistent current mode

W.S.Kim, Seoul National University; M.J.Park, Korea Electrical Engineering & Science Research Institute; J.K.Lee, Woosuk University; C.Park, Seoul National University; J.B.Song, H.G.Lee, Korea University; H.G.Lee, G.W.Hong, K.Choi, Korea Polytechnic University

It is well known that high temperature superconductors are promising for a magnet application, but it has been almost impossible so far to apply them to the magnet in persistent current mode because of poor qualities of their superconducting joint at higher current as well as their lower index values. To get rid of the joints from an HTS superconducting magnet, a wind-and-flip technique for demonstrating a persistent current mode operation of HTS magnet using YBCO coated conductors had been suggested. This paper presents experimental results of measured drift of a persistent current in the YBCO pancake coil which was made by using the wind-and-flip technique. The pancake coil was wound by YBCO coated conductor with a thickness of 12 mm, which was slit longitudinally at the center of the conductor along the conductor by a specially designed slitter. A stainless steel heater was attached on the one end of the YBCO conductor as a persistent current switch to energize the pancake coil. A temporal stability of the magnetic field was analyzed by monitoring the long-term drift of the magnetic field at different operating temperature by hall sensors.

This work was supported by Electric Power Industry Technology Evaluation and Planning.

2LPM09

Persistent current switches for a small magnet made of coated conductors

W.S.Kim, Seoul National University; S.H.Park, Korea Polytechnic University; J.K.Lee, Woosuk University; C.Park, Seoul National University; J.Han, Korea Polytechnic University; J.B.Song, H.G.Lee, K.Choi, Korea University

Due to the progress achieved in the development of HTS (High Temperature Superconducting) conductor, especially YBCO coated one, HTS conductors are expected to be a prime substitution for LTS (Low Temperature Superconducting) materials as well as a copper. One of the strong candidates as an application with YBCO coated conductor is a superconducting magnet, which is a key element of NMR or MRI. Those superconducting magnets are supposed to run in persistent current mode, which means they need a superconducting joint technology and also a PCS (Persistent Current Switch) technology. This paper presents simulated and experimental results of PCSs made of different kinds or dimensions of YBCO coated conductors. A Stainless steel heater was wound with the YBCO coated conductor in the shape of small pancake to open the switch, and impregnated by epoxy to keep the temperature. The optimal driving condition of each YBCO PCS for a small HTS magnet application was derived from the simulation and verified by the experiments with a small HTS pancake coil at the desired operating temperature.

This work was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPM10

Design and Results of a YBCO Magnet for a 94GHz Gyrotron Application

E.E.Burkhardt, D.M.Coffey, A.B.Berryhill, R.W.McGhee, Cryomagnetics, Inc.

The use of high-temperature superconductors (HTS) for cryogen-free gyrotron magnets will greatly reduce the power requirement and overall physical size of the system. Because some gyrotron systems are mounted on a vehicle and need to be mobile, the refrigeration system must be as lightweight and compact as possible. Cryomagnetics previously built a BSCCO magnet based on the design of a NbTi magnet. The limiting factors with this magnet were the cost of the BSCCO material and the excessive weight due to the necessity of field-shaping iron. Since it is projected that the cost of 2G YBCO tape will become significantly lower than BSCCO, and the critical current will also increase, the next generation of these magnets will mitigate those problems. Cryomagnetics has designed, built and successfully tested a 3.57 T magnet wound with 2G YBCO tape. This is the first full-scale magnet of its kind built using 2G YBCO tape. It consists of 10 double-pancakes operating at 140 A and 20 K. A single-stage cryocooler is used to cool the magnet. Because the performance of YBCO material is improving quickly, future magnets will be able to operate at lower current, higher temperature and will be lighter weight.

This work was supported in part by the Air Force Research Laboratory (AFRL), Propulsion Directorate

TUESDAY AFTERNOON POSTER SESSIONS 2:00pm - 4:00pm

2LPN - Fault-Current Limiters – II 2:00pm - 4:00pm

2LPN01

Testing of a resistive fault current limiter component based on Bi-2212 bulk superconductor

A.Polasek, C.V.Sena, M.A.Sens, E.T.Serra, CEPEL - Electric Power Research Center; F.C.Rizzo, PUC-Rio - Pontifical Catholic University

An insulated and shunted Bi-2212 bulk coil was cooled with liquid nitrogen (77 K) and submitted to controlled fault current tests. Prospective currents achieving 11 kA were limited to about 5 kA (first peak) and to 3 kA (following peaks), under 280 V. Symmetrical and asymmetrical short-circuits during 60-100 ms were applied. The Bi-2212 coil was able to withstand several short-circuits, showing a fast response and reproducible results. A recovery time of minutes was needed between one test and the following one. Therefore, the bulk coil was damaged when the interval between subsequent short-circuits was reduced to 30 seconds. The critical current was severely reduced by those last tests. Thermal imaging by an infrared cam revealed inhomogeneous heating of the damaged coil after short-circuit and steady-state normal current (200 A) testing. X-ray tomography showed discontinuities along the coil, probably provoked by the formation of hot-spots. The insulated bulk coil was cut in transversal and longitudinal sections, in order to evaluate the damages. Samples of the metallic shunt and of the ceramic bulk were analyzed by RxT measurements, XRD and SEM/EDS.

2LPN02

Fault Current Limiting Characteristics of the Matrix-type SFCL with the Integrated Current Limiting Modules

C.Yong-Sun, P.Hyoung-Min, C.Hyo-Sang, Chosun University; P.Chung-Ryul, H.Byoung-Sung, Chunbuk University

The matrix-type superconducting fault current limiter (SFCL) consists of the trigger and current-limiting part connected in series and parallel. The trigger part with reactors connected in parallel improves the quenching characteristics by applying the magnetic field into the superconducting units. The current-limiting part with superconducting units connected in parallel and shunt reactors connected in series limits the fault current when the fault occurs. We developed the integrated fault current limiting module with the trigger and the current-limiting parts to apply high magnetic field into the superconducting units and to increase the capacity of matrix-type SFCL. This was composed of a superconducting unit for the trigger part and two superconducting units for the current-limiting part. We confirmed that the magnetic field generated in the integrated fault current limiting module was larger than that of separated fault current limiting module. So the quenching characteristic between superconducting units was improved. The whole magnitude of the SFCL was reduced because the volume of the integrated fault current limiting module could be reduced by one thirds than that of separated fault current limiting module. We found that the quenching characteristic was improved in the integrated fault current limiting module.

This work has been supported by KESRI(R-2005-7-066), which is funded by MOCIE(Ministry of commerce, industry and energy).

2LPN03

Solid Nitrogen Cooled YBCO Thin Film Module for High Tc Superconducting Fault Current Limiter

J. B.Song, K.J.Kim, Korea Univ., Korea; H.M.Kim, KERI, Korea; H.R.Kim, O.B.Hyun, KEPRI, Korea; W.S.Kim, C.Park, J.Sim, Seoul National Univ., Korea; H.G.Lee, Korea Univ., Korea

Recently, there have been many studies about the high-Tc superconducting fault current limiter (SFCL). Conventional superconducting fault current limiters are operated by cooling systems with liquid cryogen, such as sub-cooled liquid nitrogen (LN2). However, in fault mode, the LN2 evaporates because of a joule heating and thus the SFCL system has an enormous increase of nitrogen gas volume. Therefore, thermal stability and protection of the system become the major concern in the design of the SFCL cooling system. In this paper we propose a new cooling system cooled by solid nitrogen (SN2) for the SFCL, which can be an alternative idea to enhancing the thermal stability and protection of the system because the SN2 has an excellent heat capacity. This paper contains the initial designs of the cooling system for the SFCL using the SN2 as the heat capacity. Also, we have the thermal analysis of the proto-type cooling system with the SN2 for the YBCO thin film as a test module. Thermal stability and electrical properties of the YBCO test module cooled by the SN2 are also discussed in the paper.

This work was supported in part by a grant from the CAST of the 21st Century Frontier R&D Program funded by the Ministry of Scien. and Tech., and also, was partially supported by MOCIE through EIRC program with YEPRC at Yonsei University, Seoul, Korea.

2LPN04

Short-Circuit Current Limiting Characteristics of Flux-Coupling Type Superconducting Fault Limiter according to the Direction Windings

B.I.Jung, H.S.Choi, H.M.Park, Y.S.Cho, J.H.Lee, Chosun University

The flux-coupling type superconducting fault current limiter (SFCL) is made by using the transformer. The flux-coupling type SFCL consists of the primary and the secondary coils connected in series, and the secondary coil has a superconducting unit connected in parallel. Before the fault occurrence in power system, the SFCL is operated without power loss (I2R) because of the zero impedance behavior of the superconducting unit. When the fault occurs and the short-circuit current exceeds the critical current in the superconducting unit, the superconducting unit is quenched, and the short-circuit current is limited. The flux-coupling type SFCL could be divided into the additive and the subtractive polarity winding according to the winding directions. The short-circuit current of the flux-coupling type SFCL with the additive polarity winding was limited more effectively than that of the subtractive polarity winding. It was because the direction of current according to the winding direction of secondary coil was reversed. In case of the voltage generated in the superconducting unit, the voltage in additive polarity winding was generated more than that in the subtractive polarity winding. Consequently, we confirmed that additive polarity winding could be expected to reduce the power burden of the superconducting unit in the comparison with the subtractive polarity winding.

2LPN05

Design, Fabrication, and Test of the Superconducting Fault Current Limiter with Various Types of Bypass Reactor

K.S.Chang, D.K.Park, S.E.Yang, Y.J.Kim, J.B.Na, T.K.Ko, Yonsei University; M.C.Ahn, MIT

This paper presents the study on the Superconducting Fault Current Limiter (SFCL) with various types of bypass reactor. The characteristics of an SFCL comprised of YBCO coated conductor (CC) as a switch and Bi2223 coil as a bypass reactor have been presented in a previous paper. Even though the previous one has shorter recovery time, the generated impedance after a fault was much lower than the conventional resistive SFCL without a bypass reactor. To apply the SFCL into power system, the SFCL has proper impedance during the fault. Therefore we proposed various types of bypass reactor such as YBCO CC coil or copper coil to achieve higher impedance than the conventional one in this paper. The SFCLs with various types of a bypass reactor were fabricated and short-circuit test with the SFCLs were performed. The results of the tests were compared in point of current limiting characteristics and recovery.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea

2LPN06

Characterization for the quench of the unified matrix-type SFCL with 2×2 matrix

D.C.Chung, Dept. of EE Woosuk Univ; H.S.Choi, Dept. of EE Chosun Univ.; T.S.Sung, Y.H.Choi, KEPRI; S.H.Lim, Dept. of EE Soongsil Univ.; Y.S.Cho, Dept. of EE Chosun Univ.

To apply an SFCL to the power system, the level of electrical power of SFCL must be risen compared with that of normal SFCL. In this aspect, it is important for electrical power of an SFCL with matrix structure to be uniformly distributed in the power system. We designed the unified current-limiting module to apply magnet field to superconducting devices. It consisted of a superconducting device for a trigger part and another two devices for a current-limiting part. We tested the performance of those modules with 2×2 matrix. This 2×2 matrix consisted of 4 trigger parts and 8 current-limiting parts. We confirmed the quenching with the uniformly voltage distribution for 12 superconducting devices. It was because of the reduction of the difference for critical current between superconducting devices. The measured results showed that the useful SFCLs with high level power could be made using the proposed architecture.

2LPN07

Analysis and Measurement of Current Sharing by Inductance of Non-Inductive Limiting Coil

S.E.Yang, D.K.Park, Y.J.Kim, K.S.Chang, T.K.Ko, Yonsei University; H.M.Kim, Korea Electrotechnology Research Institute

Development of superconducting power equipments is closely related to that of superconducting wires. Recently, continuing from the first generation(1G) BSCCO wire, commercialization of the second generation(2G) wire, coated conductor(CC), is near at hand. Superpower Inc., has already commercialized 2G wire of 600 m piece length. With the development of CC, superconducting power equipments are actively developed and some research groups reported successful demonstration results of the power devices such as cable, fault current limiter, and so on. Among them, superconducting fault current limiters(SFCL) are highlighted for their limitation of fault current according to continuous load increase in power system. The 13.2 kV/ 630 A class resistive SFCL using coated conductor (CC) was developed and its short-circuit test was successful. In this paper, current sharing by inductance of non-inductive limiting coil are measured by non-contact method and calculated.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPN08

Quench and Recovery Characteristics of a SFCL applied into Neutral Line of a Three-Phase Power System

S.H.Lim, J.S.Kim, J.M.Ahn, J.F.Moon, J.C.Kim, Soongsil University; C.H.Kim, Sungkyunkwan University; O.B.Hyun, Korea Electric Power Research Institute

We suggested the neutral line as more effective application location of a superconducting fault current limiter (SFCL) in a three-phase power system and analyzed the quench and recovery characteristics of SFCL applied into the neutral line in case that unsymmetrical ground faults such as the single line-to-ground fault and the double line-to-ground fault occurred. For the enlargement of the current in the neutral line to the current of the SFCL, the isolated transformer was introduced in the neutral line. Through the comparative analysis based on the experimental results for SFCL's two application locations of the neutral line and the three-phase power line, it was confirmed that the SFCL applied into the neutral line of the power system was more advantageous from the viewpoint of the practical use of the SFCL and the SFCL's coordination with other related protective devices in the power system.

2LPN09

Current Limiting Characteristics of a Voltage-Controlled Voltage Source Inverter using YBCO Coated Conductor as a Decoupling Inductor

K.I.Min, S.W.Lee, Yonsei University; S.H.Lim, Soongsil University; Y.H.Moon, T.K.Ko, Yonsei University

We proposed a voltage-controlled voltage source inverter (VCVSI) using coated conductor (CC) as a decoupling inductor. The decoupling inductor is the essential component for applying the voltage control algorithm into VCVSI. In this paper, the decoupling inductor designed with YBCO CC was applied into the VCVSI. To determine the optimal specification of CC as a decoupling inductor, it is necessary to consider design parameters such as the limited fault current, the active power flow from the system and the reactive power required by the decoupling inductor. The VCVSI using designed YBCO CC as a decoupling inductor can perform the fault current limiting operation from a short-circuit. In addition, during a normal time, it can compensate the reactive power that the non-linear load requires and perform the load voltage stabilization. The specification for a test model was determined and its various functions such as the fault current limiting and the power conditioning operations were presented and analyzed through the computer simulation. Through the analytical results based on the computer simulation, the validity of the analysis was confirmed and its multi-operation was discussed.

2LPN10

Reliability Enhancement of the Fast Switch in a Superconductor Triggered Fault Current Limiter Using Power Electric Switches

O.-B.Hyun, Korea Electric Power Research Institute; J.Sim, LS Industrial Systems; H.-R.Kim, Korea Electric Power Research Institute; K.-B.Park, LS Industrial Systems; S.-W.Yim, Korea Electric Power Research Institute; I.-SOh, LS Industrial Systems

We have investigated reliability enhancement of the fast switch (FS) by using power electric switches such as integrated gate commutated thyristors (IGCT) in the line commutation type superconductor triggered fault current limiter (STFCL). The FS utilizes a vacuum interrupter (VI) to open and close the primary power line. The operation of FS highly relies upon the complete arc extinction in the VI. Since the primary line resistance including the arc resistance may not be extremely high after the VI opens, of interest is possible remanent current in the VI, which may cause a failure in duty. The IGCTs are to completely remove the remanent current in the VI, guaranteeing the arc extinction and enhancing reliability in operation. We fabricated and successfully tested the IGCT – FS assembly in an STFCL up to 25 kArms of fault current. Test results and additional suggestions will be discussed.

This work was supported by the grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPN11

Characteristics of a Bi-2212 Bulk Superconducting Fault Current Limiting Element

Y.H.Ma, Z.Y.Li, K.Ryu, Dept. of Electrical Engineering, Chonnam National University; K.B.Park, I.S.Oh, Technology R&D Center, LS Industrial Systems

We are developing a 22.9 kV/25 MVA superconducting fault current limiting (SFCL) system for a power distribution network. A Bi-2212 bulk SFCL element, which has the merits of large current capacity and high allowable electric field during fault of the power network, was selected as a candidate for our SFCL system. In this work, we experimentally investigated important characteristics of the 190 kVA Bi-2212 SFCL element in its application to the power grid, e.g. DC voltage-current characteristic, AC loss, current limiting characteristic during fault, and so on. Some experimental data related to thermal and electromagnetic behaviors were also compared with the calculated ones based on numerical method. The results show that the total AC loss at rated current of the 22.9 kV/25 MVA SFCL system, consisting of one hundred thirty five 190 kVA SFCL elements, becomes likely 763 W, which is excessively large for commercialization. Numerically calculated temperature of the SFCL element in some sections is in good agreement with the measured one during fault. Local temperature distribution in the190 kVA SFCL element is greatly influenced by non-uniform critical current along the Bi-2212 bulk SFCL element, even if its non-uniformity becomes a few percentages.

This work was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPP - Current Leads 2:00pm - 4:00pm

2LPP01

Design and Fabrication of High-temperature Superconducting Bus with Large Current Capacity

Y.Wang, School of Electrical and Electronic Engineering, North China Electric Power University; X.Meng, Istitute of Electrical Engineering, Chinese Academy of Sciences; S.Dai, Z.Gao, F.Zhang, L.Lin, Institute of Electrical Engineering, Chinese Academy of Sciences

This paper describes the design and fabrication of a 20KA high-temperature superconducting (HTS) bus. Structure of the bus is multi-layer by clockwise and anticlockwise winding with different winding pitch and angle so that uniform current distribution and low ac losses can be obtained. The bus is modeled by an equivalent circuit consisting of liner self- and mutual inductance. Ac losses are also analyzed according to the structures. Both of terminals are optimized in order to assure the minimum Joul loss and heat-leakage flowing into cryostat. Finally, the bus was tested and its stability margin was examined at LN2 temperature. The bus was found to be very stable at high currents closer to its critical current.

This work was supported by the Chinese Ministry of Science & Technology under Grant 2006AA03Z210.

2LPP02

HIGH TEMPERATURE SUPERCONDUCTOR CURRENT LEADS FOR WENDELSTEIN 7-X AND JT60-SA

W.H.Fietz, R.Heller, A.Kienzler, R.Lietzow, FZK

The Forschungszentrum Karlsruhe has taken over the responsibility for the design, construction and testing of the HTS current leads for two fusion experiments, i.e. the stellarator WENDELSTEIN 7-X (W7-X) and the satellite tokamak JT60-SA. W7-X is presently under construction at the Greifswald branch of the Max-Planck-Institute for Plasma Physics and consists of 50 non-planar and 20 planar coils with a maximum conductor current of 17.6 kA. In total 14 current leads are required with a nominal current of 14 kA and a maximum current of 18.2 kA. In the frame of the Broader Approach Agreement between Japan and the EU and concomitantly to the ITER project, the satellite tokamak project JT60-SA has been agreed in 2006. The magnet system of JT60-SA consists of 18 toroidal field coils, 4 central solenoid modules and 7 poloidal field coils. In total 26 leads mounted in vertical, upright position are required. All current leads will be of the Cu-HTS binary type. The HTS part covers the range between 4.5 K and 60 K and is cooled by heat conduction from the 4.5 K end, only. The Cu heat exchanger is cooled with 50 K He and covers the range between 60 K and room temperature. The paper describes the status of the high temperature (HTS) current lead development for W7-X and JT60-SA.

2LPP03

Design of Conduction Cooled Coaxial HTS Current Lead

W.B.Ma, 1.Technical Institute of Physics and Chemistry, Chinese Academy of Sciences2.Graduate University of Chinese Academy of Sciences; Z.A.Zhu, Institute of High Energy Physics, Chinese Academy of Sciences; L.Q.Liu, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences; C.L.Yi, Institute of High Energy Physics, Chinese Academy of Sciences; L.Zhang, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences; Z.L.Hou, M.F.Wang, Institute of High Energy Physics, Chinese Academy of Sciences

A set of 200 A conduction cooled coaxial HTS current lead, which had advantages of simplicity, compactness and economy, was designed at Institute of High Energy Physics, CAS. This HTS current lead consisted of a resistive (copper) upper stage, a lower HTS stage and an intermediate distinctive heat exchanger. Considering the good performance of electrical insulation and thermal conductivity, the commercial available Aluminum Nitride (AlN) components were adopted within the heat exchanger. This paper deals with the principles of construction and descriptions of pilot model designs of mentioned leads. And experimental results showed good operational performance at 200 A.

This work was carried out in superconducting magnet group of IHEP, CAS. It was greatly supported by my advisors and colleagues. Thank you!

2LPP04

Improvement of the critical current of the current lead by a coaxial structure

C.Gu, T.M.Qu, X.F.Li, Z.Han, Applied Superconductivity Research Center, Tsinghua University

Current carrying capacity is analyzed for a high temperature superconductor coaxial current lead (CCL), where two parts one is responsible for current flowing in, and one is responsible for current flowing out share a common axis. Numerical calculation has been carried out for simulating the field distribution and thus, the critical current of the current lead. The size of the CCL in association with the amplitude of the field have been discussed. For an individual current lead, no significant enhancement can be found. However, big advantages can be obtained from a twin CCL structure.

2LPP05

Loss evaluation of current leads used above liquid nitrogen temperature

M.Furuse, K.Agatsuma, S.Fuchino, AIST

This paper describes evaluation of losses of current leads made of various metals used for power apparatuses operating at liquid nitrogen temperatures. The heat flow into liquid nitrogen conducting adiabatic current leads was measured by the nitrogen boil-off method. From the results, we derived average Lorenz numbers for materials between room temperature and liquid nitrogen temperatures. The average Lorenz number, having factors of thermal conductivity and electrical resistivity, is a good index of performance of current leads. A theory of loss evaluation of current leads using the average Lorenz number and a method for the optimum current lead design are described as well. In addition, we attempted to use commercial Bi2223/Ag tape conductors as current leads between room temperature and the liquid nitrogen temperature, and a higher efficiency was achieved than with pure-metal current leads.

2LPP06

An optimized bipolar current lead for the ENEA variable temperature insert test facility for critical current measurements

L.Affinito, A.della Corte, M.Napolitano, G.M.Polli, ENEA - Superconductivity Department

A facility, for the current characterization of superconducting strands in a variable current regime at different temperature and magnetic fields, is operating at the ENEA Superconductivity laboratories. Although the temperature and magnetic field range of variability be reasonably high, in comparison with other existing similar facility elsewhere, and be characterized by a highly stable temperature behaviour, the present current limit has become too low for testing the presently available advanced Nb3Sn strands. Therefore, an effort has initiated to upgrade the facility to lead more current to the tested samples. In particular, the facility upgrading process has been concentrated on a redesign of the current lead using the new generation of stabilized superconducting YBCO tapes. A hybrid (resistive/HTS) configuration has been maintained substituting brass with copper in the resistive section and keeping unaltered the present limit for the coolant and space availability. Nonetheless, to obtain an elevated sample temperature stability, and thus to limit the heat generated in the current lead by Joule effect, the length of the HTS section has been maximized. In the paper, the numerical simulation and optimization carried out in support of the current lead redesign and the relative performances measured are presented.

2LPP08

Semi-retractable Current Lead Cooled by a Cryocooler for High Field Magnet

Y.S.Choi, KBSI; T.A.Painter, NHMFL; D.L.Kim, H.S.Yang, B.S.Lee, KBSI

The semi-retractable current lead is designed for a 21 T superconducting magnet system. A semi-retractable current lead is composed of a normal metal element, conducting the current from room temperature to an intermediate temperature, and an HTS element, conducting the current down to liquid helium temperature. An HTS element and the joint between the normal metal and HTS element are continuously refrigerated by a two-stage cryocooler. The intermediate joint carries current through Multilam which is a commercially available strip of louvered material used to make electrical connections. After magnet energization the normal metal element is disengaged from the HTS element without breaking vacuum in the insulating space. The semi-retractable current lead is fabricated and installed in the conduction-cooled magnet system for feasibility test. The adaptability and reliability of the lead are tested during engage and disengage performance. The electrical contact resistance is also measured in the intermediate joint with respect to the vacuum level, performance cycle, and temperature.

2LPP09

Study of HTS Bulk Current Lead With Metal Alloy Impregnation Under Vacuum

K.Tsuzuki, D.Sugyo, Y.Kimura, M.Izumi, Tokyo University of Marine Science and Technology; N.Sakai, Superconductivity Research Laboratory, ISTEC; M.Miki, Kitano Seiki Co. Ltd

We have developed a field pole of Bi2223 superconductor winding without iron core applied to the motor of an axial gap type. In generally, there are large cryogenic losses which carry electric current from the room temperature power supply to the field pole at low temperature. That is, large heat invasion exits by using a conventional copper leads. Thanks to a very low thermal conductivity, HTS bulk can carry electric current with very small heat transfer to field pole if the HTS lead is cooled down to 90 K. Therefore, the bulk current lead (BCL) is crucial and makes the present axial-type motor length to be shortened. In contrast to the conventional HTS wire-based current leads, the BCL enables us to realize a short length of bulk HTS bar, which is the distance between high-temperature end and low-temperature end. In the present BCL, it is important to get good joining between a bulk and Cu terminals. There are, however, many pores at the surface of bulk. They cause a negative effect on contact resistance and mechanical stability. In order to solve this problem, we have improved a vacuum impregnation technique with low melting temperature alloy. As a result, the terminal resistance was 800 μΩ between 40 K (low temp. end) and 70 K (high temp. end) and the applied current was successfully reached 300 A which is satisfactory for the axial-gap motor operation.

2LPQ - Stability and Protection II – HTS 2:00pm - 4:00pm

2LPQ01

The thermal instability at normal conductor terminal of the conduction cooled HTS magnet

J.H.Bae, KERI; D.K.Bae, Chungju Univ.; H.Y.Park, M.H.Shon, S.H.Kim, H.J.Kim, KERI

This paper describes the thermal quench at the conduction cooled joint between HTS wire and normal conductor terminal according to the current ramp rates. The quench current in the conduction cooled HTS magnet is related with temperature rise in the normal conductor terminal where the HTS tape is soldered. The temperature at the normal conductor terminal rises as the ramp rate increases because the cooling time of the cryocooler is longer than charging time of the coil. This phenomenon was numerically analyzed using finite element method and compared with the experimental results. The experiment was implemented with a HTS wire contacted on the copper block electrically. The sample was cooled down to the base temperature with the Gifford McMahon (GM) cryocooler and its quench currents were measured at various current ramp rates. This results will be utilized for determining the stable operation of the conduction cooled HTS magnet.

This work was supported by Electric Power Industry Technology Evaluation & Planning, Republic of Korea.

2LPQ02

Relation between transverse and longitudinal normal zone propagation velocities in impregnated MgB2 windings

A.Stenvall, Tampere University of Technology; J.Lehtonen, AER Consulting OY; R.Mikkonen, Tampere University of Technology

The transverse normal zone propagation velocity vt in impregnated magnets controls the 3D normal zone expansion during a quench. It is dominated by the thermal conductivities of the conductor insulation and the impregnation material. The longitudinal propagation velocity vl is mainly determined by the heat generation, critical surface of the superconductor and thermal conduction along the conductor. It has been generally assumed that the ratio vt/vl is proportional to the the square root of the ratios of the corresponding effective heat conductivities. In this paper we study the validity of this approach by comparing 1D Finite Element Method (FEM) model for computing vl to 2D and 3D FEM models for computing vt. Also, the effect of the thickness of impregnation material on vt is scrutinized.

2LPQ03

Transverse thermal conductivity in an epoxy impregnated MgB2 coil

I.Hiltunen, A.Korpela, J.Lehtonen, R.Mikkonen, Tampere University of Technology

Superconducting magnets operate at low temperatures, and therefore, even small heat pulses can ruin their stable operation. For example, resistive joints and changes in the magnetic field profile or in the operation current generate heat which must be extracted to prevent a quench. For impregnated magnets the transverse thermal conductivity inside the coil has a vital influence on the heat extraction, and it dominates the 3D quench propagation. In this study, the transverse heat conductivity is measured from the cross-section of a small epoxy impregnated MgB2 coil at temperatures between 10 and 60 K. Finally, the results are analysed and compared with the results of a computational model based on heat conduction equation solved with the finite element method.

2LPQ04

Cooling performance of conduction cooled superconducting magnet using high thermal conduction plastic

T.Takao, R.Sakuma, T.Takiyama, Sophia University; A.Yamanaka, Toyobo

Aluminum nitride (AlN) has been usually used for a thermal conduction material in a conduction-cooled superconducting magnet, because AlN is high thermal conduction. However AlN is hard and brittle, and hence careful handling is necessary and cutting in a user side is difficult. We have proposed a high-thermal-conduction plastic as an alternative material to AlN. In the study, we fabricated conduction-cooled superconducting magnets having the plastics as bobbin materials, and experimentally estimated thermal stability of those magnets. To compare the test data, we also measured the stability of the magnets having the AlN bobbins. In some test conditions, stability of the magnets with the high-thermal-conduction plastic bobbins was as same as that with the AlN bobbins.

2LPQ05

HTS Tapes Cooled by Liquid Nitrogen at Overloading Conditions

S.S.Fetisov, V.S.Vysotsky, V.E.Sytnikov, Russian Scientific R&D Cable Institute

For HTS electro - technical devices the overload currents due to faults in grids are the operational reality. The fault currents may forcibly go to superconductors being sometimes dozens times more than the critical currents of HTS. It is important to take into account especially for HTS power cables design. Overloads are the working modes for fault current limiters as well. We studied before the overload conditions both theoretically [1] and experimentally [2]. In this work we model the overload conditions in different HTS 1-G and 2-G tapes experimentally by use of the rectangular current pulses with different amplitudes and durations. Voltages and temperatures along test samples have been measured. These experiments permitted us to follow the change of heat developments during overloads due to the difference of cooling regimes in the liquid nitrogen. Measuring of characteristic times of a heat development in different regimes provides the data about possible surviving times of HTS devices and bearable current overloads. We also studied the influence on heat developments of different shunting or reinforcing methods of HTS tapes. The data obtained can be used to analyze overload conditions at HTS power cables and HTS resistive FCL. 1. V.S.Vysotsky, et al, J. Phys.: Conf. Ser. 43 877-880, 2006 (Proceedings EUCAS – 2005) 2. V.S. Vysotsky, et al. The paper 028 presented at EUCAS-2007, Brussels Belgium, to be published at J. Phys.: Conf. Ser..

2LPQ06

Simulations of the quench-behavior of coated conductors with hot-spots.

A.Henning, M.Kurrat, Technical University Braunschweig, Institute of High Voltage Technology and Power Systems

In this paper the results of thermal-electric simulations of coated conductors with hot-spots are presented. Multiple 3D-simulations were made with hot-spots of different sizes. As boundary conditions Liquid Nitrogen (LN2) cooling and an AC-overcritical current density are used. The model used is based on actual commercial available 2nd Generation High-Temperature-Superconducting (HTS) tapes. For the simulations the commercially available 3D finite element program ANSYS®, which was enhanced with a superconducting element, is used. This work will help to clarify the quench behavior of HTS-tapes with hot-spots and is especially interesting for current limiting applications. In addition an ANSYS coupled field simulation setup which incorporates the 3 critical values of an superconductor T,J an B is presented.

2LPQ08

Development of Quench Detection Method on HTS Coil for 5MW-class Superconducting Motor

J.H.Joo, S.B.Kim, H.Sano, S.Murase, Okayama University; Y.K.Kwon, H.M.Kim, Korea Electrotechnology Research Institute

Recently, the superconducting devices using cryogenic and superconducting technologies were widespread in the field of electric powers. The quench protection is one of the important issues for the safety operating of the superconducting devices, because an excessive joule heating brings about damage to the superconducting magnets when a quench occurs. However, if an HTS coil starts to be transited normally by an initial quench, the HTS coil will have been recovered into the superconducting state or runaway thermally. These behaviors were mainly determined by the magnitude of a disturbance, the HTS coil size, the structure of winding wire, and cooling condition. Therefore, in order to detect more accurately transition into the normal state at HTS coil actually, it needs to investigate these effects as parameters. This paper describes the electromagnetic and thermal behavior of an HTS coil during normal transition by the initial quench. The aim is the development of the quench detection method about HTS coil for 5MW HTS motor after an initial quench. It was adopted the hardware and the software that were able to estimate the quench by monitoring the voltage and temperature for the behavior between the thermal runaway and the recovery. This paper will be presented these results and the quench protection properties with fabricated detection method.

2LPQ09

Quench Characteristics of HTS Double-Pancake Coil With AC Current Above Its Critical Current

J.Zhang, S.Dai, D.Zhang, Z.Wang, L.Lin, L.Xiao, Institute of Electrical Engineering, Chinese Academy of Sciences

The quench characteristics of high temperature superconducting (HTS) double pancake coil for AC over-current applications have been investigated at various amplitudes of the over-current and its quench developments have been analyzed by the voltage and current waveforms we measured. For this study, we developed a double pancake with 36-meter Bi2223/Ag tape which was insulated by Kapton tapes (25μm thickness). The whole double pancake was impregnated with epoxy resin. In this paper, the AC over-current experiments for the double pancake were performed to analyze its quench developments. From those analyses with the voltage and current waveforms, the numerical formula for Bi2223/Ag double pancake's resistance has been derived. By using the numerical formula to estimate the quench developments of double pancake dependent on ac over-current, it agrees with the experimental results well.

2LPQ10

Repetitive Over-Current Characteristics of the Joints between the YBCO Coated Conductor

K.S.Chang, S.E.Yang, D.K.Park, Y.J.Kim, T.K.Ko, Yonsei University; N.Y.Kwon, H.G.Lee, Korea University

In recent years, the YBCO coated conductor (CC) has been developed as a suitable material for power apparatuses. To fabricate a superconducting power apparatus of a large capacity, the joint between the superconducting tapes are inevitable because of the need to have a long length conductor. Consequently, the joint characteristic is very important for the efficiency of the superconducting part in the apparatuses. Besides, maintaining the characteristic of the joint between the superconducting tapes even after repetitive over-current is also important for stability of power apparatuses. Therefore the joints between CC tapes were developed in four different ways and the characteristics of the joints were compared. In this paper, we present the experimental results of several over-current tests with the jointed CC tapes. The results of the over-current tests and the trend of the joint characteristics are compared in point of stability of the joints. Resistance and critical current of the joints were measured from the V-I curve before and after several over-current tests for observation of the trend of the joint characteristics. This study of repetitive over-current characteristics of the joints may be useful to the development of superconducting power apparatuses in forms of magnets.

This work was supported by the Korea Science and Engineering Foundation Grant funded by the Ministry of Science and Technology (R0A-2007-000-20063-0).

2LPQ11

Stability Investigation of a LTS/HTS Hybrid Conductor

H.Liu, Y.Wang, X.Cui, Y.Wang, Y.Qu, North China Electric Power University

A new concept of LTS/HTS hybrid conductor was recently proposed. However, little theoretical and experimental research has been done in aspects of its stability. Based on the circuit model of the hybrid conductors, current redistribution between LTS and HTS is numerically investigated in transient process. Furthermore, temperature distribution, quench velocity and minimum quench energy are also simulated by solving thermal-magnetic coupling equivalent equations. Comparing with conventional superconducting conductor, the simulated results show that the stability of the hybrid conductor can be greatly improved and it has potential application in large scale and conduction cooled superconducting magnet.

2LPQ12

2D Current Distribution in a Superconducting Tube Submitted to a Rotating Magnetic Field: Comparison Between a Hybrid FEM-FVM and a Semi-Analytical Method (SAM)

A.Kameni, University of Nancy - GREEN; F.Sirois, École Polytechnique de Montréal; B.Douine, J.Leveque, D.Netter, University of Nancy - GREEN

This paper presents a comparison between two numerical methods to calculate the current density distribution in a high temperature superconducting tube submitted to a transverse rotating magnetic field. The tube used in this model is a bulk BSCCO-2212 (similar to a current lead), and acts as the rotor of a hysteretic motor. In order to solve this problem, we propose a mixed Finite Volume-Finite Element Formulation. This kind of formulation has the advantage to avoid regularisation methods, necessarily implemented because of the nonlinearity of the vector operator, and which are often used with a conventional finite element formulation. In order to validate this new numerical technique, we compared the results with a semi-analytical method (SAM) developed lately at Ecole Polytechnique de Montreal, and which consists in a generalization of the "Brant method" to triangular elements. The hybrid method proved to be very stable, and convergence of the algorithm is obtained even for n-values greater than 100 in the E(J) power law model (E=Ec*(J/Jc)^n). Finally, comparisons of the computation times of the two methods are provided.

2LPR - Superconducting RF – I 2:00pm - 4:00pm

2LPR01

Development of a system for fabrication and characterization of superconducting heterostructures for high=performance SRF

M.Bhatia, R.Blackburn, T.Elliott, P.McIntyre, N.Pogue, Texas A&M University

Gurevich proposed that a heterostructure of superconducting and dielectric layers could make it possible to significantly enhance the rf surface magnetic field that could be supported on a surface, perhaps even beyond the BCS limit. An instrumentation cluster is being built to support the development of such layers and to test the superconducting performance with high surface rf field. The system is designed to operate with 15 cm sample wafers. It consists of a hub complex containing instruments for plasma cleaning and etching, sputter deposition, and oxidation; and surface science instrumentation for characterization and mapping of surface morphology, grain structure, and chemistry. The hub cluster can move a sample wafer through the any sequence of the above operations without exposing it to air. Results from first commissioning of the system will be reported.

This work benefits from a donation of major equipment from Seagate Technologies. The work is funded in part by the US Dept. of Energy, grant DE-FG02-06ER41405.

2LPR02

Polyhedral Superconducting Cavities for Particle Accelerators

R.Blackburn, T.Elliott, A.McInturff, P.McIntyre, N.Pogue, A.Sattarov, Texas A&M University

A polyhedral cavity design is being developed for particle accelerators, with particular potential application to future linac colliders. In essence it is a polyhedral analog of a multi-cell cavity, but the beam's eye view of the boundaries is a polyhedron instead of a figure of revolution. A multi-cell cavity string is formed as a Roman arch assembly of polyhedral wedges; each wedge has its inner surface contoured to form the ellipsoidal shape desired for the accelerating mode. The polyhedral cavity design has been studied numerically and several significant results are reported. Its Q should be comparable to that of a TESLA cavity. The joints between wedge segments offer the possibility to strongly suppress all dipole-type higher-order modes by intercepting and terminating azimuthal currents. The Nb surface is provided as a thin foil bonded to a solid copper wedge machined to the desired contour. The wedge provides stiff support so Lorentz detuning is largely eliminated, and the superfluid refrigeration could be integrated within the wedges so no cylindrical cryostat is required. A first model of the polyhedral structure is being fabricated and tested.

This work is supported by funding from the US Dept. of Energy, grant DE-FG02-06ER41405.

2LPR03

Electron cyclotron plasma processing of 3.9 GHz single cell cavities

G.Wu, et al, Fermilab

Electron cyclotron resonance (ECR) permits the excitation of plasmas inside superconducting RF cavities after the input couplers have been installed. We show that sulfur can be cleaned from niobium coupons in-situ in a closed 3.9GHz niobium cavity in which ECR plasma is excited. Since sulfur is a common precipitate left behind by electropolishing, we propose that this plasma cleaning step can be added to the standard cavity processing regimen as a final touch-up or remediation. We further explored the effectiveness of adding oxygen and hydrogen diluted in argon to the plasma for cleaning and for surface passivation. These results were analyzed with an ion diffusion model to assess the oxidation process and compared to current annodization and baking approaches.

2LPR04

Quench-limited SRF cavities: failure at the heat-affected zone.

M.S.Champion, L.D.Cooley, Fermilab; R.Geng, Jlab; C.M.Ginsburg, Fermilab; H.Hayano, KEK; Y.Iwashita, Kyoto University; D.A.Sergatskov, Y.Tajima, Fermilab

With the recent progress in surface cleaning, the performance of superconducting RF cavities is mostly limited by a quench. It is important to understand the nature of the quench origin. In a common SRF cavity design the RF magnetic field is concentrated near the equatorial weld of the cavity. This weld has long been the major suspect in forming a surface defect, either as an impurity or in an increased surface roughness, that eventually gives rise to a quench. We used surface mounted thermometers to obtain a temperature map of the cavity in the quench region. A high temperature, temporal, and spatial resolution of the thermometry system allows us to pinpoint the quench origin with accuracy of a few millimeters. We found that the hot-spot precursor forms in the weld heat-affected area rather than in the melted zone. The high resolution optical inspection found surface defects in exactly the same locations as the thermometry mapping system. We will describe the measurement techniques and discuss possible scenarios of formation of these defects.

This research was sponsored in part by DOE Office of Science

2LPR05

Effect of Tumbling Media and Angle of Rotation on the Surface Finish Achieved on Single Cell 3rd Harmonic SRF Niobium Cavities

C.A.Cooper, T.Khabiboulline, D.Fischer, Fermilab

Approximately 120 microns of niobium must be removed from the surface of niobium superconducting radio frequency (SRF) cavities made using conventional techniques. The material has to be removed to eliminate defects introduced in the forming of the niobium sheets and cavity itself. This material removal is usually achieved by a combination of chemical techniques, like buffered chemical polishing (BCP) and electropolishing (EP), and sometimes a mechanical technique called tumbling. Tumbling has some unique advantages like it is environmentally friendly and produces smoother surfaces than chemistry alone can make. However even after tumbling is done some chemistry must be done to remove the impurities introduced from the tumbling media. One potential problem from tumbling, that exists in BCP and EP as well, is that there is an uneven material removal rate between the iris and equator of the cavities. Using 3rd harmonic single cell cavity shapes it was found that the difference in etch rate between the iris and equator could be minimized by oscillating the cavity from -20 degrees to 20 degrees from horizontal while the cavity was rotating. Different media was examined and average surface roughness's on the order of 5 nm were obtained. In addition, a single cell 3rd harmonic cavity was tumbled and BCP etched to achieve a quench limited accelerating gradient of 17MV/m.

2LPR06

Cryomodule Assembly at Cryomodule Assembly Facility (CAF) in Fermilab

T.Arkan, H.Carter, Fermilab

The CAF infrastructure was setup in FY 06&07 at Technical Division in Fermilab to assemble cryomodules for the SRF R&D program. The infrastructure consists of a clean room complex (Class 10,100, 1000 areas) for SRF cavity string assembly, a cold mass assembly area (production floor) and a vacuum vessel / final assembly area (production floor). After the cavity string is assembled in the clean room, it is rolled out of the clean room for cold mass assembly, alignment of the string, vacuum vessel assembly (insertion of the cold mass into the cryostat) and final assembly (warm part of the fundamental power coupler assembly, final leak checks, miscellaneous QA tasks). The SRF cavities need to be tested and qualified before they can be assembled into a string. The clean room complex at CAF is also used for preparation of the processed SRF cavities for vertical test and horizontal test. (Assembly of the probes, couplers, antennas, burst disk etc.) In late FY07, we assembled the first 1.3GHz cryomodule (CM1) at CAF. The cryomodule components were supplied as a kit by DESY. With the assistance of the DESY colleagues, CAF team assembled the first cryomodule in 7 weeks. CM1 is now ready to be installed in the test area in Fermilab. Second cryomodule scheduled to be assembled is a 3.9GHz module. We plan to start the assembly of the cryomodule by April 2008 and we will deliver this cryomodule to DESY by June 2008. In FY09, we would like to assemble the second 1.3GHz cryomodule. This cryomodule will have eight SRF cavities that will be processed and tested at US institutions. The cold mass and vacuum vessel for this cryomodule is scheduled to be delivered from INFN.

2LPR07

Cryomodule Design for Future Accelerator Projects

D.Mitchell, Y.Orlov, H.Carter, T.Peterson, C.Grimm, Fermilab

International collaborators have modified the mechanical design of the superconducting, 1.3 GHz, DESY-TTF cryomodule. This 12 meter long, 8 cavity cryomodule was re-designed to test the concept of a better supported magnet package at the center of the cryomodule and also utilizes new cavity spacing and helium vessels with INFN designed bladetuners. Along with discussions on the design of the cryostat, magnet package, BPM, and helium vessel, commentary on the formation of an international design team utilizing a single engineering data management system will be included. Additionally, details on the use of this cryomodule at Fermilab and future design plans will be included.

Scientists, engineers, and designers from FNAL, INFN (Pisa and Milan), and KEK.

2LPS - Fusion - ITER I 2:00pm - 4:00pm

2LPS01

Test results of Japanese SULTAN sample and conductor procurement in Japan for ITER TF Coils

K.Matsui, T.Isono, Y.Nunoya, T.Hemmi, Y.Nabara, Y.Okui, M.Oshikiri, N.Koizumi, Y.Takahashi, K.Okuno, JAEA; B.Stepanov, P.Bruzzone, CRPP

Conductor procurement for ITER Toroidal Field (TF) coils in Japan has just stated in the spring of 2008 under agreement with ITER organization. Before the activity, each Nb3Sn conductor must be tested at SULTAN facility in Switzerland for qualification of the conductor. The TF conductor is cable-in-conduit type with about 40 mm outer diameter and is composed of 900 Nb3Sn strands, 522 Cu strands, a central spiral and a 316LN tube. Required performance of the conductor is Tcs of 5.7K at 68 kA and 11.3T, which is operating condition of TF coils. Japan has four Nb3Snstrand suppliers for ITER and two of them were already tested as Japanese 1st and 2nd SULTAN samples. This paper shows test results of 3rd Japanese SULTAN sample using Nb3Sn strands fabricated by resting two suppliers. Both strands are fabricated bronze process.

2LPS03

Fabrication of US ITER TF Conductor Short Sample

C.Y.Gung, MIT Plasma Scinece and Fusion Center; N.N.Martovetsky, J.R.Miller, US ITER Project Office; J.H.Kim, J.H.Schultz, MIT Plasma Scinece and Fusion Center

A pair of 3.5 m long ITER TF size straight conductors have been fabricated into a hairpin short sample and submitted to the SULTAN facility at CRPP for cold test. The short sample used a triplet-based cabling pattern in one leg and septuplet-based in the other. To maintain the same void fraction in the cable space, the diameter of the Nb3Sn strands and the number of strands used in two conductor legs were different. To assure the accuracy of measurement of the conductor current sharing temperature, it is important to have uniform current distribution in the cable, which is directly affected by the uniformity of the interstrand resistivity in the termination cable. In the present sample, the cable / subcable wraps and the chrome plating on all strands were removed from the termination cable, followed by compacting the termination in a Glidcop sleeve. In the reaction heat treatment, sinter bonds in the termination were formed to improve current transfer. The sintered termination was further filled with soft solder before it was soldered to the copper profile. In response to the recent ITER activity to clarify the accuracy and effectiveness of instrumentation, the present sample was equipped with sensor mounts penetrating the conductor jacket for the majority of the thermometers and voltage taps. This paper presents the experiences in short sample fabrication and instrumentation and outlines the parameters used in the key processes.

Funding provided by US ITER Project Office.

2LPS04

Test Results of the First US ITER TF Conductors in SULTAN

N.N.Martovetsky, US IPO/LLNL; D.R.Hatfield, J.R.Miller, US IPO/ORNL; C.Y.Gung, J.S.Schultz, MIT PSFC; N.Cheggour, L.F.Goodrich, P.Bruzzone, NIST; B.Stepanov, CRPP

The US Domestic Agency is one of six parties supplying TF cable-in-conduit conductors (CICCs) for ITER. Each supplier is required to pass a qualification test of conductor samples in the SULTAN facility at CRPP, Switzerland. A test article for SULTAN comprises two conductor samples attached to the terminals of the facility current source at the top and connected through a low-resistance joint at the bottom. Previous tests have shown that measured performance of CICCs may be noticeably lower than expected from a simple consideration of strand performance at a projected uniaxial strain and that the cabling pattern may also be an important factor. To explore the effect of different cabling patterns, the conductor samples in the different legs of our test article have different cables made with slightly different strands but with the same nominal current carrying capacity. Test results of the first US-made samples are presented and discussed.

2LPS05

Coupled Thermal-Hydraulic/Electromagnetic Analysis and Interpretation of the Test Results of the ITER TFPRO2 Conductors

R.Zanino, politecnico di torino; F.Bellina, universita` di udine; M.Breschi, P.L.Ribani, universita` di bologna; L.Savoldi Richard, politecnico di torino

The performance of several different Nb3Sn cable-in-conduit conductors for the ITER TF coils is being tested in the SULTAN facility at Villigen PSI (CH). So far, one of the test issues is how the current distribution in the cable may affect the results in a way peculiar of the SULTAN configuration rather than of the coil. As the quench is approached, this is increasingly related also to the temperature distribution inside the cable. The validated THELMA code is best suited to study this coupled problem: in particular, the code can compute voltage and temperature both on the jacket, where they are measured, and inside the cable, where they are more directly representative of the conductor performance. While a parametric analysis of the ITER TF reference conductor sample is presented in a companion paper, we concentrate here on a specific sample – TFPRO2 – tested in 2007, which was very well diagnosed, in terms of both temperature and voltage traces. Our aim is to assess the role of thermal-hydraulics on the interpretation of the conductor performance up to the quench, via the self-consistent computation of temperature profiles along and across the conductor together with the voltage evolution, and the comparison with experimental results. In particular, the issues of temperature gradients, due to possibly non-uniform Joule heating in the joint and in the high field region, as well as of thermal coupling between helium, strands and jacket are addressed.

2LPS06

Helium flow-reversal in 3 m long, partially heated sections of dual-channel CICC for ITER

R.Herzog, M.Calvi, C.Marinucci, P.Bruzzone, CRPP/EPFL

In top-to-bottom cooled sections of ITER TF coils the helium flow in the outer annulus of dual-channel cable-in-conduit conductors (CICCs) may slow down, stagnate or even reverse to an upward flow if the conductor experiences increasing amounts of heat deposition. Buoyancy variations of helium at different temperatures and thus density in annulus and central channel lead to this effect. Two-channel one-dimensional models developed during the last years are able to describe the phenomenon well, but in simulations only values of flow parameters (friction factors, heat transfer coefficients etc.) outside the range of usually observed ones are able to reproduce the experimental observations. A spare CIC conductor, made according to the most recent ITER TF conductor design, allowed to conduct dedicated thermo-hydraulic experiments in the SULTAN test facility. The sample was heated by eddy-current losses induced in the strands by an applied AC magnetic field as well as by strip heaters mounted on the outside of the conductor jacket. Temperature sensors mounted on the jacket surface, in the central channel as well as at different radii in the annular region revealed a detailed picture of the temperature distribution during at different mass flow rates and heat deposition modes. A two-dimensional simulation (radial and axial) of the helium flow under the influence of heat sources led to a good understanding of the helium flow distribution as well.

2LPS07

Conceptual Design of ITER CS Alternate Lap Joint

C.Y.Gung, P.Titus, V.Fishman, J.V.Minervini, J.H.Schultz, MIT Plasma Scinece and Fusion Center; N.N.Martovetsky, J.R.Miller, US ITER Project Office

The ITER CS magnet will be assembled with 6 identical modules, each with two current leads connecting to the power supply busses. Each CS module consists of 7 submodules, including 6 hexa-pancake and 1 quadra-pancake windings, which are electrically connected in series. The reliability of all 36 submodule joints is of critical importance since every joint will be assembled, insulated, and vacuum-pressure-impregnated in epoxy, but the quality of these embedded joints can not be verified until a module is cold tested after impregnation. Currently, the butt joint is the baseline design for inter-submodule connection. In parallel to the butt joint development, the feasibility of fitting a lap joint into the present butt joint design window has been investigated. The conceptual design of an alternate lap joint, adequate for pulsed operation of the CS magnet is proposed. Preliminary evaluations of temperature rise in the proposed lap joint due to Joule heating and pulsed losses, and stress analyses of the joint box and weld joints will be presented.

Funding provided by US ITER Project Office.

2LPT - Fusion - ITER II 2:00pm - 4:00pm

2LPT02

Installation and Test Programme of the ITER Poloidal Field Conductor Insert (PFCI) in the CSMC Facility at JAEA Naka

Y.Nunoya, Y.Takahashi, T.Isono, N.Koizumi, K.Matsui, M.Oshikiri, Y.Nabara, T.Hemmi, H.Nakajima, K.Hamada, K.Okuno, JAEA; W.Baker, E.Salpietro, EFDA; H.Rajainmaki, F4E; N.Mitchel, ITER

The ITER Poloidal Field Conductor Insert (PFCI) was constructed to characterize the performance of selected cable-in-conduit NbTi conductors for the ITER Poloidal Field (PF) under relevant operating conditions. The PFCI was installed and tested inside the bore of the ITER CS model coil, which provides the background magnetic field. The PFCI is a single-layer solenoid, wound from about 50 m of a full-size ITER cable-in-conduit conductor with central cooling channel, including an intermediate joint located at relatively high magnetic field to reproduce operation under relevant conditions, i.e. around 4 T. The winding diameter and height are about 1.5 m and 1 m, respectively. The nominal design current of the conductor is 45 kA at 6 T and 5 K. Many voltage taps and temperature sensors are attached on the conductor to observe the superconducting performance. The main items in the PFCI test programme are the DC characterization of the conductor, for which current sharing temperature (Tcs) measurements will be performed, with a few critical current (Ic) measurements to confirm the results. AC loss measurement in the conductor and the joint will also be carried out, because the PF coils are operated in pulse mode. The hydraulic behaviour, such as stability and quench propagation, and the effects of cycling electromagnetic load on the performance will be evaluated. The key technology of the installation, the test methods and procedures, and some preliminary results of the testing campaigns are described and discussed in this paper.

LPT03

Stability Analysis of the ITER PF conductors and coils

L.Savoldi Richard, Politecnico di Torino, Italy; D.Bessette, ITER Organization, Cadarache, France; R.Zanino, Politecnico di Torino, Italy

The stability analysis of the reference NbTi conductors for a subset of the International Thermonuclear Experimental Reactor (ITER) Poloidal Field (PF) coils is presented. From the point of view of the temperature margin, the most critical conductor in the winding pack, as well as the most critical location along it, is identified by a Vincenta code analysis, which also provides the initial and boundary conditions for the stability study, as well as the heat load distribution on the conductor due to AC losses, nuclear heating and thermal conduction/radiation. With this input, we perform a 1D stability analysis restricted to the most critical conductor using the Mithrandir code; a much finer grid can be afforded than by Vincenta, allowing capturing the details of normal zone initiation and possible recovery to the superconducting state. Different combinations of lengths (1 cm to 1 m) and durations (1 ms to 100 ms) are considered for the stability disturbance, applied to the superconducting cable both during the most critical operating condition (4th plasma pulse for PF5, for instance), and in the normal and backup reference operating modes. In view of the relative smallness of the time and space scales involved, the grid-independence of the results is carefully verified first. Since the results are strongly influenced by the choice of the heat transfer coefficient between strands and helium, this effect is also parametrically investigated. The computed minimum quench energies are finally compared to the level of expected disturbances in the real coil operation.

2LPT04

R&D and tests of the HV components of ITER PF-1 coil.

S.A.Egorov, V.E.Korsunsky, S.V.Krasnov, V.P.Kuchtin, E.V.Lamzin, I.Y.Rodin, V.G.Yakubovsky, The D.V.Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA)

The ITER poloidal field (PF) coils shall withstand high voltages induced by operation in pulsed mode (up to 11 kV) and safety discharges. That is why the HV performance is one of the most important question of their reliability/availability. Besides other things the insulation system of the PF coils includes helium insulation breaks and ground insulation of the electrical joints. The design of these HV components could be critical for the coil as whole. For example multiple failures in helium insulation breaks could lead to coil damage. The PF-1 coil is the only ITER magnet that is supposed to be manufactured in Russia. To provide the reliable HV performance of PF-1 coil the special R&D was started in 2007 aimed on the design improvement of helium insulation breaks and full-scale modelling of the ground insulation of the electrical joints. The paper describes the main results of this R&D including the results of HV cryogenic tests.

2LPT05

VENECE 1.0 – An Universal Code for Complex Thermo-hydraulic Analysis of Superconducting Devices and Cryogenic Systems

I.Gornikel, ALPHYSICA Inc., CA, USA; M.Kaparkova, Efremov Research Instute, Russia; V.Kalinin, ITER Organisation, Cadarache, France; N.Shatil, S.Sytchevsky, V.Vasilyev, Efremov Research Instute, Russia

VENECE is a numerical tool intended for complex thermo-hydraulic analysis of superconducting devices and their cryogenic system. Being the next generation of Vincenta code, the Venice code, adsorbing all the best of Vincenta, is oriented to analysis of a range of fluids as a coolant. Helium, nitrogen, hydrogen, water etc. may be simulated together or separately for cooling of superconducting devices within one numerical model. Venice is capable of transient thermo-hydraulic analysis of rotating machines working under high centrifugal forces. Some numerical results are presented and discussed.

2LPT06

PROTOTYPE HTS CURRENT LEADS FOR ITER

P.Bauer, ITER; Y.Bi, A.Cheng, ASIPP; A.Devred, ITER; K.Ding, K.Lu, ASIPP; N.Mitchell, A.K.Sahu, ITER; Y.Song, T.Zhou, ASIPP

The ITER Organization (IO) and the Institue of Plasma Physics at the Chinese Academy of Sciences (ASIPP) are jointly developing the design of the 68 kA current leads using High Temperature Superconductors (HTS) for the Toroidal Field (TF) coil system of the International Thermonuclear Experimental Reactor, ITER. The proposed design consists of a conventional helium cooled heat exchanger operating between 65 K and 320 K and a HTS module covering the low temperature end using Bi-2223 tapes. The HTS current lead prototype will be tested in the EAST facility at ASIPP. The results of this HTS current lead development program will be reported, with particular emphasis of the issues relevant to the current lead series production for the ITER device, which should commence soon.

2LPT07

SAFETY ANALYSIS OF THE 70 KA ITER HTS CURRENT LEAD DEMONSTRATOR

R.Heller, Forschungszentrum Karlsruhe

For the superconducting magnet system of the International Thermonuclear Experimental Reactor, ITER, 60 current leads for a total current of more than 2500 kA are needed. The use of High Temperature Superconductor current leads (HTS-CL) will reduce the resultant large refrigerator load considerably. Within the EU Fusion Technology Programme, the Forschungszentrum Karlsruhe and CRPP have developed and built a 70 kA HTS-CL demonstrator optimised for 50 K Helium operation. In 2004-2005, the CL was successfully tested with 50 K as well as 80 K Helium, and finally with LN2. In the meantime, ITER has decided to use HTS-CLs for the magnet system and China has taken the responsibility to provide the sc feeders for ITER including the current leads. In this paper, the performance of a 70 kA HTS-CL in fault conditions will be analysed using the FZK-CRPP demonstrator as a model. In particular, the quench performance and the safety behaviour in case of a loss-of-flow accident (LOFA) will be described and an extrapolation of the leads performance in real ITER conditions will be given. Finally the effect of different shunt materials is discussed.

2LPU - Superconducting Magnetic Energy Storage – I
2:00pm - 4:00pm

2LPU01

Design and Performance Results of First Polish SMES

J.Kozak, Electrotechnical Institute - Laboratory of Superconducting Technology; T.Janowski, Lublin University of Technology; S.Kozak, Electrotechnical Institute - Laboratory of Superconducting Technology

The Superconducting magnetic energy storage system (SMES) cooled by SRDK-408 cryocooler has been described in this paper. The superconducting magnet consists of 7 double-pancake coils made of Bi-2223 HTS tape with the inner and outer diameters 210 mm, 315 mm and height of 191 mm. The inductance of the magnet is about 1H, stored energy 10 kJ at 50 K. Power electronic converter 30 kVA ensures bidirectional energy flow between magnet and the main side and controls different quantities in different operation condition. In the paper we report the design of the magnet and the measurements results.

2LPU02

Design of HTS magnets for a 2.5 MJ SMES

M.J.Park, KESRI / Energy conversion system; S.Y.Lee, S.Y.Kwak, Seoul National Univ. / EECS; W.S.Kim, Seoul National Univ. / Materials Science and Eng.; J.K.Lee, Woosuk Univ. / Electrical Eng.; C.Park, Seoul National Univ. / Materials Science and Eng.; J.H.Bae, K.Choi, K.C.Seong, KERI / Superconducting Devices and Cryogenics Research ; H.K.Jung, Seoul National Univ. / EECS; S.Y.Hahn, KESRI / Energy conversion system

A 600 kJ HTS superconducting magnetic energy storage (SMES) system has been developed for power system stabilization and power quality compensation as a national project in Korea. The operating test of the 600 kJ SMES system was completed successfully in recent. To meet economic feasibility and practicality in power grid, developments of high energy capacity SMES systems are required. The target energy capacity as the 2nd phase to develop high energy capacity HTS SMES system was adopted 2.5 MJ. In this paper, conceptual design of 2.5 MJ class SMES magnets of solenoid, multi-pole and toroidal type, were presented and compared. Main focuses of magnet design are not only minimization of total length of HTS wire, but also reduction of magnetic field strength in HTS coils.

This work was supported by Electric Power Industry Technology Evaluation and Planning

2LPU03

Development of Large-scale Superconducting Magnet with Very Small Stray Magnetic Field for 2MJ SMES

Q.Wang, Y.Dai, Z.Zhao, S.S.Song, IEE, CAS; S.Chen, Z.Cao, L.Yan, IEE,CAS

A large-scale superconducting magnet with four parallel solenoids was designed, fabricated and tested. The superconducting magnet is cooled down with liquid helium. The superconducting magnet is with the maximum field of 5.4 T, and operating current of 500 A, maximum storage of 2 MJ. The cryogenic system takes two GM cryocooler to cool the whole system. The high temperature superconducting current lead of Bi2223 is used and cooled through one GM cryocooler to realize absolute zero vapor liquid helium. In the paper, we report the system in detail for the superconducting magnetic energy storage system.

**The work was supported by high technology project*

2LPU04

Test of the HTS magnet for 10 kJ SMES

S.Kozak, Electrotechnical Institute - Laboratory of Superconducting Technology; T.Janowski, Lublin University of Technology; J.Kozak, Electrotechnical Institute - Laboratory of Superconducting Technology

The paper describes a HTS magnet for the Superconducting Magnetic Energy Storage system (SMES). The magnet consists of 7 double-pancake coils made of 1621 m of the HTS high strength wire (American Superconductor). The weight of the magnet is 45.77 kg. The stored energy of the magnet is 0.8 kJ at 77.4 K and 10 kJ at 50 K and under the critical current of the magnet. The bobbins of the double-pancakes and the thermal bridges were made of Al alloy. The magnet is constructed so as to be cooled by SRDK-408 cryocooler in high vacuum cryostat. The paper shows the main parameters of the magnet and the test results of V-I characteristics and critical current. The critical current of the each double-pancake and the magnet have been determined from the V-I characteristics by using an electrical field criterion 10^-6 V/cm.

2LPU05

Study on the fabrication and evaluation of a conduction cooled HTS magnet for SMES

J.H.Bae, S.H.Kim, D.S.Sim, H.J.Kim, K.C.Seong, E.Y.Lee, M.H.Shon, KERI

This paper describes design, fabrication, and test of the conduction cooled high temperature superconducting (HTS) magnet for SMES. The optimal design of the magnet was conducted using the objective function of minimizing the total required amount of the HTS conductor. The electromagnetic and mechanical behaviors on the magnet are analyzed and The prototype magnet composed of 22 double pancake coils (DPC) made of AMSC 4-ply conductor was fabricated on the basis of design and analysis results. The 4-ply conductor is composed of 2 AMSC Bi-2223 tapes and 2 brass tapes, which are soldered at each side of Bi-2223 tapes for the mechanical reinforcement. Each DPC consists of 2 modular single pole solenoid coils with an inner diameter of 500mm, an outer diameter of 691mm, and a height of 10mm. It is wound on the aluminum alloy bobbin to drain the heat generation at the coil. The aluminum bobbins were anodized for the additional electrical insulation. The magnet was cooled down to 5.6K with two stage Gifford McMahon (GM) cryocoolers. The temperatures of the HTS magnet were measured in the charging and discharging process. The successful operation of the magnet illustrates that the technology of cooling HTS magnet with GM type cryocoolers is fully established. These results will be utilized in the optimal design for conduction cooled HTS magnet for SMES.

This work was supported by Electric Power Industry Technology Evaluation & Planning, Republic of Korea.

2LPU06

Development of a Large Bore Superconducting Magnet with Narrow Liquid Helium Channels

Y.M.Dai, Institute of Electrical Engineering, Chinese Academy of Sciences

A large bore NbTi superconducting magnet is designed, manufactured and tested. The superconducting magnet has an inner diameter of 460 mm, outer diameter of 600mm and height of 540 mm. Round superconducting wires with the diameter of 1.3 mm are used to wind the magnet coil windings. In order to improve the cooling effect, narrow liquid helium channels are set between the adjacent layers. The magnet can generate 4 T central magnetic field at the designed operating current of 325 A. The magnet has been tested in a compact cryostat. Experiment results show that the superconducting magnet reached the designed magnetic performance. Details of the magnet design, fabrication and test are described in this paper.

2LPU07

A New YBCO SMES Device

W.Yuan, Engineering Department, University of Cambridge; M.Zhang, Beijing Institute of Architecture Design; T.A.Coombs, Engineering Department, University of Cambridge

As an energy storage device, a Superconducting Magnetic Energy Storage (SMES) system utilises a relatively simple concept, energy is stored in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. It has low cycle losses and a fast response. Historically, SMES devices have used low temperature superconducting (LTS) conductor and have been built with storage capacities up to several thousand MJ. We are building a high temperature SMES (HTS SMES) device and this paper explains the advantages of using HTS conductors to wind a SMES coil. Compared to LTS SMES, HTS SMES has the obvious advantage that they can operate at a much higher temperature reducing the cooling cost overhead. The paper also summarises the current status of HTS SMES projects. Worldwide there have been many projects which are building lab-scale HTS SMES based on the first generation of HTS conductor – BSCCO wire, these SMES usually have a capacity from several kJ to several hundred kJ. We are looking at second generation conductors as the critical current density versus magnetic field characteristics are much more favourable than BSCCO. This paper presents a simulation result based on an model of YBCO SMES. A prototype device designed by University of Cambridge to supply power for the ground taxiing of aircraft is under construction. A case study of this YBCO SMES is also given in this paper.

2LPV - HTS Motors and Generators - III 2:00pm - 4:00pm

2LPV01

Invited

Superconducting Ducted Fan and Electrical System Design for Zero-Emissions Aeropropulsion

P.J.Masson, CAPS/Florida A&M University; T.Nam, T.P.Choi, ASDL/Georgia Tech; C.A.Luongo, NHMFL/Florida State University

HTS technology is anticipated to benefit aviation as a key enabler of a new class of vehicle systems: the zero-emissions electrical aircraft. Electrically driven ducted fans, for instance, are envisaged to replace the conventional turbofan engines while power is generated on board by less environmentally objectionable sources such as fuel cells. In support of this long-term vision, a concerted effort has been initiated within the aerospace community to research improved algorithmic and methodological capabilities that are also applicable to the design of future more/all-electric aircraft. Consequently, advanced aerospace systems design techniques, which leverage upon what was previously considered to be out-of-domain knowledge, are now available for this generation of conceptual design engineers.This paper presents a design tool for a new kind of ducted fan concept that is driven by a fully superconducting motor as the prime mover. An electro-thermal sizing model for HTS motors was coupled to a ducted fan model to create an automated environment for rapidly generating new aeropropulsion alternatives. Proof-of-concept examples are presented along with parametric cycle analysis and sizing results to showcase optimal thrust and fuel consumption ranges for such a revolutionary aeropropulsion technology.

2LPV02

Study on inductor-type synchronous motors using superconducting coils and bulks

H.Ohsaki, M.Sekino, T.Suzuki, The University of Tokyo

Superconducting motors and generators are highly expected applications of superconducting technologies. Recent progress of high-performance coated conductor and bulk superconductor with strong flux pinning has enabled to design electric machines with higher power density than conventional machines. We have studied an inductor-type superconducting synchronous motor, which has arc-shaped bulk superconductors as an inductor in the rotor, HTS coils for DC field generation, and armature windings. The DC field generation coils and the armature windings are placed on the stator side. The bulk superconductors in the rotor are used as diamagnetic or magnetic shielding components, or can be used as a flux source if the initial magnetization of the bulk superconductors was made. Three-dimensional finite element analysis of electromagnetic characteristics of the motor has been carried out to evaluate its fundamental performance. A small rotor model was fabricated for experimental study of the function and performance of the superconducting inductor. We discuss the performance of the motor and the comparison between the analysis and experimental results.

2LPV03

Cryogenic considerations about the design of a superconducting servomotor.

R.Torres, UPC; X.Granados, ICMAB-CSIC; J.Lopez, UPC; J.Grau, CEIB (UPC); J.Lloberas, ICMAB-CSIC; R.Maynou, E.Trillas, R.Bosch, UPC

The viability of a low power superconducting servomotor for control applicationsis strongly related to the cooling system. In this work we discuss about cooling options and cryogenic parameters of a superconducting servomotor with a four poles radial field configuration. On the basis of an integradtion of part of the cryogeneration in the mootor We have made some simulations in order to know velocity, mechanical flux, and minimun dimensions needed of cool circuitery of cooling gas that allows extracting the heat generated from superconducting pellets and the heat received from external radiation. Details of simulations obtained will be reported.

2LPV04

Toothless SC Servomotors, Improvements and Viability

X.Granados, ICMAB-CSIC; J.López, CEIB-UPC; J.Lloberas, ICMAB-CSIC; R.Maynou, R.Torres, J.Grau, CEIB-UPC; R.Bosch, X.Obradors, UPC

Conventional toothless servomotors have been developed in order to avoid nonlinear effects due to the variation of reluctance produced by the tooth-slot configuration of the iron yoke. Although the torque performance is, however, strongly diminished, the accuracy and control efficiency are increased. Superconductivity allows both, accuracy of the toothless structure and high torque density because the drastic increasing of the magnetic field density. In this work we report about two SC servomotors by comparing the radial and axial magnetic flux topologies. Essential trends of the design including cryogenic viability in industrial environment are discussed.

2LPV05

Magnetic flux concentration HTS motor

R.Moulin, J.Leveque, D.Netter, University of Nancy - Green; J.C.Mercier, Converteam Motor Nancy; A.Rezzoug, University of Nancy - Green

High power density can be achieved using HTS technology in electromechanical devices. In particular second generation HTS wire to use in motors and generators are very promising in term of high current density. Some synchronous HTS motors have been prototyped for marine applications (ship propulsion) and onboard systems. Weight and volume have been effectively reduced but only conventional motor designs were considered. Some patent exist for these standard HTS motor. Unfortunately, there is no breakdown for this motor nowadays. We propose an original topology of HTS motor. We use magnetic flux screens made of bulk YBCO material. 3D Finite Element method is used to design this motors and to obtain an induction from 3T to 5 T in the air gap. Several structures are studied and compared. This machine is previous for high torque application.

2LPV06

Proposal of a Fully Superconducting Motor for Liquid Hydrogen Pump with MgB2 Wire

K.Kajikawa, Kyushu University; T.Nakamura, Kyoto University

Possibilities of the future society with hydrogen utilization have been discussed as one of the advanced technologies for improvement of energy and environmental problems in recent decades. In order to obtain effective energies by oxidizing the hydrogen with a fuel cell etc., it is necessary to produce, transport, store and transfer the hydrogen safely and stably. In such situations, it can also be essential to use the hydrogen as a liquefied gas as well as a compressed gas. For the purpose of a convenient use of the liquid hydrogen, therefore, an electric pump to circulate or transfer the liquid will be needed in a pipeline, tanker or filling station for hydrogen in the near future. In this study, the outline design of a fully superconducting motor for the liquid hydrogen pump with an MgB2 superconducting wire is carried out to present various advantages arising from its prospective performances. The squirrel-cage rotor winding composed of superconducting loops with the MgB2 wire enables us to operate the motor not only in a slip mode but also in a synchronous rotation mode, and consequently the rotor winding loss can be suppressed under an allowable level. Furthermore, it would be expected that the stator winding loss becomes smaller by using the MgB2 wire compared with familiar normal metals as typified by a copper. The time evolution of magnetic field distribution around the stator winding is obtained by means of a finite element analysis in order to estimate the AC loss and the primary circuit resistance.

2LPV07

The Design of Lightweight HTS Synchronous Generator Cooled by Subcooled Liquid Nitrogen.

M.K.Al-Mosawi, W.Bailey, K.Goddard, C.Beduz, Y.Yang, University of Southampton

The paper presents the final design of the coreless 100 kW HTS synchronous generator, to be built at the University of Southampton. The new generator will use the same conventional 2-pole, 3 phase stator. The new HTS rotor has no central core and the rotor winding now consists of 32 identical racetrack pancake coils. Each coil is wound separately using about 40 turns of BiPb2223 superconducting tape, with nominal current of 180A at 77K provided by Sumitomo Electric Industries Ltd. In this design, flux diverters are only used at the ends of the winding stack, to help in the magnetic field shaping around the winding. Removing the remainder of the diverters between coils greatly reduces the weight of the rotor. The winding assembly is fully encapsulated by a stainless steel liquid cryogen vessel which closely follows the shape of the coils. The rotor pole pieces needed to improve the waveform characteristics of the machine are located in the vacuum space on the bore of the warm vacuum vessel. This arrangement simplifies the choice of the material used for magnetic pole pieces, which can now be just mild steel. The lightweight HTS assembly is supported by a four-legged fibreglass torque tube. In this design the field current will be 150A which gives an air gap flux density of about 0.6T. The machine will be cooled using subcooled liquid nitrogen at 65K.

This work is sponsored by EPSRC United Kingdom

2LPV08

Design study of 10 kW direct driven superconducting generator for wind turbine applications

A.B.Abrahamsen, Materials Research Department, Risoe - DTU, Roskilde, Denmark; M.P.Soerensen, Department of Mathematics, DTU, Lyngby, Denmark; N.F.Pedersen, Department of Electrical Engineering, DTU, Lyngby, Denmark

The challenges of future energy demand and the possible global warming due to fossil fuel consumption have increased the interest of large-scale use of wind turbines for electricity production. Most present turbines are operated on-shore, but the interference with the residents and higher wind speeds at sea is the motivation for building off-shore wind farms. A major fraction of the cost of off-shore farms is due to the foundations of the turbines, the grid connection and maintenance. Thus there is an incentive to place large turbines at sea and power ratings of 10 MW are desirable in 10 years. A superconducting generator might be advantageous for 10 MW turbines, because the weight and volume can be reduced compared to a conventional generator and thereby simplifying the turbine design. The gearbox of present turbines can also be omitted by utilizing a multi-pole generator which is driven directly by the turbine rotor. We have done finite element simulation of the performance of two 10 kW direct driven multi-pole superconducting generators, which can be installed in a small wind turbine and used to evaluate the robustness of the superconducting technology in a wind turbine environment. A semi classical generator based on a superconducting rotor and copper armature windings will be compared to a fully superconducting generator.

The work is funded by the superwind.dk project of the Technical University of Denmark

2LPV09

Design of damper to protect the field coil of HTS synchronous motor

H.M.Kim, KERI; S.H.Lee, J.P.Hong, Hangyang Univ.; E.Y.Lee, KERI; J.B.Song, H.G.Lee, Korea Univ.; Y.G.Kwon, Y.C.Kim, KERI

This paper deals with the design method of room temperature damper to protect field coil of High Temperature Superconducting (HTS) Synchronous motor. HTS Synchronous motor mainly consists of rotational and stationery part which are of HTS coil and copper coil, respectively. Alternating magnetic field generated from the stator coil does not cause an effect to HTS coil at synchronous speed operation of machine, but the alternating magnetic field highly cause an effect to field coil at the initial operating condition or transient state operation. In this paper, It tried to analysis the design parameter of damper for 5 MW HTS synchronous motor by using the computational result of the transient characteristic of stator current which is proportional to the alternating magnetic field of stator. It used the comparison of design parameters with respect to variation of the material property of damper and it calculated the optimal design factor of damper which is demanded in motor development.

This work was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPV10

Pulse field magnetization technique for a multidisc bulk arrangement

J.Lloberas, ICMAB-CSIC; J.Lopez, R.Maynou, EUETIB-CEIB; X.Granados, X.Obradors, ICMAB-CSIC

Flux trapped SC motors normally use HTSC pellets which should be previously magnetized, mostly using a pulsed external magnetic field. In order to determine the external field required several experiments have been reported. The experimental situation, however, does not match the actual situation in the device. A clear example is the case of motors where the pellets are aligned sandwiched with the coils. In this work we will report about the differences between the magnetization process of a single pellet with a large shape factor and a stack of HTSC pellets with distributed magnetizing coils

2LPW - Power Transmission Cables – III 2:00pm - 4:00pm

2LPW01

A study on the Current Distribution of Conducting Layer and Shield Layer of HTS Power Cable at Utility Fault Condition

J.H.Kim, M.Park, A.R.Kim, J.G.Kim, I.K.Yu, Changwon National University; K.D.Sim, S.H.Kim, J.Cho, KERI

HTS power cable consists of a conducting layer and shield layer for carrying the required current. Conducting layer and shield layer have the self-inductance each. And, the mutual inductance exists between conducting and shield layer. Therefore, the direction of the current of shield layer is reverse against the direction of conducting layer current over 95% of conducting layer current at the steady states. However, if the fault current occurs and passes into HTS power cable, the quench is generated in both conducting and shield layer of HTS power cable. After quench, the resistance is appeared and the even self inductance value is not changed largely, but the mutual inductance value is directly effected. According to the above, the current distribution of conducting and shield layer is changed by fault current. In this paper, in order to confirm the phenomenon above, a solenoid type HTS power cable model core which considers of both conducting and shield layer was actually manufactured. The manufactured system was also coupled with RTDS in which a utility gird was depicted and simulated. The current distribution of conducting and shield layer is verified by real manufactured solenoid type HTS power cable model core.

HTS power cable, Current distribution, RTDS

2LPW02

Invited

Over-current characteristics of 20-m long YBCO model cable

X.Wang, H.Ueda, A.Ishiyama, Waseda University; T.Watanabe, N. Kashima, S.Nagaya, Chubu Electric Power Company; M.Yagi, S. Mukoyama, Furukawa Electric; T.Masuda, M.Ohya, Sumitomo Electric; Y. Shiohara, ISTEC

To realize large current capacity and mechanical flexibility, YBCO superconducting power cables consist of a number of YBCO coated conductors which are assembled and wound in spiral on a Cu-former. In practical uses, superconducting cables might be subjected to short-circuit fault currents 10 to 30 times the operating current. Therefore, in order to secure stability and feasibility of superconducting cables and protect from the fault currents, it is important to demonstrate the redistribution of the transport current and the electromagnetic coupling among the HTS conductor layer, the HTS shield layer and the Cu-former. In this study, we carried out experiments on a 20-m long YBCO model cable, which was jointed two 10-m long YBCO model cable. Over-current with a peak of 31.5kArms and a duration of 2.0s, which was established by JEC (Japanese Electrotechnical Committee), was applied to the model cable. We performed numerical simulations by using a newly developed computer program based on the 3D finite element method (FEM) in order to clarify the electromagnetic and thermal behaviors of the YBCO model cable during an over-current. *This work was supported by NEDO as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.*

2LPW03

Study on Over-Current Characteristics of HTS Tape by Stabilizing material

H.I.Du, Chonbuk National University; S.W.Yim, Korea Electric Power Research Institute; C.R.Park, M.JKim, B.S.Han, Chonbuk National University

High-temperature superconducting tapes have been applied to diverse power devices through previous researches. Nevertheless, there has been no clear theoretical investigation of a mix of superconducting and normal conditions; in particular, there have been poor researches on changes in properties by kinds of superconducting tapes in case of mechanical transformation for application to devices. In this study, therefore, we discovered voltage-current and resistance properties by kinds of superconducting tapes and stabilizing materials through a test and compared and examined effects of mechanical transformation of each tape. To do this, Bi-2223 tapes and two kinds of YBCO tapes with different stabilizing materials were selected and divided in the unit of 100cm to compare the resistance curve between the straight state and the wound state with mechanical transformations. In addition, current application properties of tapes were examined according to series and parallel connection with tapes wound round the manufactured former.

2LPW04

Study on the Quench Protection Method of HTS Cable Using Various Type SFCL

H.I.Du, Chonbuk National University; S.W.Yim, S.C.Han, Korea Electric Power Research Institute; C.R.Park, B.H.Choi, M.J.Kim, B.S.Han, Chonbuk National University

As efforts for the application of high temperature superconducting (HTS) cables to practical field has been made, the studies on the protection of the cable are also to be a issue for the safe and effective operation. Among the proposed protective devices, superconducting fault current limiters (SFCLs) are expected to be a appropriate candidate. According to the limiting mechanism, there are various types of SFCLs. In particular, resistive, flux lock and matrix type SFCL have been broadly studied. Since they have merits and drawbacks for the application, many researches have been carried out to overcome the problems. In this study, those three kinds of SFCLs are examined for the application to the protection of the prototype HTS cable. An prototype HTS cable consists of HTS wires was prepared, and the over-current characteristics was investigated. Based on the results, each SFCL will be adopted to the prototype HTS cable, and examined the optimal application method.

2LPW05

Resistance growth of coated conductor to design the stabilizer of 154 kV/1 GVA HTS power cable under the fault current.

S.Kim, K.Sim, J.Cho, H.Kim, Korea Electrotechnology Research Institute; H.Jang, LS Cable Ltd.

The final goal of the HTS power cable project of DAPAS program is 154 kV/ 1 GVA, which is transmission level. To design the cable core, thermal and mechanical stability against the large fault current, which is 50 kA and more than hundred cycles, should be considered. Unlike 1G HTS tape, the coated conductor has large resistance at nomal state and the critical temperature is much lower than 1G HTS tape. The drastic increase of resistance component of the HTS power cable may have influence on the power grid during the fault current. In addition, the induced shield current depends on the resistance variation of the shield layer and its stabilizer. This paper describes resistance growth for the several kinds of coated conductor under various temperature and current conditions. Some coated conductors are specially designed for our HTS power cable. The results will be used to design the stabilizer of the HTS power cable.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

2LPW06
Shielding Current Behavior of the High Temperature Superconducting Cable in the Fault State
K.Sim, S.Kim, J.Cho, Korea Electrotechnology Research Institute
The cold dielectric HTS cable is composed of conducting layers, dielectric layers and shielding layers immersed in the cryogen such as liquid nitrogen. The shielding layer surrounding the conducting layer acts as a magnetic shield which shields the magnetic field produced from the conducting layer. Because the shielding layer is in the superconducting state in the normal operating condition of the cable the induced current of the shielding layer is almost same as the conducting current and the magnetic field can be perfectly shielded. However, in case of the fault state, the current over 10 times of the quench current flows through the conducting layer and it also induces the quench on the shielding layer. This process can produce some transient variations of the cable impedance. The increase of the resistance of the cable is basically caused by the quench phenomenon of the superconductivity and that of reactance is caused by the magnetic interaction between each phases. We investigated the behavior of the shielding current and the impedance variation of the HTS cable and the results will be showed in this paper.
This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

TUESDAY LATE AFTERNOON ORAL SESSIONS 4:00pm - 6:30pm

2LX - Superconducting RF – II 4:00pm - 6:30pm

4:00pm
Invited
2LX01 - Superconducting RF Cavity Development for (toward) the International Linear Collider
***A.Yamamoto**, KEK*
The International Linear Collider (ILC) relies on Superconducting RF Cavities in the Main Linac to accelerate each of the beams from 15 GeV to 250 GeV. The baseline design assumes an average accelerating gradient of 31.5 MV/m in these cavities. The cavity and cryomodule (cryostat) design and R&D efforts are in progress with a global effort and in close cooperation with the European X-ray Free Electron Laser Project (XFEL). This paper describes the technical challenges in the ILC design beyond those addressed by the XFEL design, and the R&D currently underway worldwide to meet those challenges.

4:30pm
2LX02 - Niobium Coating of Copper Cavities using Cathodic Arc
***R.RUSSO**, ICIB-CNR, It; L.Catani, A.Cianchi, D.DiGiovenale, INFN-TorVergata, It; J.Lorkiewicz, SINS, PL and INFN-TorVergata, It; S.Tazzari, Università di Roma and INFN-TorVergata, It; C.Granata, A.Andreone, ICIB-CNR, It; G.Lamura, INFM-CNR "Coherentia" and INFN-Na, It; B.Visentin, M.Bruchon, CEA-Saclay, F*
Niobium thin film coated copper RF cavities are an interesting alternative to niobium bulk cavities, however the sputter-coated cavities present a degradation of the quality factor with increasing accelerating field ("Q-Slope"). To try and overcome this limitation, we have developed an alternative coating technique based on a Cathodic Arc system working under UHV conditions (UHVCA). High quality Nb samples under different deposition angles have been easily synthesized and their characteristics are presented here. The UHVCA technique has been used to deposit 1.3GHz TESLA-type single cell cavities. Results of the RF cavity measurements are also shown. To further improve cavity performance the first critical field has to be enhanced. An alternative way to do so is the use of multilayers consisting of alternating insulating and superconducting layers whose thickness must be smaller than the London penetration depth. Such coating increases the vortex penetration field and the cavity quality factor determined by a smaller surface resistance RS in the Meissner state. To this aim, we present the experimental characterization of the superconducting properties (TC, JC, HC1) of Nb/AlOx/Nb multilayers.

4:45pm
2LX03 - CRYSTAL ORIENTATION EFFECTS ON WELDING OF SINGLE OR MULTI-CRYSTAL NB SRF CAVITIES
***D.Baars**, T.R.Bieler, Chem Eng & Mat Sci, MSU; A.Zamiri, F.Pourboghrat, Mech Eng, MSU; C.Compton, NSCL, MSU; G.E.Ice, R.Barabash, W.Liu, Oak Ridge Natl Lab*
Single and large-grain Nb SRF cavities are of interest due to possible reduction of cost and problems associated with inconsistent texture and surface finish among batches of rolled polycrystalline Nb sheet. In cavity fabrication, single- or multi- crystal sheets are deep drawn and machined, introducing dislocation substructure dependent on crystal orientation. Crystal orientation and dislocation substructure effects on recrystallization and recovery after plastic deformation and e-beam welding were investigated. In steps similar to cavity forming, single crystal tensile specimens with different crystal orientations were deformed, cut, and different halves joined by e-beam welds and chemically etched. Surface finish was found to depend on strain and crystal orientation. Recrystallized grains nucleated outside the melt pool; new orientations grew both epitaxially into the solidifying weld, and away. Dislocation density increased with deformation, was reduced in recrystallized and recovered areas post-weld, and examined using 3-D X-ray analysis. Deformation modeling used crystal plasticity; recrystallization models were nucleated growth and maximum strain energy release, from literature.

5:00pm
2LX04 - Effect of Different Cutting Techniques on the Surface Morphology and Composition of Niobium
C.A.Cooper, Fermi; A.Wu, JLab; P.Bauer, ITER; ***C.Antoine**, CEA - Saclay*
The surface morphology and chemical purity of superconducting radio frequency (SRF) niobium cavities is very important for proper accelerator operation. Typically on the order of 120 microns of niobium is removed from the cavities to remove damage done during the forming of the niobium sheets and cavities. A study was done to find the effect of cutting or finishing niobium with a band saw, diamond saw, EDM wire, garnet water jet, sheer, and mill. Surface contamination for the samples was measured before and after buffered chemical polish (BCP) by Secondary Ion Mass Spectroscopy, Energy Dispersive Spectroscopy, and Relative Resistivity Ratios. Surface morphology was examined with a digital microscope, a surface profilometer and scanning electron microscope. It was found that all techniques altered the top 3-5 microns of the niobium. It was also found by SIMS that the water jet technique introduced the most hydrogen and oxygen to the niobium in the first 2.5 microns of the sample. The EDM wire cutting technique introduced the least amount of hydrogen to the niobium. After 5 microns were etched away by BCP on the various no contaminants were found except for on the water jet cut samples. Even after 20 microns of niobium removal silica could be seen on the surface with EDS. The milled sample was the smoothest sample with Ra's in the micron range. The water jet produced the roughest surface with 50-100 micron deep pits made from embedded garnet particles. It was found that the garnet water jet damages the surface to the point where even the typical 120 microns of BCP etching may not remove all the defects created.

5:15pm
Invited
2LX05 - Tunneling Study of SRF Cavity Grade Nb: Evidence of Possible Magnetic Scattering at the Surface
***T.Proslier**, J.F.Zasadzinski, Illinois Institute of Technology; L.Cooley, Fermi National Accelerator Laboratory; M.Pellin, Argonne national laboratory, MSD; J.Moore, J.Norem, Argonne national laboratory, HEP; C.Antoine, Commissariat de l`energie atomique*
Niobium, with its very high HC1, has been used in superconducting radio frequency (SRF) cavities for accelerator systems for 40 years with continuous improvement. The quality of cavities (Q) is governed by the surface impedance RBCS, which depends on the quasiparticle gap, delta, and the superfluid density. Both of these parameters are seriously affected by surface imperfections (metallic phases, dissolved oxygen, magnetic impurities). Loss mechanism and Surface treatments of Nb cavities found to improve the Q factor, are still unsolved mysteries. Point contact tunneling spectroscopy was performed on Nb pieces from the same processed material used to fabricate SRF cavities. Air exposed, electropolished Nb exhibited a surface superconducting gap delta=1.55 meV, characteristic of clean, bulk Nb, however the tunneling density of states (DOS) was broadened significantly. Nb pieces treated with the same mild baking used to improve the Q-slope in SRF cavities revealed a much sharper DOS. Good fits to the DOS are obtained using Shiba theory suggesting that magnetic scattering of quasiparticles is the origin of the degraded surface superconductivity and the Q-slope problem of Nb SRF cavities.

5:45pm
2LX06 - Fabrication of Niobium Sheet for SRF Cavities
***S.Balachandran**, K.T.Hartwig, Texas A&M University; R.E.Barber, Shear Form, Incorporated; R.B.Griffin, Texas A&M University*
A common problem encountered in forming cup shaped radio frequency superconducting (RFS) cavities from pure niobium sheet is non-uniform deformation. The origin of this problem is in the microstructure: non-uniform grain size and unfavorable texture. The present study follows a multifold approach to fabricate Nb sheet with improved deformation characteristics for the SRF cavity application. The objective is to fabricate Nb sheet, which exhibits high ductility and uniform deformation during deep drawing. Our approach is to begin with large grained bulk Nb, severely plastically deform (SPD) this by simple shear using equal channel angular extrusion (ECAE) to refine the grain size and establish a uniform texture, and then to roll the microstructurally refined bulk material into sheet. The independent variables under study include Nb purity and thermo-mechanical processing history. Niobium bars 25 mm square were ECAE processed through strains of nine then rolled to 90 percent area reduction. Measurements of microhardness, tensile properties, and texture, as well as optical metallography evaluations are used to characterize the SPD processed Nb sheet. Experimental results and the development of a phenomenological model to explain the trends observed will be presented.

6:00pm
2LX07 - Dielectric-loaded superconducting cavity for testing wafer samples at 1.3 GHz with high Q and high surface field
*R.Blackburn, M.Bhatia, T.Elliott, P.McIntyre, **N.Pogue**, A.Sattarov, Texas A&M University*
A superconducting test cavity and cryostat are being developed to support the testing of round wafer samples of new superconducting materials, with the potential to test at superfluid He temperature, Q~10^10, and surface rf fields up to and beyond the BCS limit on Nb. The work is motivated by the suggestions of Gurevich that superconducting heterostructures might be capable of surface fields far beyond the BCS limit for a homogeneous substrate. The cavity operates in the TE011 mode, and the bottom of the cavity is flanged to accept a 15 cm-diameter sample wafer. A dielectric hemisphere of low-loss sapphire is located just above the wafer surface. It reduces the surface field on all cavity surfaces except the wafer, so that the maximum field there is 4 times greater than anywhere else. In this way it should be possible to drive the cavity with high Q ~10^10 and to evaluate the rf surface resistance of the sample up to surface fields at or beyond the BCS limit.
This work is funded in part by the US Dept. of Energy, grant DE-FG02-06ER41405.

6:15pm
2LX08 - Performance of 3.9 GHz SRF Cavities at Fermilab's ILCTA_MDB Horizontal Test Stand
*E.Harms, **A.Hocker**, Fermi National Accelerator Laboratory*
Fermilab is building a cryomodule containing four 3.9 GHz superconducting radio frequency (SRF) cavities for the Free electron LASer in Hamburg (FLASH) facility at the Deutsches Elektronen-SYnchrotron (DESY) laboratory. Before assembling the cavities into the cryomodule, each individual cavity is tested at Fermilab's Horizontal Test Stand (HTS). The HTS provides the capability to test fully-dressed SRF cavities at 1.8 K with high-power pulsed RF in order to verify that the cavities achieve performance requirements under these conditions. The performance at the HTS of the 3.9 GHz cavities built for FLASH is presented here.
Work supported by the U.S. Department of Energy under contract No. DE-AC02-07CH11359.

2LY - Power Transmission Cables – IV 4:00pm - 6:00pm

4:00pm
Invited
2LY01 - A New HTS Cable Project in Japan
***M.Takato**, M.Ohya, T.Kikuta, M.Hirose, Sumitomo Electric Inductries, Ltd.; S.Honjo, T.Mimura, Y.Kitoh, K.Yamamoto, Tokyo Electric Power Company; M.Ikeuchi, R.Ohno, Mayekawa Mfg. Co.,Ltd.*
A new HTS cable project supported by Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO) has just started in Japan. Target of this project is to operate a 66kV, 200MVA HTS cable in the real grid in order to demonstrate its reliability and stable operation. Tokyo Electric Power Company (TEPCO) provides the real grid and studies the influence of connecting the HTS cable to the existing conventional facilities in Yokohama. Sumitomo Electric Industries, ltd. (SEI) manufactures the HTS cable, terminations and joint. Mayekawa Corporation provides a cooling system. The total project period is 5 years. In 2007, components of HTS cable system were studied and designed. In 2008 and early 2009, the pre-system will be constructed in the factory to demonstrate basic performance of the HTS cable and its accessories. Then the 200MVA HTS cable is manufactured in 2009 and constructed and operated at the site in 2010 and 2011. One of the technical targets in the project is to reduce the AC loss of superconducting cable. For this purpose, a new type DI-BSCCO wire with twisted superconducting filaments is planed to be applied in the cable. A 1 m cable core used with the new wires shows its AC loss as less than 1 W/m/ph at 2kArms, which is 1/4 of AC loss with normal DI-BSCCO.

4:30pm

2LY02 - Testing of 3-meter prototype fault current limiting cables

***M.J.Gouge**, R.C.Duckworth, J.A.Demko, C.M.Rey, ORNL; D.Willen, C.Thidemann, H.Lentge, J.C.Tolbert, D.L.Lindsay, Ultera; W.L.Carter, AMSC*

Two 3-m long, single-phase cables have been fabricated by Ultera from second generation (2G) superconductor supplied by AMSC Superconductors. The first cable was made with two layers of 2G tape conductor and had a critical current of 5,100 A while the second had four layers and a critical current of 8,500 A. AC loss was measured for both cables at ac currents of up to 4 kArms. Ultera performed initial fault current studies of both cables in Denmark with limited currents in the range from 5.5 to 30 kArms. Results from these tests will provide a basis for a 50-m long, three-phase prototype cable to be tested at ORNL later this year and a 300-m long, fault current limiting superconducting cable to be installed in a ConEd facility in New York City.

Research sponsored by the U.S. Department of Homeland Security, Science and Technology Directorate, under Interagency Agreement HSHQDC-08-X-00062 with Oak Ridge National Laboratory, managed and operated by UT-Battelle, LLC.

4:45pm

2LY03 - Development and Demonstration of a Fault Current Limiting HTS Cable at Con Edison Grid

***J.F.Maguire**, D.Folts, J.Yuan, American Superconductor; D.Lindsay, Southwire; S.Kurtz, Consolidated Edison*

The US Department of Homeland Security is currently funding the design, development and demonstration of an inherently fault current limiting HTS cable, utilizing the Secure Super Grids™ technology, under the Hydra project with Con Edison. This new technology is capable of carrying very large amounts of power while also being able to automatically suppress power surges. The cable is 300m long and is being designed to carry 96MVA at a distribution level voltage of 13.8kV. The cable will be built using cable system experience gained by AMSC and Southwire on previous projects. The underground cable will be permanently installed and energized in New York City in 2010. The project is led by American Superconductor who is teamed with Southwire and Con Edison. This paper describes the general goals and design criteria of the project. An overview of the concept of Secure Super Grids and the advantages of this type of cable are presented in grid-based network modeling. In addition, the design issues such as tailoring of the HTS wire to provide adequate thermal stability and electrical properties both under normal operation and during a fault are presented.

5:00pm

2LY04 - Balanced Three-Phase Distributions of Tri-Axial Cable for Transmission Line

***T.Hamajima**, N.Hu, N.Ozcivan, K.Shimoyama, S.Soeda, T.Yagai, M.Tsuda, Tohoku University*

High Temperature Superconducting (HTS) cables have been studied because of low loss and compactness, compared with conventional copper cables. Recently, a tri-axial cable, composed of three concentric phases, has been intensively developed, because it has advantages such as reduced amount of HTS tapes and small heat loss, compared with the three single-phase cables. However, there is an inherent imbalance in the three-phase distribution in the tri-axial cable due to the differences in radii of the three-phase layers. The imbalance of the currents causes additional loss and leakage field outside the cable, and deteriorates the electric power quality. Therefore, we proposed a new tri-axial cable model which is composed of two longitudinal sections with different twist pitches to obtain the balanced three-phase and homogeneous current distribution in the tri-axial cable. We derived a general equation as functions of winding pitches satisfying the both distributions. We fabricated and tested a 1m long HTS cable composed of 1 layer per phase in order to verify the proposed theory that satisfies the balanced distribution. The results demonstrated the theory is right. We investigate the voltage distributions along the long tri-axial cable considering the imbalanced capacitances between the layers in the tri-axial cable, and proposed a additional capacitor arrangement to obtain the balanced distributions.

5:15pm

2LY05 - Design Options for HTSC dc Submarine Transmission Cables

***P.M.Grant**, W2AGZ Technologies*

A manifold of opportunities exist and are emerging for the deployment of high capacity dc submarine transmission cables, ranging from wheeling to landside the offshore generation of wind and nuclear power, to inter-coastal merchant lines and gridding together island nations in Southeast Asia. An obvious technology candidate for their realization would be to utilize HTSC dc cables. But this technology has an equally obvious drawback – the necessity to provide submersible refrigeration and pumping facilities appropriately distributed throughout the length of the cable.

Thus in the present paper, we will examine possible as well as some unique alternatives to this traditional approach by exploring cable designs which allow much wider margins of temperature, pressure and cryogen flow rate than normally considered in overland underground superconducting transmission systems, whilst at the same time preserving the performance advantage expected from the use of superconductivity.

5:30pm

2LY06 - A High-Power Superconducting DC Cable

***W.V.Hassenzahl**, Advanced Energy Analysis; S.E.C.Eckroad, EPRI; B.Gregory, CCI; P.M.Grant, EPRI; S.Nilsson, Exponent*

The long-range future of large electric power systems depends on achieving secure and reliable transmission of electric power at the gigawatt level. Also, changes in the production and use of electricity vis-a vis the drive to "green" power sources have heightened the importance of improving the efficiency of electric power transmission.. With these thoughts in mind, a small group supported by EPRI began assessing the possible function and form of a high-temperature superconductor based DC cable of the future. The goal of the effort being to produce a conceptual design with sufficient engineering content that it could be built with present day engineering capabilities. The only recognition of potential advancements in the concept is the anticipated performance of superconductors some 15 to 20 years hence. This presentation will discuss results of the effort to date and will describe much of the cable and infrastructure design necessary to install and operate a multi gigawatt SC-DC Cable.

5:45pm

2LY07 - Cooling Configuration Design Considerations For Long-Length HTS Cables

***J.A.Demko**, R.C.Duckworth, ORNL*

Recent successes in demonstrating high temperature superconducting (HTS) cable systems hundreds of meters in length have inspired even longer length projects. A compact and energy efficient cooling configuration can be achieved using a counterflow cooling arrangement. This is particularly attractive when all three phases are contained in a single cryostat because of the elimination of the space and thermal requirements of separate liquid nitrogen return line. Most new cable projects will utilize second generation (2G) wire which is expected to become lower in cost but may have different thermal requirements than first generation BSCCO wire due to the lower critical temperature and to a lesser extent, the lower thermal conductivity of the wire. HTS cable configurations will be studied with a numerical model to assess thermal hydraulic performance with AC and thermal losses; a summary of the results from the analysis will be presented. An analysis of the cable thermal-hydraulic response to over-current faults will be presented.

Research sponsored by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, Superconductivity Program for Electric Power Systems, under contract No. DE-AC05-00OR22725 with UT-Battelle, LLC.

WEDNESDAY, AUGUST 20, 2008

WEDNESDAY MORNING ORAL SESSIONS
10:00am - 12:30pm

3LA - Detector Magnets – II 10:00am - 11:15am

10:00am
Invited
3LA01 - ATLAS Superconducting Magnet System completion
***H.H.J.Ten Kate**, CERN - Physics Department*
The superconducting magnet system of the ATLAS Detector at the Large Hadron Collider at CERN has four magnets, a Barrel Toroid, two End-Cap Toroids and a Central Solenoid. It provides the magnetic field for the muon- and inner detectors, respectively. The Barrel Toroid with outer dimensions of 25m length and 20m diameter is an assembly of eight racetrack coils. The coils are wound with an aluminum stabilized NbTi conductor and operate at 20.5kA and 3.9T peak magnetic field. The coils, in total 370 tons of cold mass, are conduction cooled at 4.8K by circulating forced flow helium in cooling tubes attached to the cold mass. The two End Cap Toroids are smaller sized, still 11m in diameter and 5m in height. The Central Solenoid has dimensions of 2.4m diameter and 5.7m length. The system stored energy is 1.6GJ. After the successful on-surface tests the magnets were installed in the ATLAS cavern 100m underground. The Barrel Toroid and Solenoid were successfully charged to full field in autumn 2006 while the two End Cap Toroids were charged in the past months. A last but crucial step, however, has been the test of the entire system with all coils switched on by which the maximum forces are exerted. Test results of this complex and unique magnet system and some of the lessons learnt are reported.
Acknowledged are the engineers and technicians from the participating magnet laboratories CEA-Saclay, INFN-LASA, RAL, NIKHEF, KEK and CERN service groups. This project is funded by the ATLAS Collaboration, presently about 1900 scientific authors from 164 institutes in 35 countries and supported in part by CERN.

10:30am
3LA02 - Testing and Final Construction of the Superconducting Magnet for the Alpha Magnetic Spectrometer
***S.M.Harrison**, S.R.Milward, R.C.Stafford Allen, M.A.Gallilee, N.R.Shaw, Scientific Magnetics; R.J.Anderson, Scilutions; S.C.C.Ting, Massachusetts Institute of Technology*
The Alpha Magnetic Spectrometer (AMS) is a particle physics experiment based on the International Space Station (ISS). At the heart of the detector is a large superconducting magnet, cooled to a temperature of 1.8 K by superfluid helium. The magnet and cryogenic system have been designed and built by Scientific Magnetics (formerly Space Cryomagnetics) of Culham, England. This paper describes the results from magnet testing, and the final assembly of the magnet and flight cryostat.

10:45am
3LA03 - The BESS-Polar ultra-thin superconducting solenoid magnet and its operational characteristics during long-duration scientific ballooning over Antarctica
***Y.Makida**, KEK; R.Shinoda, The University of Tokyo ; A.Yamamoto, K.Yoshimura, K.Tanaka, J.Suzuki, S.Matsuda, M.Hasegawa, KEK; S.Mizumaki, Toshiba; R.Orito, Kobe University; K.Sakai, The University of Tokyo; A.Horikoshi, KEK; J.W.Mitchell, M.Sasaki, NASA; A.Kusumoto, Kobe University*
Ultra-thin superconducting solenoids have been developed for cosmic-ray spectrometers ballooning over Antarctica, BESS-Polar. The coils with a diameter of 0.9 m, a length of 1.4 m and a thickness of 3.5 mm, were wound with high-strength aluminum stabilized superconductor and provide 0.8 T in the spectrometer. Based on the experience at the BESS-Polar-I solenoid realizing the persistent mode operation at an altitude of 37 km for nine days in 2004, the BESS-Polar-II solenoid, which was cryogenically improved, realized a persistent mode operation of 25 days during the second flight in December 2007 though January 2008. The liquid helium life during the flight of 25 days shows better performance than that of 21 days on the ground test. It has contributed to accumulate the cosmic-ray observation data up to 16 terabyte in a hard disk unit, compared with the 2 terabyte in the first flight. This report will describe the flight characteristics of the second solenoid.

11:00am
3LA04 - Design, manufacturing and performance of a Pair of Superconducting Solenoids for a Neutron Spin-Echo Spectrometer at the SNS
***W.Walter**, M.Borlein, Babcock Noell GmbH; T.Kozielewski, M.Monkenbusch, M.Ohl, A.Paul, Jülich Research Center; B.Schrauth, C.Tiemann, Babcock Noell GmbH*
A Neutron spin-echo spectrometer (NSE) of the next generation is under construction at the Spallation Neutron Source (SNS) in Oak Ridge, USA. A NSE spectrometer measures tiny velocity changes of the neutrons encoded by the neutrons spin clock at a sample while the Neutron spin precesses in large magnetic fields following Bloch's equation. This instrument will be best of its class both with respect to resolution and dynamic range. In order to reach this ambitious goal, a large magnetic precision field integral before and after the sample is required which directly scales linearly with the resolution of the instrument. Therefore superconducting technology will be used to allow for a higher magnetic field integral. Here, we present the design, manufacturing and test performance of the solenoids which emerged from a co-operation of Jülich Research Center (FZJ) and Babcock Noell GmbH (BNG).

3LB - Superconducting Magnetic Energy Storage – II 10:00am - 12:00pm

10:00am
Invited
3LB01 - Field test result of 10MVA/20MJ SMES for Lord fluctuation compensation
***T.K.Katagiri**, H.N.Nakabayashi, Y.N.Nijo, T.T.Tamada, T.N.Noda, N.H.Hirano, T.N.Nagata, S.N.Nagaya, Chubu Electric Power Co.Inc.; M.Y.Yamane, Mitsubishi Electric; Y.I.Ishii, Toshiba*
We actually manufactured SMES of the output 10,000kW for the power system control, and connected this in a real system. This 10,000kW class SMES(stored energy 20MJ) provides the function to prevent the electric power system from becoming unstable by the turbulence of the stop of the function and the dynamo which decreases the influence on the electric power system by the change of the load.we connected in a real system to combine the element equipment as a system, and to confirm the effect in the spot and confirmed the effect. And, we operated so that SMES may compensate for the fluctuating load of the effective power and the reactive power of the factory. SMES was able to have compensated for the effective power according to the fluctuating load, and confirm the situation with a smooth load change of 66/11kV transformer of hydro power plant. Therefore, it is necessary to achieve the best fusion of equipment. and SMES to achieve the stability of the transmission system.
This work was supported by the New Energy and Industrial Technology Development Organization (NEDO), under the Research and Development of Superconducting Magnetic Energy Storage System sponsored by Agency of Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI).

10:30am
Invited
3LB02 - The Status and Prospects for HTS SMES in Korea
***H.J.Kim**, K.C.Seong, J.H.Bai, H.M.Kim, S.H.Kim, K.D.Sim, E.Y.Lee, M.H.Sohn, Korea Electrotechnology Research Institute; D.Y.Koh, Korea Institute of Machinery & Materials; K.D.Choi, Korea Polytechnic University; M.W.Park, Changwon National University; S.H.Kim, Gyeongsang National University*
The superconducting magnetic energy storage(SMES) system have both large power output and fast response time, so it can be used to improve power quality and power system stability. We successfully finished development of a 3 MJ class low temperature superconducting(LTS) SMES 5 years ago. But it was more expensive than competition technologies, like the Supercapacitor Energy Storage and Battery Energy Storage. Until now, the price of high temperature superconducting(HTS) wire is still more expensive than LTS wire, however price will be goes down in near future and also HTS SMES has an advantage in part of operational temperature, Therefore we carried on this study. the development of HTS SMES was started in 2004, overall period of the project is 10 years. the final goal is a commercialization of this system. We divided our project period into 3 phase. First phase we developed a 600 kJ class HTS SMES system during 3 years, and now we are started a second phase, it will be developed 2.5 MJ class HTS system for 4 years. The 2.5MJ HTS SMES system will be used to protect sensitive equipments of semiconductor factories or LCD manufacturing factories in this phase. This paper describes a brief status and prospects of HTS SMES in Korea.
This work was supported by Electric Power Industry Technology Evaluation & Planning

11:00am
3LB03 - Summary of a 1 MJ Conduction-Cooled LTS Pulse Coil Developed for 1 MW, 1 s UPS-SMES
***T.Mito**, H.Chikaraishi, NIFS; A.Kawagoe, Kagoshima University; R.Maekawa, NIFS; R.Abe, Shibuya Kogyo Co., Ltd.; T.Baba, NIFS; K.Okumura, A.Kuge, JSO; F.Sumiyoshi, Kagoshima University*
The development of a 1 MJ conduction-cooled low temperature superconducting (LTS) pulse coil used for a 1 MW, 1 s UPS-SMES is summarized. We have developed a conduction-cooled LTS pulse coil as a key technology for the UPS-SMES. The AC loss reduction and the high stability are required for the SC conductor for a LTS pulse coil because of a limited cooling capacity of 4 K cryocooler. The conductor of a NbTi/Cu compacted strand cable extruded with an aluminum was designed to have the anisotropic AC loss properties to minimize the coupling loss. The coil has been wound, utilizing a new machine which performs an innovative twist-winding method. The Dyneema FRP (DFRP) spacers and the Litz wires (braided wires insulated copper strands) were inserted in each layer in order to enhance the heat transfer in the coil windings. The coil was installed in the test cryostat and was connected to three GM cryocoolers, which has a total cooling capacity of 4.5 W at 4 K and 180 W at 50 K. The coil was cooled conductively without liquid helium by attaching the end of the Litz wires directly to the cold heads of the cryocoolers. The cooling and excitation test of the 1 MJ coil has been done successfully. The test results validated the high performance of the conduction-cooled LTS pulse coil, because the high thermal diffusivity resulted in the rapid temperature stabilization in the coil. The results and discussion of the cooling and excitation test including the energy extraction test for a UPS-SMES are reported.

11:15am
3LB04 - Fabrication and Demonstration of 1MJ/500kVA HTS SMES at Live Distribution Network
***L.Y.Xiao**, Z.K.Wang, C.H.Zhao, S.T.Dai, J.Y.Zhang, D.Zhang, Z.Y.Gao, N.H.Song, F.Y.Zhang, L.Z.Lin, Institute of Electrical Engineering*
A 1MJ/500 kVA HTS SMES was fabricated and demonstrated. The magnet for the SMES was made of BSSCO tapes. The inductance is of the HTS magnet is 6.28 H and the rated operation current is 567 A at 4.2 K, and the central field is up to 4.87 T at rated current. The 500 kVA power converter consists of cascade inverter and current regulator. The 1MJ/500kVA SMES is demonstrated at a distributed network and serve for a high technology factory. The results show that the SMES can be used to improve the power quality significantly.
The author are grateful to the Chinese Academy of Science and China National Natural Science Foundation for the finacial support to this project.

11:30am
3LB05 - Quench Properties of a 7-T Force-Balanced Helical Coil for Large-scale SMES
***S.Nomura**, K.Kasuya, N.Tanaka, K.Tsuboi, H.Tsutsui, S.Tsuji-Iio, R.Shimada, K.Arai, Tokyo Tech; A.Ninomiya, T.Ishigohka, Seikei University*
A superconducting force-balanced coil (FBC) has been developed. The FBC is a helically wound coil of toroidal field coils and a solenoid. This coil can minimize the required mass of the structure for induced electromagnetic forces. The model FBC, with an outer diameter of 0.53 m, will have 270 kJ stored energy at the critical magnetic field of 7.1 T using NbTi strands. The hand-made winding of the model FBC was carried out without reinforcing materials such as stainless steel wires. Two excitation tests were conducted at an interval of several months. The first quench current was 293 A, which is 53% of the critical coil current. The training phenomena of the model FBC could be observed without any sudden decreases in the quench current even after the coil was warmed up to room temperature. After successive excitations it was successfully excited up to 5.9 T without reinforcing materials for the NbTi strand. The third excitation test is planned in order to evaluate the mechanical vibrations in the helical windings using acoustic emission measurements. This study contributes to obtaining the relationship between the quench properties and the winding techniques of the FBC.

11:45am
3LB06 - Cryogenic Fuel Cooled SMES for Hybrid Vehicle Application
***L.Trevisani**, A.Morandi, F.Negrini, P.L.Ribani, M.Fabbri, Dept. of Electrical Engineering, University of Bologna, Italy*
A novel energy storage system based on a SMES cooled by cryogenic fuel has being developed at the Dept. of Electrical Engineering of the University of Bologna. The system (which was patented by the authors) represents an alternative solution with respect to nowadays battery packs for the storage of electrical energy with large specific power. The device may find suitable application on board of road vehicles fed by liquid hydrogen with hybrid power-train (internal combustion engine and electric motor-generation), where a cryogenic tank is already present and no additional cryogenic costs are needed. The housing of the SMES inside the tank used for fuel storage, allows the exploitation of the thermal power required for the continuous evaporation of the fuel for the engine feeding to remove the AC losses from the magnet, thus avoiding the need of external supplied cooling power. In this paper both the design of the magnet and its operation in combination with electronic converter and electric motor during charge/discharge cycles are discussed. Moreover the ongoing activity for the development of a laboratory-scale prototype based on MgB2 superconductor is briefly presented.

3LC - Fault-Current Limiters – III 10:00am - 11:45am

10:00am

3LC01 - DC MAGNETIZATION SYSTEM for a 35kV/90MVA SUPERCONDUCTING SATURATED IRON-CORE FAULT CURRENT LIMITER

H.Hong*, Z.J.Cao, X.M.Hu, J.Z.Wang, W.Z.Gong, Y.Xin, Innopower superconductor cable Co., Ltd.; Y.He, A.G.Wu, Tianjin University Automation & Energy College*

Abstract—A controllable magnetization system, including a HTS dc bias coil, a dewar, a dc power supply, an energy release and voltage suppressing unit, and a high speed switch was built for a 3 phase 35kV/90MVA saturated iron-core fault current limiter. There are three typical working states for the magnetization system. During a normal power transmission, the dc power supply feeds the dc bias coil to magnetize the iron-core of the current limiter. Under a fault condition, the high speed switch breaks the feeding circuit within a few milliseconds and the magnetic energy stored in the iron-core during normal operation was absorbed by the energy release unit. After the clearing of a fault, the switch closes the dc magnetization circuit to magnetize the iron-core into deep saturated state again in a few hundred milliseconds, so the current limiter is ready for resuming normal power transmission. In this paper, we will present the key design parameters of the magnetization system. Index Terms-- High-temperature superconductivity, Superconducting fault current limiter, Superconducting magnets, dc power supply

10:15am

3LC02 - Design and development of 15 MVA class fault current limiter for distribution systems

L.Martini*, M.Bocchi, R.Dalessandro, CESI RICERCA; C.Ravetta, A.Ruffini, A2A Elettricità*

As electric power systems grow and become more interconnected, the fault current levels increase. Conventionally, handling of increasing fault currents often requires costly replacement of substation equipment or imposition of network configuration changes. Therefore, there is a considerable interest for fault current limiting devices. The Superconducting Fault Current Limiter (SFCL) is a self-triggering and self-recovering innovative device able to limit within few milliseconds the short-circuit currents to lower levels, so that underrated switching equipment can be operated safely. In this work, we report on design and simulation of 9kV/15MVA class resistive SFCL for distribution system applications based on first and second generation HTS. Single and multi-phase short-circuit of different duration and severity have been simulated by means of a self-developed mathematical model able to fully describe the SFCL limiting characteristics. Two typical SFCL installations have been considered and analyzed: i) incoming feeder (Inom=1000A), and ii) outgoing feeder (Inom=300A). Time evolution of limited current and other important SFCL characteristics have been analyzed simulating fault events with prospective steady-state short-circuit currents as high as 12kArms for three-phase faults. SFCL current limiting capability and grid impact are reported and discussed in view of the final assembly and installation of a SFCL unit in a MV grid for field testing.

10:30am

3LC03 - Resistive and Inductive Fault Current Limiters: Kinetics of Quenching and Recovery

A.Usoskin*, R.Dietrich, B.Prause, A.Rutt, K.Schlenga, European High Temperature Superconductors GmbH & Co. KG*

Two groups of parameters, the operational time constants and the cooling power, largely determine the applicability of fault current limiters (FCL) in connection with energy transportation and energy distribution. We here report results of a comparative study of resistive, respectively inductive coated conductor (CC) based FCLs, regarding their general performance and, especially, regarding the parameters mentioned above. It is shown how the time- and cryo-performance are influenced by the type of intra-connections within the CC tape and the type of interconnections employed for electrical jointing of different CC elements within the FCL. The kinetics of sharing of transient currents between superconducting and normally conducting elements is investigated for different resistive and inductive FCL models with power consumption up to 2MW.

10:45am

3LC04 - Methods to increase current capacity of superconducting thin-film fault current limiter using Au-Ag alloy shunt layers

K.Arai*, National Institute of Advanced Industrial Science and Technology(AIST); H.Yamasaki, K.Kaiho, Y.Nakagawa, M.Sohma, W.Kondo, I.Yamaguchi, T.Kumagai, AIST*

We have been studying a superconducting fault current limiter (FCL), in which YBCO thin films on sapphire substrates are used. Our approach is to employ high-resistivity Au-Ag alloy shunt layers in the films, which enable the total length of FCL elements to be reduced with high electric fields of more than 40 Vpeak/cm, thus greatly reducing the cost of FCLs. In this presentation, two methods are demonstrated to increase current capacity of the thin films for the development of the FCLs. We firstly show that parallel connections of the thin films using superconducting tapes make the most of critical current of each thin film. Even in the case that critical currents in each thin-films were largely different (Ic = 96 and 192 A), this method was very effective. The second method is about protection of the films using capacitors as well as external resistors. The capacitors decrease rapid voltage rise in the films at the moment of quenching. It was shown that high rate of voltage rise of 2740 kV/s was reduced to be 1020 kV/s using a capacitor of 50 micro-F, relieving “hot-spots” problem. Using these two methods, we successfully tested parallel-connected two thin films prepared by MOD in our institute. 5-cycle over-current tests at 50 Hz showed good results that quenching current was 502 A, 1.6 times of the total critical current of 320 A, and electric field in the films was 45.7 Vpeak/cm without degradation.

11:00am

3LC05 - Study of Superconducting Fault Current Limiter to High Speed Reclosing

T.Koyama*, M.Endo, Tokyo Denki University; K.Arai, National Institute of Advanced Industrial and Technology; K.Kaiho, H.Mizoguchi, S.Yanabu, Tokyo Denki University*

Using a high temperature superconductor, we constructed and tested a model superconducting fault current limiter (SFCL). The superconductor might break in some cases because of its excessive generation of heat. Therefore, it is desirable to interrupt early the current that flows to superconductor. So, we proposed the SFCL using an electromagnetic repulsion switch which is composed of a superconductor, a vacuum interrupter and a by-pass coil, and its structure is simple. Duration that the current flow in the superconductor can be easily minimized to the level of less than 0.5cycle using this equipment. On the other hand, the fault current is also easily limited by large reactance of the parallel coil. There is duty of high speed reclosing after interrupting fault current in the electric power system. After the fault current is interrupted, the back-up breaker is reclosed within 0.35 seconds. So, the electromagnetic repulsion switch should return to former state and the superconductor should be recovered to superconducting state before high speed reclosing. Then, we proposed the SFCL using an electromagnetic repulsion switch which employs our new reclosing function. We also studied recovery time of the superconductor as there is heat generation in the superconductor at the time of quenching.

11:15am

3LC06 - Numerical modeling of ac limiting properties of MgB2 strands in different cooling conditions

***M.Majoros**, M.D.Sumption, E.W.Collings, The Ohio State University*

It is known that MgB2 material may be used in fault current limiters as a cheaper alternative to high-temperature YBCO coated conductors. Numerical modeling of ac limiting properties of different kinds of MgB2 strands in different matrices and different cooling conditions have been performed using finite element method. Two 2D and 3D ac Poisson equations for electric field and heat transfer were solved simultaneously with input parameters taken from experiment. As a boundary condition, full non-linear curves of the heat flux into liquid coolants (liquid hydrogen or liquid neon) were used. Also a modeling of cooling using different kinds of cryocoolers was performed. Influence of different values and durations of fault electric fields has been studied and maximum temperatures, limiting currents and recovery times calculated. Overheating effects on dc current-voltage characteristics were also modeled. Obtained results may be useful for understanding the behaviors of different kinds of MgB2 multifilamentary wires in conditions encountered in fault current limiters.

11:30am

3LC07 - Superconducting Coils Wound with Stacked YBCO Coated Conductors for 6.6 kV Fault Current Limiter

***K.Koyanagi**, T.Yazawa, M.Takahashi, M.Ono, M.Urata, Toshiba Corporation; Y.Iijima, T.Saitoh, N.Amemiya, Fujikura Ltd.; Y.Shiohara, Superconductivity Research Laboratory, ISTEC*

A three-phase 6.6kV superconducting fault current limiter (SFCL) using Yttrium or Gadolinium-based high-temperature superconducting (YBCO / GdBCO) coated conductors has been developed. The YBCO tapes were produced using ion-beam-assisted-deposition (IBAD) and pulsed-laser-deposition (PLD). To obtain an instantaneous increase in the coil impedance during the superconducting to the normal state transition of the resistive-type FCL, the thickness of the protective Ag layer was decreased to 10 micron meters. A nickel-chromium alloy, which has high electric resistivity, was laminated on the Ag layer with an appropriate solder. Two tapes were electrically insulated and were wound in parallel to form a non-inductive SFCL coil. In this study, we conducted current limiting tests of the coil using a short circuit generator. The coil successfully limited the short-circuit current of 17kA to about 700A within 2 ms.

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

WEDNESDAY AFTERNOON POSTER SESSIONS 2:00pm - 4:00pm

3LPA - Accelerator Magnets – III 2:00pm - 4:00pm

3LPA01

Invited

Test Results of Superconducting Magnets for the J-PARC Neutrino Beam Line

T.Okamura, K.Sasaki, T.Tomaru, Y.Ajima, T.Ogitsu, N.Kimura, M.Iida, H.Ohhata, S.Sugawara, K.Tanaka, T.Nakamoto, N.Higashi, Y.Makida, O.Araoka, K.Kasami, KEK

All 32 superconducting combined function magnets including four auxiliary magnets for the primary proton beam line for the J-PARC neutrino experiment are being fabricated and excitation tests at 4.5 K, 1atm, in a vartical cryostat, will be completed by summer of 2008. Excellent excitation and quench performances have been observed so far. In the field measurement during cold tests, all the magnets showed sufficient field quality to fullifll the specification. The field measurement at room temperature has been also performed with all magnets for checking the dipole field component. Test results of the superconducting combined function magnets will be presented in this conference.

3LPA02

Invited

Electromagnetic design of the coil-ends for the FAIR SIS300 prototype dipole

M.Sorbi, University of Milan and INFN-LASA; F.Alessandria, INFN-LASA, Milan; G.Bellomo, University of Milan and INFN-LASA; P.Fabbricatore, S.Farinon, INFN-Genova; U.Gambardella, INFN-Frascati; R.Musenich, G.Volpini, INFN-Genova

Design activities, conductor R&D and model coil construction are under way for developing a curved fast cycled superconducting dipole for the SIS300 synchrotron at FAIR. The main target is the construction within 2009 of a half-length prototype magnet (cold mass fully integrated in a horizontal cryostat). This magnet is designed for a maximum central field of 4.5 T in a bore of 100 mm, with a ramp rate of 1 T/s. The magnetic length of the prototype is 3.8 m with a curvature radius of 66.67 m (27 mm of sagitta). This paper describes the mechanical and electromagnetic design of the coil-ends of the magnet. Particular emphasis is given to the study of the losses due to the eddy currents in collar and yoke, and to the other losses in the conductor during the cycling of the magnet. The study has been performed with finite element codes, and it allowed to optimize the configuration in order to minimize both the peak field on the conductor and the total losses.

3LPA03

Invited

Persistent Current Effects on the Superconducting Combined Magnet Prototype for XFEL

F.Toral, L.Garcia-Tabares, S.Sanz, I.Rodriguez, E.Rodriguez, J.L.Gutierrez, D.Carrillo, J.Calero, CIEMAT; H.Brueck, R.Bandelmann, DESY

The design and fabrication of a prototype of a combined magnet is part of the Spanish contribution to XFEL. This magnet consists of a superferric quadrupole for focusing and two dipoles (horizontal and vertical) for steering, glued around the beam tube. The magnet will be operated in a superfluid helium bath. The aperture is 78 mm. The quadrupole gradient is 35 T/m whereas each dipole field is about 0.04 T. Persistent current effects have been measured during the tests, both in the quadrupole and dipole coils, with single or combined powering. Strange behaviours have been detected: for instance, the magnetization of dipole coils was higher when the quadrupole background field was larger. Next step was to analyse the magnetization of superconducting combined magnets. Besides, detailed computations were made using ROXIE, as it is able to take into account different orientations of the magnetizing field. The results matched the measurements and, furthermore, other amazing features were detected: the dipole coil magnetization for a constant quadrupole field was lower for large filament diameters. However, an optimal design needs to find a trade-off, because large filaments in the dipole wires also mean large magnetization effects during quadrupole cycling for a given dipole field.

Work partially supported by the Spanish Ministry of Education and Science under Project FPA2002-00841.

3LPA04

A prototype dipole for FAIR SIS300: design of the mechanical structure

S.Farinon, P.Fabbricatore, R.Musenich, INFN-Genova; F.Alessandria, G.Bellomo, M.Sorbi, G.Volpini, U.Gambardella, INFN-Milano

Design activities coupled with conductor R&D and model coil construction are under way for developing a curved fast cycled superconducting dipole suitable for operations of the SIS300 synchrotron at FAIR. The main target is the construction within 2009 of a half-length prototype magnet (cold mass fully integrated in a horizontal cryostat).
This magnet is designed for generating 4.5 T magnetic field in a bore of 100 mm, able to be operated at a field rate of 1 T/s. The magnetic length is 3.8 m with a curvature radius of 66.67 m (the sagitta is 27 mm). The mechanical structure is based on 3 mm laminated stainless steel collars, assembled through keys, and 1 mm laminated iron shells, assembled through large C-shaped keys. A 2D finite element analysis has been performed to evaluate stresses and deformations coming out during assembly, cool-down and energization. Particular emphasis has been given to the possible fatigue problems ensuing from the large operating field rate over a large lifetime cycle number, 10^7. Numerical results are presented and discussed.

3LPA05

Design Study for the SIS 300 Main Quadrupoles

H.Mueller, S.Y.Shim, G.Moritz, GSI

For the main dipole of the SIS 300 models have been manufactured for example by GSI and Brookhaven (GSI001) IHEP (a 1m long 6T model magnet currently under construction) and INFN (a 4.5 T curved magnet for the actual FODO lattice, also under construction). These different magnets reflect the design changes of the SIS 300 over the recent years. Based on the current lattice design studies for the main quadrupoles were started at GSI. In the presentation the actual status of the work on these magnets will be presented. Magnetic field quality, AC losses and mechanical aspects of the current design will be addressed.

3LPA06

The GSI cryogenic test facility - measurement equipment and first experience gained on superconducting prototype magnets of the FAIR project

A.Stafiniak, C.H.Schröder, E.Floch, F.Walter, F.Marzouki, Gesellschaft für Schwerionenforschung mbH

The Facility of Antiproton and Ion Research (FAIR) will feature two superconducting fast ramped synchrotrons (SIS 100, SIS300). The core components of this new facility are two-phase forced cooled superferric magnets ramped with 4T/s up to 2T and single-phase forced cooled cos magnets ramped with 1T/s up to 4T. The GSI test facility consists on 2 test benches. One of them is equipped with universal cryostat and second is dedicated to cryostated magnets. A few models of superconducting magnets have been tested. We report on the training, quench behaviour of the magnets and results of AC loss measurements using electrical and calorimetric methods. The second test bench and the equipment used for testing are described.

3LPA07

Design Study of Corrector Magnets for SIS 100/300

K.Sugita, G.Moritz, GSI

FAIR (Facility for Antiproton and Ion Research) contains two rapid-cycling superconducting synchrotrons, SIS 100 and 300. Both synchrotrons have 252 and 228 corrector magnets, respectively. Due to lack of longitudinal space along the ring, quadrupole, sextupole and octupole correctors are nested and assembled as one module. Also, steering magnet contains nested horizontal and vertical dipole winding. Maximum operation current of those correctors should be limited to 300A in order to reduce the lead losses, because all magnets are powered individually. Besides those constraints, SIS 100 corrector magnets will use the same cooling scheme as the main magnets (indirect cooling by two-phase forced-flow helium). We present design studies of these nested correctors for SIS 100. Additionally we will describe design options for the SIS 300 nested correctors.

3LPA08

Design study of compact IR quadrupoles for linear colliders based on Rutherford type cable

M.L.Lopes, V.V.Kashikhin, V.S.Kashikhin, A.V.Zlobin, Fermilab

The upcoming and disrupted beams in the interaction region (IR) of a linear collider are focused by FD doublets consisting of two small-aperture superconducting quadrupoles. These magnets need an effective compact magnetic shielding to minimize magnetic coupling between two channels and sufficient temperature margin to withstand high radiation-induced heat depositions in the coil. This paper presents conceptual designs of IR quadrupoles for linear colliders based on NbTi and Nb3Sn Rutherford-type cables which meet the above requirements. The results of magnetic and thermal analysis are reported and discussed.

**Work is supported by the U.S. Department of Energy*

3LPA09

Transient 3D Finite Element Simulations of the Field Quality in the Aperture of the SIS-100 Dipole Magnet

S.Koch, Technische Universitaet Darmstadt, Institut fuer Theorie Elektromagnetischer Felder; H.De Gersem, Katholieke Universiteit Leuven, Subfaculteit Wetenschappen; T.Weiland, Technische Universitaet Darmstadt, Institut fuer Theorie Elektromagnetischer Felder

The dipole magnets for the new heavy-ion synchrotron SIS-100, planned within the Facility for Anti-Proton and Ion Research (FAIR) at GSI, Darmstadt, Germany, have to be optimized under certain design requirements. At the intended high beam intensities, the field quality in the aperture is crucial, as substantial beam losses are not acceptable. In the acceleration phase as well as during injection of the beam into the ring, the relative field perturbation in terms of higher order multipoles must stay well below 1e-4 at any time. The geometry of the window-frame magnet featuring superconductive coils was already optimized with respect to the field quality in DC mode using 2D Finite Element (FE) simulations. During fast ramping up to 2T with a triangular excitation profile lasting 1s, however, additional perturbations arise due to local saturation and due to eddy currents in both the yoke and the metallic beam pipe. These have been investigated using transient 2D FE simulations. In order to support these results, transient 3D FE simulations, capturing the eddy-current effects at the end plates as well as the closing currents in the beam pipe are carried out. For that purpose, semi-analytical models are applied to model the virtually infinite length of the beam pipe.

This work was supported by the Gesellschaft fuer Schwerionenforschung mbH (GSI), Darmstadt, Germany.

3LPA10

Geometry of Quadrupole for the SIS300

L.Tkachenko, S.Kozub, V.Zubko, Institute for High Energy Physics

Main parameters for the SIS300 quadrupole, GSI, Darmstadt, project FAIR, are 45 T/m central field in 105-mm aperture, the effective length of the quadrupole is 1 m. Optimized geometric parameters of 1-layer magnet are presented both in cross section and in end parts. The coil consists of 3 blocks in one quadrant. Collars are self-supporting mechanical structure. Integral multipoles are suppressed by central harmonics. Thermal and mechanical characteristics of the magnet are presented too.

3LPB - Superconducting RF – III 2:00pm - 4:00pm

3LPB01

Investigation of the influence of trapped vortices on high-field RF losses in superconducting niobium cavities

G.Ciovati, Jefferson Lab; A.Gurevich, FSU/NHMFL

Superconducting radio-frequency (RF) cavities made of high-purity bulk niobium exhibit strong anomalous RF losses starting at peak surface magnetic fields of about 90-100 mT in the gigahertz range. This phenomenon is referred to as "Q-drop". Temperature maps of the cavity surface reveal the presence of "hot-spots" in the high magnetic field region of the cavities. Several models have been proposed over the years to explain this phenomenon but there is still no clear experimental evidence on its nature. In order to test the possibility of trapped vortices as being responsible for the anomalous losses, we did experiments where a local thermal gradient was applied to the hot-spot regions of a cavity in order to displace the vortices. Temperature maps before and after applying the thermal gradient allows us to determine changes in the hot-spot positions and strengths and their effect on the cavity performance.

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3LPB02

Progress on the Development of a Superconducting Connection for Niobium Cavities

P.Kneisel, G.Ciovati, Jefferson Lab; J.Sekutowicz, DESY; L.Turlington, Jefferson Lab

The availability of a superconducting connection between adjacent niobium radio-frequency (RF) cavities with the capability to carry up to 30 mT of the magnetic flux would be particularly of great benefit to layouts of long accelerators like the International Linear Collider (ILC). It would shorten the distances between structures and therefore the total length of an accelerator with the associated cost reductions. In addition, the superconducting connection would be ideal for a super-structure – two multi-cell cavities connected through a half wavelength long beam pipe providing the coupling. Two single-cell niobium cavities have been designed with Nb1%Zr flanges welded to one of the irises to allow a connection between them with a niobium gasket. A transition to the normal-conducting state of the connection due to the applied RF field causes a reduction of the cavities' quality factor. Results from the RF tests of this 2-cell system will be presented in this contribution. In addition, we attempted to measure the critical current densities of point-contact Josephson junctions for Nb1%Zr and Nb with the same geometry as for the cavity connection.

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3LPB03

The effect of grain boundaries on large-grain, high-purity niobium for an SRF cavity

Z.H.Sung, P.J.Lee, A.Gurevich, A.A.Polyanskii, V.Griffin, D.C.Larbalestier, Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University

Grain boundaries (GBs) in a superconducting RF niobium cavity may be one cause of the extra power dissipation and the drop of the quality factor (Q0) at medium or higher accelerating RF magnetic field because vortex penetration is accelerated on the GBs if the superconducting gap and the local depairing current density Jb are locally reduced. Therefore, we correlated the global superconducting properties (as determined by magnetometry and transport measurement) with the local properties (as determined by magneto-optical imaging and atomic-scale structure analysis by STEM) of BCP-treated bi-crystals isolated from as-received large-grain, high purity (RRR>250)niobium sheet.

3LPB04

Magnetic Shielding for the Fermilab Vertical Cavity Test Facility

C.M.Ginsburg, C.Reid, D.A.Sergatskov, Fermilab

A superconducting RF cavity has to be shielded from magnetic fields present during cool down below the critical temperature, to avoid freezing in the magnetic flux at localized impurities, thereby degrading the cavity intrinsic quality factor, Q0. The magnetic shielding designed for the Fermilab vertical cavity test facility (VCTF), a facility for CW RF vertical testing of bare ILC 1.3 GHz 9-cell SRF cavities, was recently completed. For the magnetic shielding design, we used two cylindrical layers: a room temperature "outer" shield of Amumetal® (80% Ni alloy), and a 2K "inner" shield of Cryoperm 10®. The magnetic and mechanical design of the magnetic shielding, and measurement of the remanent magnetic field inside the shielding are described.

3LPB05

The Variable Input Coupler for the Fermilab Vertical Cavity Test Facility

M.Champion, C.M.Ginsburg, A.Lunin, Fermilab; W.-D.Moeller, DESY; R.Nehring, V.Poloubotko, Fermilab

A variable input coupler has been designed for the Fermilab vertical cavity test facility (VCTF), a facility for CW RF vertical testing of bare ILC 1.3 GHz 9-cell SRF cavities at 2K, to provide some flexibility in the test stand RF measurements. The variable coupler allows the cavity to be critically coupled for all RF tests, including all TM010 passband modes, which will simplify or make possible the measurement of those modes with very low end-cell fields, e.g., pi/9 mode. The variable coupler assembly mounts to the standard input coupler port on the cavity, and uses a cryogenic motor submerged in superfluid helium to control the antenna position. The RF and mechanical design and RF test results are described.

3LPB06

High-Gradient Superconducting RF Cavity R&D at Fermilab/Argonne

T.Arkan, M.Champion, C.M.Ginsburg, A.Lunin, A.Mukherjee, R.Nehring, D.Olis, J.Ozelis, V.Poloubotko, A.Rowe, D.A.Sergatskov, Fermilab; M.P.Kelly, Argonne National Lab

We describe a new cavity processing and test complex for 1.3 GHz 9-cell superconducting RF cavities which has recently been built and commissioned at Fermi National Accelerator Laboratory and Argonne National Laboratory. The goal of the complex is to prepare and test bare cavities for eventual installation in the International Linear Collider or another linear accelerator. An electropolishing setup and a vertical RF test stand are operational; the high-pressure ultrapure water rinsing and ultrasonic rinsing capability are under development. We discuss the current status of these cavity processing and test facilities and the related cavity R&D accomplishments and plans.

3LPB07

Multiplexed Diode Array for Temperature Mapping of ILC 9-Cell Cavities

N.Dhanaraj, C.M.Ginsburg, A.Mukherjee, D.A.Sergatskov, Fermilab

The mapping of cavity temperature during tests of superconducting radio-frequency (SRF) cavities is a powerful diagnostic for locating defects. We show the design and preliminary results from a system which uses low-cost diodes as the sensors. The diodes are mounted on industry standard Kapton® flex circuit boards. The use of diodes allows multiplexing to reduce the cable needs, while the flex boards eliminate the need for explicit springs. The system monitors 960 points per cell on a roughly 1cm x 1cm grid. All 8640 sensors for a 9-cell cavity can be read out every 100microsec.

3LPB08

Surface synthesis for controlling the high frequency superconducting properties of Niobium for RF cavities

M.J.Pellin, T.Proslier, Argonne National laboratory/MSD; J.F.Zasadzinski, Illinois Institut of technology; J.Moore, J.Norem, Argonne National laboratory/HEP; L.Cooley, Fermi National Accelerator Laboratory; C.Z.Antoine, Commissariat de l`energie atomique, Saclay

Niobium, with its very high HC1, has been used in superconducting RF cavities for accelerator systems for 40 years with continuous improvement. For superconducting RF cavities the Nb surface composition is relevant both because the electric and magnetic fields are confined to the surface within a thickness given by the magnetic penetration depth (~450 Å) and because the Nb is extraordinarily reactive, which invariably develops a complex set of oxides including NbO, NbO2 and Nb2O5. Recently we have demonstrated using point contact tunneling spectroscopy that the magnetism of some of these oxides can provide a significant and complex dissipation mechanism. Here we show that Atomic Layer Deposition (ALD) an industrially widely-used surface synthesis method can be used to precisely fabricate 3 nm Al2O3 surface films stabilizing the underlying Nb metal from oxidation and providing an annealing path to significantly reduce the dissipation present in an air exposed Nb surface. We demonstrate the enhancement with both XPS surface spectroscopy and point contact tunneling measurements.

3LPC - Fusion - non-ITER I 2:00pm - 4:00pm

3LPC01

YBCO coated conductors for fusion magnets

R.Fuger, M.Eisterer, H.W.Weber, Atomic Institute of the Austrian Universities

Coated conductors (cc's) are considered as an alternative for low temperature superconductors in fusion magnets. High magnetic fields are needed to confine the plasma, which can be generated by YBCO coated conductors at relatively high temperatures (50-77 K). The critical current densities of cc's were improved continuously during the last few years and the production was scaled up. The conductors will be exposed to neutron radiation in a fusion magnet, which could potentially improve or degrade their properties. Industrial YBCO coated conductors were characterized by magnetisation and direct transport measurements in magnetic fields of up to 15 Tesla and temperatures between 50 and 85 K. The critical current, its anisotropy and the irreversibility line were determined. The measurements were performed on different samples, which were sequentially irradiated up to a fluence of 2x10^22 m^-2 (two times the ITER specification). The measurements were repeated after each irradiation step to record changes in the superconducting parameters. Depending on the production process of the cc and on the actual operation conditions, an increase or a decrease of the critical current density is observed. The measurements show that the performance of the cc nearly reaches the required specification for ITER conductors at present. Neutron irradiation generally does not degrade their properties in the operating range of fusion magnets.

3LPC02

Mechanical butt joint of laminated HTS cable with metal jacket for remountable HTS magnet

S.Ito, T.Kato, H.Hashizume, Tohoku University

For realization of a commercial fusion reactor, the remountable HTS magnet was proposed to reduce both construction and maintenance costs. The butt joint of laminated BSCCO 2223 cable, where cross-sections of the cable are just jointed mechanically with external joint force, has been investigated as a fundamental study for the concept. Joint resistance in the butt joint decreases when the joint force increases until a certain stress value because contact area at the interface becomes larger. The joint resistance of 500 nano-ohm was achieved with the 10-layered BSCCO 2223 cable. Lower joint resistance is required for the concept, however, degradation of the HTS material, buckling of the cable and deformation of the joint surface rise the joint resistance above the certain stress value. In this study, a laminated BSCCO 2223 cable with metal jacket is used as a test cable to strengthen the cable structure and to prevent the joint surface from being deformed. A relationship between joint resistance, current value, loaded stress value is evaluated where the cable is cooled by immersion chilling in liquid nitrogen. The result showed that the optimum stress giving the minimum joint resistance becomes larger than that in the previous laminated BSCCO 2223 cable. And the joint resistance is influenced by material of the jacket because difference of coefficient of thermal expansion between materials of the BSCCO 2223 tape and the jacket induces deformation of the joint surface.

3LPC03

Characterization of Nb3Al strands subjected to an axial-strain for fusion DEMO reactor

T.Hemmi, N.Koizumi, Y.Nunoya, Y.Okui, K.Matsui, Y.Takahashi, K.Okuno, N.Banno, JAEA; A.Kikuchi, Y.Iijima, T.Takeuchi, NIMS

Nb3Al cable-in-conduit (CIC) conductors have been developed as one of candidates for the fusion DEMO reactor. The performances of superconducting strands in the CIC conductor are affected by transverse electromagnetic force and thermal strain at reaction heat treatment. In order to accurately design the conductors for the fusion DEMO reactor, the performance evaluation of the Nb3Al strands, which is processed by a rapid heating, quenching and transformation (RHQT) method, was performed under various temperature, magnetic field and axial-strain conditions. The measured and parameterized results of the Nb3Al strands are presented.

A part of this study was financially supported by the Budget for Nuclear Research of the Ministry of Education, Culture, Sports, Science and Technology, based on the screening and counseling by the Atomic Energy Commission.

3LPC04

Application of the ENEA Joint Concept to NbTi CIC Conductors

A.Di Zenobio, U.Besi Vetrella, V.Corato, A.della Corte, G.Giorgi, F.Maierna, G.Messina, L.Muzzi, S.Turtù, ENEA

In superconducting coils for fusion applications, the cable-in-conduit (CIC) conductor is the most adopted solution. ENEA reported last year about its newly developed compact joint, successfully tested for Nb3Sn conductor in the configuration suitable for the EFDA Dipole, which is currently in construction phase. The main advantages of this new concept are the low room occupancy, the low price and the easiness of manufacturing process. In the present paper, new results coming from the characterization of NbTi joint samples are presented, suggesting new applications for this innovative junction. An optimization study by means of simulation codes is included as well.

3LPC05

ENFASI: Conceptual Design of a 15 T Large Bore Superconducting Test Facility

A.della Corte, A.Di Zenobio, L.Muzzi, G.Pasotti, G.M.Polli, L.Reccia, S.Turtù, ENEA C.R. Frascati

The fast development of the High Temperature Superconductors (HTS) is driving the interest of the international community toward the realization of coils based on these new materials. The present work illustrates the conceptual design of a new test facility, ENFASI (Enea FAcility for Superconducting Inserts), which has been mainly conceived to test wound conductor samples of long length for future tokamaks, as DEMO and ITER. It consists of a background 15T Nb3Sn solenoid, with a warm bore of 90cm diameter, divided into three concentric sections corresponding to high field (15T), medium field (13T) and low field (8T), and globally composed of 983 turns. The three different conductors, one for each section, operate at 20kA and are constituted both of superconducting strands, with different Cu/nonCu ratios, and segregated copper. The facility permits to feed the sample with a current up to 70 kA and to perform AC losses characterization in the 0.2-2Hz range. The main results of electro-magnetic, structural and thermo-hydraulic analyses which brought to the detailed design definition, are presented here.

3LPC06

Status of the EDIPO Project

A.Portone, W.Baker, Fusion For Energy; E.Salpietro, EFDA; P.Testoni, RFX; A.Vostner, Fusion For Energy; P.Bruzzone, CRPP; E.Theisen, A.della Corte, BNG; A.Baldini, LUVATA

The aim of this paper is to present an up to date review the current status of the superconducting dipole magnet EDIPO, scheduled to be operational in CRPP (Switzerland) in late 2009. This saddle-shaped magnet is being built in Europe by a close collaboration among EURATOM, European Associations (CRPP, ENEA) and European Industries (BNG, LUVATA). Detailed analysis (3D electromagnetic, stress-analysis, thermo-hydraulic, etc.) of the coil confirms the soundness of the design chosen for its projected performances (12.5 T in a bore of 100 mm x 150 mm over a length of ~ 1.5 m). The conductors and inter-layer joints have been qualified. The winding line has been set up at BNG and the first dummy double layers are being produced. Impregnation trials and shear tests have been made (and numerically simulated) at room as well as at operating temperature. The installation work at CRPP proceeds with the procurement of the main components (cryostat, transformer, etc.) and the detailed design of the main interface installations (support platform, cryo-lines etc.).

3LPC07

Proposal of Large-Current Capacity HTS Conductors for the LHD-Type Fusion Energy Reactor

N.Yanagi, National Institute for Fusion Science; G.Bansal, The Graduate University for Advanced Studies; K.Takahata, T.Mito, A.Sagara, National Institute for Fusion Science; M.Iwakuma, Kyushu University

Based on the successful progress of fusion relevant plasma experiments in the Large Helical Device (LHD), the conceptual design studies on the heliotron-type fusion energy reactor (FFHR) are being conducted. Though further optimization of the configuration is being examined, the basic specifications give a major radius of 14-18 m with a stored magnetic energy of 120-150 GJ. A pair of continuous helical coils are wound with a toroidal pitch number 10. By choosing a lower pitch parameter of the helical windings than that of LHD, larger spaces between the blankets and plasma are secured while the electromagnetic force on the helical coils is reduced. For FFHR, a 100 kA-class advanced superconductor is required used at the maximum magnetic field of 13 T. As the third candidate for the conductor selection, high-temperature superconductors (HTS) are considered to be feasible with indirect cooling scheme operated at 20-25 K. Our proposal is to employ RE123-based coated-conductors by simply stacking a number of tapes. Good mechanical properties are expected both with a stainless-steel jacket and fully packed tapes at the conductor center with a bending strain limited at 0.05% level. The error magnetic field generated by shielding currents is in the acceptable level for the plasma confinement. Segmentation of the coils with joints is also feasible for easing the construction.

3LPD - Fusion - non-ITER II 2:00pm - 4:00pm

3LPD01

Deign and Thermohydraulic Stability Analysis of PUMA Upgrade for the Developement of a Test Facility of Superconducting CICCs

D.K.Oh, H.J.Lee, K.Kim, NFRI

As a part of the activity to build a test facility for superconducting CICCs(Cable In Conduit Conductors), engineering designs to upgrade the existing KSTAR CS(Central Solenoid) model coils, which are called PUMA main coils, were carried out to implement the superconducting magnet system capable of pulse operation up to 12 T by insertion of 4 T field enhancing solenoid into PUMA main coils. As well as designing the upgrade of magnet system including the specification of the CICC for the upgrade coils, their winding scheme and optimal position of joints, we investigated thermohydraulic stability of the superconducting magnet employing developed numerical codes for the verification of safe operation especially in the pulse mode, cross-checking the result with the GANDALF code.

3LPD02

Quench Detection Based on Voltage Measurement for the KSTAR Superconducting Coils

Y.Chu, H.J.Choi, H.Yonekawa, Y.O.Kim, E.N.Baang, K.R.Park, Y.K.Oh, National Fusion Research Institute

To protect the Korea superconducting tokamak advanced research (KSTAR) superconducting coils against a quench, the quench detection system based on voltage measurement was fabricated. It uses a detect/dump scheme which detects the presence of non-recovering normal zones and to activate a dump circuit that transfers most of the stored energy into a dump resistor. Even though it is desirable to discharge the coil energy as fast as possible after quench detection, a time delay between the time of quench detection and the time of a complete dump circuit actuation will be necessary in order that the quench voltage is to be distinguished from various noises. The quench threshold voltage and the delay time should be set before operation for quench voltage detection so that the maximum hot-spot temperature could be limited to 150 K. The criterion for the quench voltage detection was studied by the thermo-hydraulic quench analysis. This paper will also describe the hardware techniques to lesson the malfunction of the quench detection due to various noises and to increase the fail-safe operation. Finally, we briefly describe how the quench interlock will interface with the quench protection circuit and the KSTAR supervisory interlock system.

3LPD03

Commissioning of the KSTAR Superconducting Coils for the First Plasma operation

K.R.Park, Y.Chu, K.O.Kim, E.N.Baang, H.Yonekawa, H.J.Lee, Y.K.Oh, J.S.Bak, National Fusion Research Institute

To achieve the first plasma of the Korea superconducting tokamak advanced research (KSTAR), the KSTAR superconducting coils were tested in advance. As they should be operated in excessively low temperature of 4.5 K and high magnetic field environment of 7.5 T, it is crucial to monitor the cryogenic and the structural behaviors of KSTAR device during the commissioning period including a cool-down. The temperatures of the KSTAR toroidal field (TF) coil and the poloidal field (PF) coils were measured during the current operation and compared with the calculated values. The mechanical stresses on the TF and PF structures were continuously monitored to check if they go beyond the limiting value calculated through the simulation. The alignment of the KSTAR device was checked by using displacement sensors. The TF coils were supplied 15 kA DC current for 8 hours, and the maximum 5 kA/s flux swings of the PF coils were tested. For the main experiment, the end to end operation of the quench detection for the KSTAR coils was carried out at reduced currents of 1 kA. From these results, the quench protection circuit, and the current-flow of the KSTAR superconducting coils proved to be well performed for the first plasma operation.

3LPD04

Hydraulics of KSTAR Central Solenoid Model Coil 2nd Campaign

S.H.Park, W.S.Han, K.M.Moon, W.W.Park, J.S.Kim, H.Yonekawa, Y.Chu, H.J.Lee, K.W.Cho, K.R.Park, W.C.Kim, Y.S.Kim, Y.K.Oh, J.S.Bak, NFRI

KSTAR (Korea Superconducting Tokamak Advanced Research) superconducting magnet consists of a CICC (Cable-In-Conduit Conductor) and is cooled down less than 5 K using supercritical helium. The length of CICC is 610 m for TF coil and maximum about 2,500 m for PF coil respectively, especially the cooling channel is about maximum 300 m in PF coil because of continuous winding scheme. The pressure drop between CICC terminals has a close relationship with not only CICC performance but also helium refrigerator's performance and efficiency. The friction factor which is a representative parameter can be obtained under real operation condition with cryogenic coolant. We attempt to find out the friction factor of KSTAR CS and PF CICC according to the test result of KSTAR CSMC 2nd campaign and compare the results with previous tests. We can observe the KSTAR CICC's unique hydraulic behavior during cool down and current charging period. Also, we expect that measured data will help to predict the pressure drop in KSTAR real operation and be a reference for thermo-hydraulic simulation.

This work is supported by the Korean Ministry of Science and Technology under the KSTAR project contract.

3LPD05

KSTAR Magnetic Field Measurement during the Commissioning and Remanent Field Evaluation

H.Yonekawa, Y.O.Kim, H.J.Lee, S.W.Yoon, S.H.Hahn, K.S.Lee, S.H.Park, Y.Chu, E.N.Baan, K.R.Park, Y.K.Oh, J.S.Bak, D.K.Lee, NFRI; J.A.Leuer, GA

The magnetic field generated by the Korea Superconducting Tokamak Advanced Research (KSTAR) superconducting magnets was measured before the initial cool-down in order to investigate the quality of the magnetic field, which is required for the first plasma operation. The Nb3Sn cable-in-conduit conductors (CICCs) with Incoloy-908 jackets are used for the sixteen TF magnets and PF1 ~ PF5 magnets. The NbTi CICCs with SS316LN jackets are used for the PF6 and PF7 magnets. These magnets were charged a current between -100 A and +100 A; then the magnetic field in the vacuum vessel was measured by using Hall sensors and gauss meters. The TF magnets generated a toroidal magnetic field of approximately 100 G around the plasma center at 100 A, which was direct-proportional to the transport current and agreed with the design value. In contrast, the PF magnets generated a vertical magnetic field around the plasma center, which was obviously non-linear to the transport current and had a remanence of 7 G at the maximum. The PF7 magnets, which have SS316LN-jacket CICCs, also generated a hysteretic magnetic field. Therefore the other magnets locating inside the PF7 magnets appeared to function as the magnetic core of the PF7 magnets. It is should be emphasized that the vertical remanent field after the PF chargings were greatly reduced by the TF chargings. Consequently, the cleared vertical remanent field seemed to be generated by the magnetized Incoloy-908 jackets of the TF magnets.

3LPD06

Commissioning results of the KSTAR cryogenic system

Y.S.Kim, D.S.Park, H.S.Chang, Y.J.Lee, K.W.Cho, Y.M.Park, Y.K.Oh, J.S.Bak, National Fusion Research Institute

The cryogenic system for the KSTAR superconducting magnet is under commissioning. It consists of cold box, distribution box(DB) and cryogenic transfer lines. The cold box and DB#1 provides 600 g/s supercritical helium to cool the superconducting(SC) magnet, their SC bus-lines, and the magnet support structures, and provide 17.4 g/s liquid helium to the current leads, and also supplies a cold helium flow to thermal shields. The cooling power of the cold box at 4.5 K equivalent is 9 kW which is extracted by 6 turbo-expanders. The DB#1 include 49 cryogenic valves, 2 supercritical helium circulators, 1 cold compressor, and 7 heat exchangers immersed in a 6 m3 liquid helium storage. The main duties of the DB#2 are the relative distribution of the cryogenic helium among the cooling channel of each KSTAR cold component and the emergency release of over-pressurized helium during abnormal events such as quench of SC magnets. After individual commissioning, the system will be integrated and cooled down with KSTAR device. In this paper, the construction and commissioning results of the KSTAR cryogenic system will be introduced. In addition, we will present the cool-down results of the KSTAR device.

3LPD07

Status of the KSTAR Helium Distribution System

Y.J.Lee, Y.M.Park, Y.S.Kim, H.S.Jang, S.W.Kwag, Y.B.Jang, H.T.Park, I.S.Woo, N.H.Song, E.N.Bang, S.Baek, M.K.Kim, W.C.Kim, Y.K.Oh, J.S.Bak, National Fusion Research Institute

KSTAR cryogenic components for the superconducting magnet operation are connected to helium refrigeration system(HRS)through helium distribution system(SHDS), the final helium distributing station. There are mounted 28 cryogenic valves including 4 quench valves, lots of sensors such kinds of temperature sensor, pressure transmitter, and mass flowmeter. It should have to control the 4.5 K supercritical helium(600 g/s) for 30 superconducting coils and their bus-lines, 55 K helium(280 g/s) pressurized to 18 bars for the thermal shields and the gravity supports, and maximum 17.5 g/s liquid helium for the 18 current leads, provided from HRS with the cooling power 9 kW at 4.5 K. It consist of helium distribution box(DB), 5 helium transfer lines, helium control system(HCS), and so on. The helium control system connected to the KSTAR supervisory control & interlock system. Detailed status regarding the construction, commissioning, and I&C are included in this paper.

3LPD08

Commissioning of the KSTAR Current Feeder System

Y.M.Park, Y.J.Lee, I.S.Woo, S.W.Kwag, Y.B.Chang, N.H.Song, C.S.Kim, K.S.Lee, H.T.Park, Y.S.Kim, J.S.Bak, National Fusion Research Institute

The function of current feeder system (CFS) is for passing a large current from the power supply to the KSTAR superconducting (SC) magnets. The bus-line conductor is circular shaped cable-in-conduit conductor (CICC), which consists of 4.5 mm thick stainless steel 316L seamless pipe containing 324 strands of chrome coated NbTi superconductor and 243 strands of OFHC. At the end of CICC, it is assembled by specially designed lap joint. The joining resistance is controlled to keep less than 2.5 nano-ohm concerning Joule heat and AC loss. The outer surface of the CICC jacket is electrically insulated up to 15 kV, using Kapton film and prepreged E-glass tape and helically wrapped conducting fiber to measure the voltage of busline quench. Two pairs of prototype brass leads for PF and TF coils have been fabricated and tested up to the currents of 26 kA for PF leads and 35 kA for TF leads. Test results satisfied all the requirements so that all the 18 leads were manufactured and assembled on site. This paper will describe detailed manufacturing progress and commissioning results of KSTAR CFS.

3LPE - Superconducting Magnetic Energy Storage – III
2:00pm - 4:00pm

3LPE01

System coordination of 2 GJ class YBCO SMES for power system control

K.Shikimachi, N.Hirano, S.Nagaya, Chubu Electric Power Co., Inc.; T.Kawashima, Mitsubishi Heavy Industries, Ltd.; K.Higashikawa, T.Nakamura, Kyoto University

We study an SMES system using YBCO coated conductor for power system control such as load fluctuation compensation. IBAD/ CVD-YBCO coated conductor is expected to be applied to SMES, since it has not only much higher transport properties at high temperatures in high magnetic fields but also has much higher mechanical properties than conventional metallic superconductors and other HTS conductors. A YBCO coil applied in a higher magnetic field can be compact, and a YBCO coil applied at a higher temperature than that of boiling helium has high thermal stability and can be operated in high cooling efficiency. These lead to lower cost and higher reliability, which are required for the SMES system. The target model capacity of the SMES system for load fluctuation compensation is 100 MVA output and input for 18 seconds. The stored energy of the YBCO coils required for the SMES system is 2.4 GJ. YBCO coils of a toroid type, converters of a multi-cell type, cryo-coolers of 20 K class, and so on have been coordinated into the SMES system of 100 MVA-2.4 GJ.

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO), under the Research and Development of Superconducting Magnetic Energy Storage System sponsored by Agency of Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI).

3LPE02

Superconducting power integration (SPT) of SMES for medium voltage power grid application

C.Zhao, L.Xiao, L.Lin, Institute of Electrical Engineering, Chinese Academy of Sciences

In this paper, Superconducting power integration (SPT) is proposed to design a 1MJ/1MW /10kV SMES for medium voltage power grid application. SPT consists of three techniques, and they are superconducting magnetic integration technique, cascaded DC-DC converter integration technique to design the converter to change the DC current form of energy from the coil to DC voltage, and cascaded DC-AC inverter integration technique to design the medium voltage converter to connect with the power grid. The concept is primarily validated by the experiment on the model SMES prototype.

3LPE03

Multi-terminal Fault Current Limiting SMES for Substation Applications

C.Zhao, L.Xiao, L.Lin, Institute of Electrical Engineering, Chinese Academy of Sciences

In this paper, a new concept of Multi-terminal fault current limiting SMES (Superconducting Magnetic Energy Storage) for substation applications is proposed. The principle of fault current limiting SMES is analyzed first, then the configuration and operation mechanism of Multi-terminal fault current limiting SMES (M-FCL-SMES) are presented. M-FCL-SMES not only can do real-time compensation to provide high-quality power for all the substation customers, but also can limit the fault current very quickly to protect the whole substation. Its effectiveness is verified by the numerical simulation and experiment.

3LPE04

Design and analysis of robust SMES controller for stability enhancement of interconnected power system taking coil size into consideration

S.Dechanupaprittha, N.Sakamoto, Kyushu Institute of Technology; K.Hongesombut, Tokyo Electric Power Company; M.Watanabe, Y.Mitani, Kyushu Institute of Technology; I.Ngamroo, King Mongkut`s Institute of Technology Ladkrabang

Recent increase in wide area disturbances and complexity in operating power systems have led to the need for stability enhancement of interconnected power systems. Today's technology has encouraged the utilization and application of superconducting magnetic energy storage (SMES) in power system. With proper control, SMES can be regarded as a promising solution for leveling load demands and alleviating power system oscillations. Also, power system stability can be effectively enhanced. However, different controller parameters and SMES coil sizes can significantly yield different damping performance. In this paper, the design of robust SMES controller for stability enhancement of interconnected power system is presented. Different SMES coil sizes are analyzed and investigated. The controller structure is based on lead/lag compensators. A multiplicative uncertainty is considered to cope with system uncertainties. The controller design problem is formulated as an optimization problem, and parameters of robust controller are optimized by the hybrid tabusearch/evolutionary programming. Finally, robust SMES controllers with different coil sizes are designed based on the proposed design method and are examined under various situations via simulation studies to exhibit their performance and robustness.

3LPE06

Optimal Design of a 10kJ class SMES model coil which will demonstrate the grid interaction performance with RTDS

A.R.Kim, J.H.Kim, M.Park, I.K.Yu, Changwon National University; H.J.Kim, S.H.Kim, K.C.Seong, KERI

Before the installation of SMES into utility, the system analysis has to be carried out with a certain simulation tool. Using the Real-Time Digital Simulator (RTDS), authors demonstrated the electrical properties of miniaturized SMES model coil are same with those of real size SMES coil. Based on these results, authors will manufacture the real 10kJ SMES model coil and which will demonstrate the grid interaction performance with RTDS. SMES system has different characteristics such as operating current and operating temperature in accordance with the sort of the wires and cooling method. Therefore, if a certain value; 10kJ in this paper, of SMES coil has to be fabricated, the SMES coil has also to be designed optimally under given conditions according to characteristic of wire and cooling method. In order to optimize the size and the energy storage capacity of 10kJ class SMES model coil, authors have considered both the conduction cooling and liquid neon cooling, and most kinds of wire were under discussion for instances, Bi-2223, YBCO and also MgB2 which is paying attention recently. After the analysis results, authors have selected the most suitable case which met the conditions of desired size and energy storage capacity. The results will be discussed in this paper.

This work was supported by grant No. RTI04-01-03 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy (MOCIE).

3LPE07

A Study on the Operating Characteristics of SMES for Distributed Power Generation System

H.Y.Jung, Changwon National University; I.K.Park, RTDS Technologies Inc.; M.Park, I.K.Yu, Changwon National University

Distributed power generation systems are expected as important electric power supply systems for the next generation. Wind power generation and photovoltaic power generation systems are widely being introduced in the world. Wind and Photovoltaic power generation systems have some merits and demerits as well. Wind turbine generator output fluctuates due to wind speed variations and Photovoltaic power generation output is changed by sudden cloudy weather conditions. Hence, if a large number of wind turbine and Photovoltaic power generators are connected to power system, their output can cause a serious influence on the power system operation, that is, frequency and voltage fluctuations. In order to solve these problems, the control of generator output fluctuations is very important. With these points as background, Superconducting Magnet Energy Storage (SMES) is probably a key technology to overcome these fluctuations. There are several reasons for using SMES instead of other energy storage methods. The most important advantages of SMES is that charging or discharging time is quite short. Power is available instantaneously and very high power output can be provided for a brief period of time. Therefore, SMES can compensate even small disturbances without affecting power conditions. Generally, the larger the capacity of SMES is, the better the smoothing ability will be. However, the applications of larger size of SMES is hard to implement due to its cost. In this paper, an evaluation method for the determination of the SMES capacity is presented and the PSCAD/EMTDC based simulation results are discussed in detail.

This work was supported by grant No. RTI04-01-03 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy (MOCIE), and this research is also financially supported by Changwon National University in 2008.

3LPE08

ENHANCEMENT OF POWER SYSTEMS RELIABILITY USING SUPERCONDUCTING DEVICES

S.I.Kopylov, N.N.Balashov, S.S.Ivanov, A.S.Veselovsky, Joint Institute for High Temperatures, Russsian Academy of Sciences; V.S.Vysotsky, Cable Insitiute, Moscow, Russia; V.D.Zhemerikin, Joint Institute for High Temperatures, Russsian Academy of Sciences

An opportunity of using superconductors as active elements of electric power systems designed to control the electric power distribution, to enhance the systems operating modes and to limit fault currents, was very attractive to investigators for a long time. In this paper, is considered an opportunity to enhance the electric power systems operating mode and their reliability with the aid of superconducting magnetic energy storage systems (SMES) and superconducting fault current limiters (SFCL) operating together. It has been shown that the joint operation of both these superconducting devices allows additional varying of their parameters, what in turn gives a further opportunity to reduce their mass and dimension and consequently the costs. There had been also shown an additional advantage of the SMES and SFCL joint operation consisting in that they can ensure a more effective protection for a power system generator preventing its uncontrolled load-off and subsequent acceleration up to the unaccessible rotation speed.

This work was supported by the RFBR

3LPE09

Research of SMES for Improving the Power System Transient Stability

X.H.Huang, Y.Ye, Z.F.Zhang, C.H.Zhao, L.Y.Xiao, Key Laboratory of Applied Superconductivity,Institute of Electrical Engineering,Chinese Academy of Sciences

This paper presents simulation and experimental results of a model power transmission system by using a superconducting magnetic energy storage (SMES) to improve the transient stability of electric power system. The fuzzy logic control strategy is suggested. The fuzzy rule-bases are designed and explained. SMIB system simulation and 100kJ/20kW SMES laboratory experiments are carried out. From the results of simulation and experiments they were demonstrated that stabilizing effect by mean of SMES was very significant.

This project is supported by the Key Project of National Natural Science Foundation of China (No. 50225723).

3LPE10

On-line Evaluation of a Electric Power System by Use of SMES - Experimental Study on Power System Simulator with Rotating Generator Models-

H.Ishikawa, Y.Morita, Y.Shirai, Kyoto University; T.Nitta, J.Baba, T.Yonezu, University of Tokyo; K.Shibata, K.Takenaka, Kansai Electric Power Company Inc.

A new application of SMES (Superconducting Magnetic Energy Storage) for on-line grasping of power system stability is proposed. Experiment was carried out on a power system simulator with actual rotating generator models, which is a property of Central Research Institute of Electric Power Industry, Japan. SMES system was designed and developed. Small power deviation of known pattern was generated by SMES and by means of system identification, eigenvalue of the power system was computed. It was successful in evaluating the stability by eigenvalue measured with the proposed method.

3LPF - Power Transmission Cables – V 2:00pm - 4:00pm

3LPF01
Invited
Qualification High Voltage Testing of Short Triaxial HTS Cables in the Laboratory
D.R.James, I.Sauers, A.R.Ellis, E.Tuncer, M.J.Gouge, J.A.Demko, R.C.Duckworth, C.M.Rey, ORNL
In order to qualify the electrical insulation design of future HTS cables installed in the electric grid, a number of high voltage qualification tests are generally performed in the laboratory on either single-phase model cables and/or actual three-phase cable samples. Prior to installation of the 200-m triaxial HTS cable at the American Electric Power Bixby substation near Columbus, Ohio, in September, 2006, such tests were conducted on both single-phase model cables made at ORNL and tri-axial cable sections cut off from cable made on a production run. The three-phase tri-axial design provides some specific testing challenges since the ground shield and three phases are concentric about a central former with each phase separated by dielectric tape insulation immersed in liquid nitrogen. The samples were successfully tested and qualified for partial discharge inception, ac withstand, and lightning impulse where voltage is applied to one phase with the other phases grounded. In addition one of the phase pairs was tested for dc withstand as a "worst case" scenario to simulate the effect of VLF (Very Low Frequency) tests on the actual cable installed on site. The model and prototype cables will be described and the high voltage test results summarized.
Research sponsored by the U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, Superconductivity Program for Electric Power Systems under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, managed and operated by UT-Battelle, LLC.

3LPF02
Development of HoBCO Superconducting Cable
M.Ohya, Y.Ashibe, M.Watanabe, T.Masuda, T.Kato, Sumitomo Electric Industries, Ltd.
High temperature superconducting (HTS) cables achieve large power capacity and low-loss power transmission in a compact size, and have economical and environmental advantages such as energy saving, resource conservation, carbon-dioxide reducing and electromagnetic interference (EMI)-free performance. There are two types of HTS wires, which are Bi2223 superconducting wires and RE123 (RE = rare earth element) coated conductors. At present, Bi2223 wires have reached the mass production stage, but RE123 coated conductors are at the stage of development. However, RE123 coated conductors have advantages such as higher critical current density and lower AC loss under parallel magnetic field compared with Bi2223, Sumitomo Electric has been developing Ho123 coated conductors, and a 10-meter "3-in-One" HTS model cable using the Ho123 coated conductors was manufactured to evaluate the characteristic of the Ho123 coated conductors as superconducting cable wires. This paper describes the manufacturing results and the over-current characteristics of the Ho123 superconducting cable.
A part of this work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as the Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

3LPF03
The Study of Mechanical Properties of HTS Tapes for Power Cables Use
V.E.Sytnikov, V.S.Vysotsky, I.P.Radchenko, Russian Scientific R&D Cable Institute
Power cables are considered as the most advanced HTS applications. During cables' production some numbers of HTS tapes are twisted around a circular former, sometimes in several layers. The twisting brings to mechanical stresses for the tapes that may affect their superconducting properties. In his work we model experimentally the influence of twisting on superconducting properties of HTS tapes. The HTS tapes were wound with different twist pitch around a former with the certain diameter and critical currents of tapes have been measured when twist pitch have been changing. We found the minimal twist pitch when the critical currents start decay after twisting. Several types of HTS tapes we tested to compare their certified parameters with the measured ones. The details of the experimental method used are discussed and data about mechanical properties of different HTS tapes are presented. Recommendations are formulated that could be useful for HTS power cables designers.

3LPF04
Techno-economic feasibility study on HTS power cables
L.Ren, Y.Tang, J.Li, J.Shi, S.Cheng, Huazhong University of Science and Technology
Superconducting power cables operated at 77 K temperature could carry a lot more current through the same old underground city pipes and could satisfy the requirements for use in electrical networks. As this new technology still lacks practical operating experience, power network planners are eager to come to know its technical and economic feasibility. Under the pressure of reducing the cost of electric power transmission, it is crucial to demonstrate their profitability over conventional cables besides their technical feasibility. In this paper, a network planning with HTS superconducting cables are expected to offer an economic alternative to 220kV level conventional cables. The study shows that the use of superconducting cables in an underground transmission circuit is promising from the technical and economic point of view.
This work was support by 863 program of China under Contract No. 2006AA03Z209 and No.2007AA03Z243.

3LPF05
Recent Progress of Experiment in DC Superconducting Power Transmission Line in Chubu University
M.Hamabe, I.Yamamoto, T.Famakinwa, A.Sasaki, Y.Nasu, S.Yamaguchi, A.Ninomiya, T.Hoshino, Y.Ishiguro, K.Kawamura, Chubu University
An experiment of a DC superconducting power transmission line was started in Chubu University, Japan in autumn 2006. Thirty-nine tapes of Bi-2223 HTS conductor were employed in a superconducting power cable of the experimental system, and arranged in two layers of nineteen and twenty tapes. One feature of the experimental system is the employment of Peltier current leads for the reduction of the heat leak through current leads. The first cooling experiment was successfully carried out from October to December, 2006. After some modification, we performed the second cooling experiment from June to August, 2007. During the second cooling operation, a cryogenic circular system for liquid nitrogen was continuously operated to carried out the experiment with
This work was partly supported by the University-Industry Joint Research Project of MEXT, Japan, 2005-2009.

3LPF06

Long Term Performance Test of KEPCO HTS Power Cable

H.S.Yang, D.L.Kim, Korea Basic Science Institute; S.H.Sohn, J.H.Lim, Korea Electric Power Research Institute; H.O.Choi, Y.S.Choi, B.S.Lee, W.M.Jung, Korea Basic Science Institute; H.S.Ryoo, Korea Electrotechnology Research Institute; S.D.Hwang, Korea Electric Power Research Institute

A project for verification of HTS power cable system by KEPCO (Korea Electric Power Corporation) was started in 2002. As the first step, the HTS power cable system of 100m, 22.9kV, 1.25kA manufactured by Sumitomo Electric Industries has been installed and tested at the KEPCO's Gochang power testing center in Korea since 2006. A liquid nitrogen decompression cooling system with a cooling capacity of 3kW at 66K and a closed-circulation system of subcooled liquid nitrogen were employed for this purpose. Several performance tests of the HTS power cable system, such as cooling capacity, electrical loading, heat load, AC loss and temperature stability, were performed at operating temperature of 66.4K. Thermal cycle test cooling down to liquid nitrogen temperature and warming up to room temperature, was also performed to investigate thermal cycle influences for several times.

This work was partially supported by the Electric Power Industry Technology Evaluation and Planning (ETEP), an agency of the Korean government Ministry of Commerce Industry and Energy (MOCIE).

3LPF07

HTS power cable model component development for RTDS/RSCAD considering conducting layer and shield layer

K.Jin-Geun, K.Jea-Ho, P.Minwon, Y.In-Keun, Changwon National University

Before applying the HTS power cable to the real utility, the system analysis should be carried out by simulation analysis tools. Among power system analysis tools, RSCAD/RTDS can only simulate on real time. And also, even the impedance of superconductor is changed by the value of current, temperature and magnetic field, RSCAD/RTDS does not provide the superconductor component which has the characteristic explained above. Authors have developed the HTS power cable component in EMTDC program which are included same electric characteristic of real HTS power cable previously. Based on this research authors have developed the HTS power cable component model operated in RTDS/RSCAD. In case of HTS power cable, there are both conducting layer and shield layer. The development model in RTDS/RSCAD also includes the transient characteristics of both conducting layer and shield layer. In this paper, the results of analysis will be discussed in detail.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by Ministry of Science and Technology, Republic of Korea.

3LPF08

The Manufacture and insulating test of mini model for 154 kV-Class HTS Cable

J.W.Choi, H.G.Cheon, Gyeongsang National Univ. and Eng. Research institute; H.J.Kim, J.W.Cho, Koera Electrotechnology Research Institute; S.H.Kim, Gyeongsang National Univ. and Eng. Research institute

The application of high-temperature superconducting (HTS) power cable system is has been studied because HTS cable has a large current capacity, compact size and low ac losses.it is important that study on cryogenic electrical insulation design to develop the cold dielectric type HTS cable because the cable is operated under the high voltage environment in cryogenic temperature. Therefore, this paper describes a design method for the electrical insulation layer of the cold dielectric type HTS cable adopting the partial discharge-free design under ac stress, based on the experimental results such a partial discharge inception stress and V-t characteristics, and an impulse breakdown strength of liquid nitrogen / laminated polypropylene paper (LPP) composite insulation system in which the mini-model cable is immersed into pressurized liquid nitrogen.

This research was supported by a grant from the Center for Applied Superconductivity Technology of the 21s Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

3LPG - Fault-Current Limiters – IV 2:00pm - 4:00pm

3LPG01

An Experimental Investigation of Magnetic Saturation of a Transformer-Type Superconducting Fault Current Limiter

T.Kataoka, TIT; H.Yamaguchi, AIST

The transformer-type superconducting fault current limiter (SCFCL) consists of a transformer and a superconducting current limiting device. The primary winding of the transformer is connected in series with the power transmission line, and the secondary winding is short-circuited by the superconducting current limiting device. When the short-circuit fault occurs in the transmission line, an excessive current corresponding to the fault current flows through the transformer secondary winding and the current limiting device. As a result, the S-N transition of the device occurs and the fault current is reduced to a limited value. According to our previous investigations, It was shown that magnetic saturation of the transformer iron core could occur just after the S-N transition of the current limiting device, depending on the phase angle of fault occurrence. Since the magnetic saturation deteriorates the current limiting function of the FCL, its detailed investigation is necessary. In this paper, a detailed experimental investigation of the magnetic saturation of the transformer-type SCFCL is carried out using an experimental FCL. It is shown that the primary current shows a high peak due to magnetic saturation just after the S-N transition of the device, and that the value and polarity of this current peak vary with the value of fault phase angle. It is also shown that the current peak due to magnetic saturation is influenced by the resistance included in the short circuit at fault occurrence. These results can be used as a basis for the design of the transformer-type FCL.

3LPG02

Current Limiting Characteristics of Parallel-Connected YBCO Coated Conductors for High-Tc Superconducting Fault Current Limiting Transformer (HTc-SFCLT)

N.Hayakawa, K.Omura, H.Kojima, F.Endo, H.Okubo, Nagoya University; M.Noe, Forshungszentrum Karlsruhe

We have been developing SFCLT (Superconducting Fault Current Limiting Transformer) as a superconducting transformer with current limiting function. In the previous Step-4 of the SFCLT project, HTc-SFCLT with the ratings of 100 kVA, 6600/210 V was designed and fabricated with YBCO coated conductors, and exhibited the ideal self-recovery characteristics into superconducting state after the current limitation and fault clearance. We are now in the Step-5 of the SFCLT project for the up-graded ratings of current and voltage capacity. In this paper, we focused on the larger current capacity by parallel-connected YBCO coated conductors. Based on the asymmetric configuration of coated conductors, different parallel connections were tested, i.e. face-to-face (F-F), face-to-back (F-B) and back-to-back (B-B), where the "face" is the stabilizer-side and the "back" is the substrate-side. Experimental results revealed that the B-B parallel connection was superior to the other connections in terms of the critical current level at 77K in liquid nitrogen and the current limiting characteristics under large ac current. Taking account of the above results, HTc-SFCLT in the Step-5 will be designed, fabricated and tested to verify both functions of superconducting transformer and superconducting fault current limiter.

3LPG03

Superconducting Winding for Inductive Type SFCL Made of HTS Tape With Increased Resistivity

T.Janowski, Lublin University of Technology; B.Kondratowicz-Kucewicz, W.Wojtasiewicz, M.Majka, Electrotechnical Institute in Warsaw - Laboratory of Superconducting Technology in Lublin

Currently produced and available HTS tapes with increased resistivity, like 2nd generation YBCO 344/Fe tape made by American Superconductors, have enough parameters to build inductive type current limiters to limit faults in medium-voltage power grid. The paper describes the assumption for 6,9kV/1.15kA superconducting fault current limiter with superconducting secondary winding made of high resistivity HTS tape as well as the results of numerical analysis. The technical parameters of the winding's construction elements were described too.

LPG04

Subcooled Liquid Nitrogen Cryocooling System for long-term operation of Hybrid Superconducting Fault Current Limiter

J.Sim, LS Industrial Systems Inc.; M.J.Lee, H.M.Chang, Hong Ik University; B.W.Lee, Hanyang University; H.R.Kim, O.B.Hyun, Korea Electric Power Research Institute; I.S.Oh, LS Industrial Systems Inc.

In oder to prepare the field test of 24kV hybrid superconducting fault current limiters (SFCL) developed by LSIS and KEPRI in Korea, compact cryogenic cooling system with 3 bar subcooled liquid nitrogen were designed and tested. This cryogenic system has implemented compact design and structure compared to conventional cryogenic systems due to minimized AC loss of superconductor. Minimized AC loss was accomplished by the introduction of hybrid SFCL which use superconductor for only fault detection, not for current limiting purpose. Electrically insulated current leads were directly connected from the top plate of external vessel to the inner liquid nitrogen within a vessel. In oder to exchange heat generated by liquid nitrogen, copper band was installed on the vessel side wall, and the temperature of liquid nitrogen was continuously maintained at 77K. Long-term experiment results showed that external heat penetrations were effectively removed and we achieved the spacially uniform temperature all over the test periods.

This work was supported by the Center for Applied Superconductivity Technology (CAST) under the 21st Century Frontier R&D Program in Korea.

3LPG05

Hybrid superconducting fault current limiter with non-half cycle fault current limiting function

K.B.Park, LS Industrial Systems Inc.; J.Sim, LS Industrial Systems Inc; K.H.Lee, LS Industrial Systems Inc.; I.S.Oh, LS Industrial Systems Inc; O.B.Hyun, Korea Electric Power Research Institute; B.W.Lee, Hanyang University

Resistive superconducting fault current limiters are assumed to be a prospective solution for commercialization. But in spite of excellent current limiting performances realized by resistive superconducting fault current limiters, the commercialization and the installation of superconducting fault current limiters have been delayed due to the difficulties in overcoming some technical problems especially concerning with coordination with conventional relays. Resistive type superconducting fault current limiters could not have delayed operation time which sometimes substantially needed for coordination with relays, because superconductor might react to excessive fault current instantaneously due to its quench characteristics. In order to solve these problems, novel fault current limiting device which have non-half cycle current limiting function was developed by LS Industrial systems and KEPRI in Korea. This paper dealt with the characteristics of this hybrid superconducting fault current limiter which equipped with non-half cycle current limiting function, and its configuration and test results were also shown. Finally, we`d like to suggest the set-up 24kV/630A 3 phase configuration of hybrid fault current limiters and test results.

This work was supported by the Center for Applied Superconductivity Technology (CAST) under the 21st Century Frontier R&D Program in Korea.

3LPG06

Basic experiments on transformer type SCFCL of rewound structure using BSCCO wire

T.Nii, Y.Shouno, Y.Shirai, Kyoto University

High temperature superconducting (HTS) materials have an advantage of cooled by Liq. N2, however its resistance in normal conducting state is low. So, it has been difficult to apply HTS materials to SCFCLs. Then, we propose a transformer type SCFCL of a new structure, which was expected to reduce this problem. Both primary and secondary coils of the proposed SCFCL are made by rewound coils. The rewound coil means two coils whose wires are wound in the same direction and connected each other. Therefore, the rewound coil can be made in high resistance by using a long wire and its inductance can be also determined independently to some extent by partially canceling the magnetic fluxes of two coils each other. We call this proposed one the transformer type SCFCL of rewound structure. We fabricated the SCFCL of Ag sheathed BSCCO wire and the experiments were carried out to investigate the fundamental characteristics of it. From the experiments, it was confirmed that the SCFCL of rewound structure could be made as the proposal and limit the fault current when the current through the secondary coil (I2) reached to the critical current. However, I2 had to exceed the critical current (Ic) largely in order to obtain sufficient resistance in the secondary coil wire for effective current limit of the primary, that is, the line current. Thus, the trigger current level for the current limiting can not be designed only by Ic of the secondary wire. Additionally, it is expected that the better current limiting effect can be obtained when transformer type SCFCL of rewound structure is made of YBCO wire.

3LPG07

A Comparison of Current Limiting Characteristics in Separated and Integrated Three-Phase Flux-Lock Type SFCL

C.R.Park, Department of Electrical Engineering/Chonbuk National University ; H.I.Du, S.G.Doo, B.S.Han, Department of Electrical Engineering, Chonbuk National University ; H.S.Choi, Y.S.Cho, Department of Electrical Engineering, Chosun university ; Y.H.Han, Korea Electric Power Research Institute

For the application of flux-lock type SFCL into real power systems, there are two types, separated and integrated three-phase flux-lock type SFCL. The separated three-phase flux-lock type SFCL consists of three flux-lock reactors and three iron cores because each phase has a single-phase flux-lock type SFCL. However, the integrated three-phase flux-lock type SFCL consists of three flux-lock reactors and one iron core because the SFCL consists of three-phase flux-lock reactors wound on an iron core with the same turn's ratio between the primary coils and secondary coils for each phase. In this paper, current limiting characteristics of the separated and the integrated three-phase flux-lock type SFCL were investigated in fault types. From the experimental result, current limiting characteristics of the integrated three-phase flux-lock type SFCL went down a bit compared with the separated three-phase flux-lock type SFCL. However, in a view of the weight and the volume of the three-phase SFCL using the iron core, structure of the integrated three-phase flux-lock type SFCL is more simple and economical.

3LPG08

Analysis of Fault Current Limiting Characteristics According to the Fault Current Level in Separated Three-Phase Flux-Lock Type SFCL

S.G.Doo, C.R.Park, H.I.Du, Y.J.Kim, Department of Electrical Engineering/Chonbuk National University; T.H.Sung, Korea Electric Power Research Institute; B.S.Han, Department of Electrical Engineering/Chonbuk National University

We investigated the quench characteristics of the separated three-phase flux-lock type superconducting fault current limiter (SFCL) according to the fault current level. The single-phase flux-lock type SFCL consists of two coils. The primary coil is wound in parallel to the secondary coil on an iron core. The separated three-phase flux-lock type SFCL consists of single-phase flux-lock SFCL in each phase. To analyze the current limiting characteristics of a three-phase flux lock type SFCL, the short circuit experiments were carried out various three-phase faults such as the single line-to-ground fault, the double line-to-ground fault and the triple line-to-ground fault. From the experimental results, the fault current limiting characteristic was improved according to increase of the fault current level.

3LPG09

Analytical and Experimental Studies on the Hybrid Fault Current Limiter Employing Asymmetric Non-Inductive Coil and Fast Switch

D.K.Park, K.S.Chang, S.E.Yang, Y.J.Kim, T.K.Ko, Yonsei University; M.C.Ahn, MIT; Y.S.Yoon, Ansan College of Technology

This paper deals with design and operating test of a novel hybrid fault current limiter (FCL). It consists of a novel HTS coil, a fast switch and a resistor for bypass the fault current. The switch was driven by novel non-inductance coil suggested in this paper while the extra driving coil was required for fast switch in existing hybrid FCL. We used two kinds of HTS wire for the coil. The impedance of the coil was negligible in normal operation. But different properties of HTS wires such as index number and quench resistance caused asymmetric current distribution which induced effective magnetic flux in the coil during the fault. The switch was opened by repulsive force from this magnetic flux in fast response to the fault. Then, all current bypassed through the normal conductive resistor parallel connected to both the coil and the switch. Electromagnetic analysis of the coil based on finite element method was performed. Also, a small-scale asymmetric non-inductive coil was designed and fabricated. Short circuit tests of the hybrid FCL were performed in liquid nitrogen. The proposed hybrid FCL system showed efficient current limiting characteristic and it is expected to be compact and low cost.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

3LPG10

Quench and Recovery Characteristics of SFCLs using Magnetic Coupling of Two Coils

S.H.Lim, J.S.Kim, J.M.Ahn, J.F.Moon, J.C.Kim, Soongsil University; C.H.Kim, Sungkyunkwan University; O.B.Hyun, Korea Electric Power Research Institute

The quench and recovery characteristics of SFCLs using magnetic coupling of two coils were investigated through the fault current limiting experiments. The SFCLs using magnetic coupling of two coils can be divided into the insulated type and the non-insulated type depending on whether two coils are insulated through one iron core or not. For the comparative study for these SFCLs, the operational current and the limiting impedance of SFCL were drawn from each SFCL's electrical equivalent circuit. In addition, together with the resistance variation of high-TC superconducting (HTSC) element comprising each SFCL, the quench and recovery times of each SFCL were compared based on the fault current limiting experiments. It will be shown in final paper that the merit and demerit analysis for the SFCLs using magnetic coupling of two coils from the point of view of both the SFCL's current limiting capacity and the HTSC element's power burden will be shown.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea

3LPG11

Improvement on Current Limiting Characteristics of a Flux-Lock Type SFCL using E-I Core

S.H.Lim, J.C.Kim, Soongsil University

We investigated the current limiting characteristics of a flux-lock type SFCL using E-I core. Unlike the previous flux-lock type SFCL, the parallel connected two coils and high-TC superconducting (HTSC) element were placed on a center leg among three legs of E-I core and an air gap was introduced into either left leg or right leg of the three-legged E-I core. Through analysis for the fault current limiting experiments of the flux-lock type SFCL with this E-I core structure, the leg having air gap in E-I core could be confirmed to be contributed to the suppression of the magnetic saturation of the iron core and the improvement of the current limiting characteristics of the flux-lock type SFCL.

3LPH - Stability and Protection III – Modeling 2:00pm - 4:00pm

3LPH01

Numerical Study of the Quench Protection for Fast-Ramping Accelerator Magnets

N.Schwerg, B.Auchmann, K.H.Mess, S.Russenschuck, CERN

We study quench protection schemes for fast-ramping superconducting magnets using the numerical analysis tools recently implemented in the CERN field computation program ROXIE. The voltage signal of a quench during a fast ramp consists of a small resistive voltage competing with a much larger differential inductive voltage and a very high common mode inductive voltage. The sensitivity of the electronics in detecting the resistive voltage determines the limits of the quench detection. We compare the signal-to-noise-ratio of the electronics to the detection threshold and study the detection delay depending on the ramp-rate. In the worst case a quench cannot be detected during the ramps, and thus the cables must be sufficiently stabilized for the magnet to survive a complete excitation cycle. By means of the quench simulation software we study the objective conflicts between high current density versus high stability, as well as low ramp induced losses versus quench-back (low hot-spot temperature).

3LPH02

Effects of the Nb3Sn Wire Cross Section Configuration on the Thermal Stability Performance

L.Trevisani, M.Breschi, Dept. of Electrical Engineering, University of Bologna, Italy; L.Bottura, CERN, Geneva, Switzerland; A.Devred, ITER IO, Cadarache, France; P.L.Ribani, Dept. of Electrical Engineering, University of Bologna, Italy; F.Trillaud, MIT, Boston, USA

The thermal and electrical conductivities of the normal matrix of LTS wires have a remarkable influence on the actual wire stability performance. The bronze matrix in the region of the superconducting filaments may act as a thermal barrier between the filaments and the copper matrix, affecting its thermal and electrical stabilisation effect. Effects of the transverse conductivities on the quench development in Nb3Sn wires in liquid helium bath have been reported earlier. These phenomena could be reproduced through a detailed numerical model accounting for the thermal and electrical transverse resistances among sub-elements. This paper presents an application of the validated numerical code to the parametric analysis of the effect of electrical and thermal properties of the wire on the quench energy and quench velocity. The analysis is especially focussed at assessing the impact of the transverse thermal and electrical conductivities and of the RRR of the copper matrix. The paper also presents a method for the evaluation of the transverse electrical and thermal conductivities through a 2D analysis of the wire cross section. This method is applied to investigate the impact on thermal stability of the choice of different configurations of the wire cross section, obtained with keeping the same Cu/non-Cu ratio.

3LPH03

Numerical modelling of combined longitudinal and transverse quench propagation in stacks of superconducting wire

M.Alessandrini, G.Majkic, K.Salama, TcSUH-University of Houston

In order to allow superconductors to operate at very high current density, thermal stability is a key issue in quench development and propagation. In this study, heat propagation in stacks of superconducting wires is analyzed taking into account both longitudinal heat transfer along the wire and transverse heat transfer through insulation to adjacent wire segments. The model takes into account the composite nature of the wire and uses a 2D domain and finite elements to simulate quench propagation. One important feature addressed in this model is the current density redistribution that takes place when only a part of the wire cross section is quenched, forcing an increase in current density in the superconducting part of the wire towards and above critical current. Temperature dependencies of the all the main properties and n-values are taken into account. Different scenarios are considered for different superconductor/matrix combinations under their most common operating condition. A comparison is reported and discussed in order to better identify the advantages of each superconductor under different operating conditions.

3LPH05

Analysis of Voltage Spikes in Superconducting Nb3Sn Magnets

S.Rahimzadeh-Kalaleh, Embry-Riddle Aeronautical University; C.D.Donnelly, University of Pennsylvania; M.A.Tartaglia, G.Ambrosio, G.Chlachidze, Fermilab

Fermi National Accelerator Laboratory has been developing a new generation of superconducting accelerator magnets based on Niobium Tin (Nb3Sn). The performance of these magnets is influenced by thermo-magnetic instabilities, known as flux jumps, which can lead to premature system trips due to large voltage transients, or quenches at low current. In an effort to better characterize and understand these instabilities, a system for capturing fast voltage transients was developed and used in recent tests of R&D model magnets. A new automated voltage spike analysis program was recently developed in order to allow qualitative and quantitative analysis of large amounts of voltage-spike data. We report results from the analysis of large statistics data samples for several short and long model magnets that were constructed using both PIT and RRP strands having a range of sub-element size and structure. We then assess the implications for quench protection of long Nb3Sn magnets.

The authors thank Fermilab, especially the Technical Division and the SIST program, for making this research work possible.

3LPH06

Quench Limit Measurements for Steady State Heat Deposits in LHC Magnets

D.Bocian, CERN / IFJ PAN Krakow; B.Dehning, A.Siemko, CERN

A quench, transition of a conductor from the superconducting to the normal conducting state, occurs irreversibly in accelerator magnets if one of the three parameters: temperature, magnetic field or current density, exceeds a critical value. Energy deposited in the superconductor by the particles lost from the beams, provoke quenches detrimental for the accelerator operation. The protons impacting on the vacuum chamber create a secondary particle shower which deposes its energy in the magnet coil. A network model is used to study of the thermodynamic behaviour of the LHC magnets. The results of the heat flow simulation in the magnets with the network model were validated with measurements performed in the CERN magnet test facility. A steady state heat flow was introduced in the coil by using a dedicated internal heating apparatus installed inside cold bore. The heat loads from this heat source needed to initiate quenches as function of the coil current are calculated from the network model and compared to the settings leading to quench occurrence.

3LPH07

Analysis of Quench Behavior in TQS02a, a Nb3Sn Quadrupole Magnet for LARP

J.Lizarazo, Lawrence Berkeley National Laboratory; G.Ambrosio, Fermi National Accelerator Laboratory; B.Bingham, S.Caspi, Lawrence Berkeley National Laboratory; G.Chlachidize, Fermi National Accelerator Laboratory; D.Dietderich, P.Ferracin, A.F.Lietzke, G.L.Sabbi, Lawrence Berkeley National Laboratory; M.Tartaglia, Fermi National Accelerator Laboratory

TQS02a is a 90 mm aperture quadrupole aimed at demonstrating the feasibility of Nb3Sn technology for the LHC luminosity upgrade. Following three tests of the TQS01 magnet, with maximum gradients of 170-197 T/m, TQS02a demonstrated significant improvements in training characteristics using higher performance conductor and coil parts made of Titanium. The maximum gradient achieved was above 220 T/m at both 4.5 K and 1.9 K. In this paper we report on the voltage signals collected during the test, and discuss the quench origins and training limitations based on several measurements and analysis techniques.

Research supported by the U. S. Department of Energy, under Contract No. DE-AC02-05CH11231.

3LPH08

3D Simulative Analysis of Quench Behavior of a Superconducting Solenoid Magnet

N.Peng, L.Y.Xiong, L.Q.Liu, L.Zhang, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences

A 'notched' superconducting solenoid of 170 mm in inner diameter, 223.8 mm in outer diameter and 504 mm in length has been designed, manufactured and tested by a group comprising the members from Technical Institute of Physics and Chemistry (TIPC) and Institute of Modern Physics (IMP) of CAS. The solenoid magnet will be used as a 3T standard magnet. Because the stability is a crucial task in the design of safe and reliable superconducting magnets, a new 3D FEM model was developed to study the quench behavior of this magnet. The minimum quench energy, peak temperature rising, maximum voltage drop, current decay and coil resistance with various protections were analyzed and the feasibility of this novel model is confirmed by experimental data.

The authors thank IMP of CAS for the magnets manufacture and experiment.

3LPH09

Quench study on SIS100 dipole prototypes

E.Floch, A.Stafiniak, F.Marzouki, F.Walter, C.Schroeder, H.Mueller, H.Leibrock, E.Fischer, G.Moritz, GSI

The FAIR project will lead to the construction of two superconducting synchrotrons (SIS100 and SIS300). This article reports on the quench calculations and measurements performed on one SIS100 dipole model (1 m) and one full length prototype (3 m). Quench propagation velocities and time to reach the quench threshold (0.3 and 0.6 V) were measured inside the coil and in the bus bars and compared to computed values. The hotspot temperature was measured for different Miits (integral of I2.dt) values in good agreement with computed temperatures. Furthermore, a new protection scheme using inductive quench heaters was tested.

3LPH10

Temperature margin measurement in Nb3Sn accelerator magnets

R.Bossert, G.Chlachidze, V.V.Kashikhin, M.Lamm, I.Novitski, A.V.Zlobin, Fermilab

Fermilab is developing Nb3Sn accelerator magnet technology for particle accelerators. One of the possible practical applications of the Nb3Sn accelerator magnets is the LHC luminosity upgrade that involves replacing the present NbTi focusing quadrupoles in two high luminosity interaction regions (IR). The IR magnets are exposed to strong radiation from the interaction point that requires a detailed investigation of the magnet temperature margins with respect to the expected radiation induced heat depositions. This paper presents the results of simulation and measurement of quench limits and temperature margins for Nb3Sn model magnets using special strip heaters.

Work supported by the U.S. Department of Energy

3LPH11

Instrumentation and Quench Protection for LARP Nb3Sn magnets

H.Felice, S.Caspi, P.Ferracin, R.Hafalia, A.Lietzke, S.Prestemon, G.L.Sabbi, G.Ambrosio, Lawrence Berkeley National Laboratory; G.Chlachidize, Fermi National Laboratory; J.Muratore, J.Schmalze, Brookhaven National Laboratory; A.McInturff, Texas A&M

The US LHC Accelerator Research Program (LARP) is developing Nb3Sn prototype quadrupoles for the LHC interaction region upgrades. Several magnets have been tested within this program and the understanding of their behavior and performance is a primary goal. The instrumentation is consequently a key consideration, as is protection of the magnet during quenches. In all LARP magnets, the so-called traces combine the instrumentation and the protection heaters. Their fabrication relies on printed circuit technology based on a laminate made of a 40-micron thick kapton sheet and a 25-micron thick deposition of stainless steel. This paper reviews the trace designs used in the TQ (Technological Quadrupole) and LR (Long Racetrack) series. It also presents the design of the traces for the Long Quadrupole (LQ), addressing challenges associated with the stored energy and the length of the magnet. This work was supported by the Director, Office of Science, High Energy Physics, U.S. Department of Energy under contract No. DE-AC02-05CH11231

3LPH12

Aluminium strand coating for increasing the interstrand contact resistance in Rutherford type superconducting cables

C.Scheuerlein, European Organization for Nuclear Research (CERN), 1211 Geneva, Switzerland; A.Bonasia, M.Taborelli, L.Oberli, A.Verweij, G.Willering, CERN; R.Richter, Rasant-Alcotec Beschichtungstechnik GmbH, Overath, Germany

The interstrand contact resistance (RC) in Rutherford type cables for fast cycling superconducting magnets must be sufficiently high in order to limit eddy current losses. The required value for RC depends on the cable and magnet geometries and the foreseen cycling rate, but is typically of the order of 1-10 mOhm. Such values can be reached with a dedicated strand coating or with a resistive internal cable barrier. As a possible candidate Al strand coatings have been tested. For a Rutherford type inner conductor cable of the Large Hadron Collider (LHC) made of Al coated strands RC values higher than 500 µOhm are achieved. The native Al2O3 oxide layer formed at ambient temperature in air is sufficient to reach this high contact resistance. A 6 h-200 °C oxidation heat treatment in air with 100 % relative humidity further increases RC to values above 600 µOhm. Due to the high thermal and mechanical stability of Al2O3 only a relatively moderate RC drop of about 40 % is obtained during a 190 °C heat treatment under 50 MPa pressure (the so-called curing cycle of the coil insulation) subsequent to the 6 h-200 °C oxidation heat treatment.

3LPH13

Void fraction, interstrand contact surface and free strand surface in a Rutherford cable determined by neutron tomography and optical microscopy

G.Frei, S.Hartmann, G.Kuehne, Neutron Imaging and Activation Group, Paul Scherrer Institut (PSI), 5232 Villigen, Switzerland; C.Scheuerlein, G.Willering, European Organization for Nuclear Research (CERN), 1211 Geneva, Switzerland

The thermal-electromagnetic stability of a superconducting cable against local heat depositions is of great importance for the reliable operation of superconducting high field accelerator magnets, as those used for the Large Hadron Collider (LHC) at CERN. Simulations of the cable stability require as an input the cable void fraction filled with liquid He (LHe), the strand surface area exposed to LHe in the cable and the interstrand contact area. In particular, differences in the interstrand volume at the cable edges and in the cable center can have a strong influence on the heat transfer simulation results. We report quantitative neutron tomography results of Rutherford type cables and coils for the LHC magnets that have been performed at the ICON neutron imaging facility of the Paul Scherrer Institut (PSI).

WEDNESDAY LATE AFTERNOON ORAL SESSIONS 4:00pm - 6:15pm

3LX - MRI and Medical Applications I – Memorial to Emanuel Bobrov 4:00pm - 5:15pm

4:00pm

Invited

3LX01 - Designing cryogen-free magnets: Selecting the most cost-effective conductors

***C.M.Friend**, Z.Melhem, P.G.Noonan, Oxford Instruments NanoScience*

There is a growing market demand for cryogen-free magnet systems, both as replacements for existing commercial devices and for new applications. The magnet designer has a choice of several different conductors: LTS, MTS or HTS (available now or in the near future). They all have different competing performance characteristics, so which conductor is best for a particular device? For most applications, this choice will be determined by the maximum allowable system cost. It is easy to see how the cost of cooling can come down as the operating temperature is increased, whilst in return, the conductor cost per kiloAmp of current capacity will increase. However, there are many other important factors related to conductor characteristics that, directly or indirectly, affect the system cost. The detailed assessment can often be complex. This paper will provide an overview of the most important magnet design considerations related to conductor choice. Using example illustrations of device costings, we will attempt predictions as to which materials are likely to be preferred for certain applications in the future.

This work is supported in part by the Technology Strategy Board (TSB) Programme of the UK, No. TP/5/MAT/6/I/H0647BT

4:30pm

3LX02 - A prototype for assessing the field homogeneity of the Iseult MRI magnet

***T.Schild**, G.Aubert, CEA/Irfu; F.Beaudet, A.Bourquard, Alstom/MSA; A.Chancé, F.Nunio, L.Quettier, L.Scola, P.Vedrine, CEA/Irfu*

As part of the Iseult/Inumac project, the development of a 500 MHz whole body MRI magnet has been launched in 2006. This magnet with a central field of 11.7 T in a warm bore of 900 mm has outstanding specifications with respect to usual MRI systems. During the design process of this magnet, an innovative winding method using double pancakes has been made up which allows to reach the MRI required field homogeneity, i.e. 0.5 ppm peak-to-peak in a 22 cm diameter sphere. As the field homogeneity is a key issue of this project, a reduced scale prototype magnet has been designed and built in order to demonstrate the magnet manufacturing feasibility at the required accuracy, and to analyse the field quality of such a design taking into account the manufacturing errors. Dedicated tooling machines with on line measurement controls have been built with the objective of having a full geometrical description of each turn of each pancake. In addition to these toolings, an algorithm has been implemented in order to estimate the effect of the winding deformation, compared to the ideal pancake, on the field homogeneity. These results will be used to estimate the prototype bare magnet homogeneity before its cryogenic test.

4:45pm

3LX03 - Research and Development of Magnetic Drug Delivery System using Bulk High Temperature Superconducting Magnet

***S.Nishijima**, F.Mishima, Osaka University; Y.Tabata, Kyoto University ; H.Iseki, Y.Muragaki, Tokyo Women`s Medical University; A.Sasaki, Hitachi Medical Corp.; N.Saho, Hitachi, Ltd.*

The magnetic force control of the drug motion in the body has been studied. The calculation was made to study the possibility of the magnetic force control of the drag motion from the outside of the body. The condition which enables the magnetic force control was clarified. The magnetic drug delivery system (MDDS) was demonstrated to be possible using the rat and permanent magnet and the validity of the calculation was confirmed by the experiment. The magnetite suspension was introduced into a liver through portal vein in the rat experiment. A permanent magnet was used to navigate the magnetite. The navigation and accumulation of the magnetite was successfully performed. Based on the results, the MDDS experiment was made with an HTS magnet for a large-sized animal, pig. The HTS magnet of which size was 45 mm in diameter and 90mm in length produced 5T at 30K. The suspension of the magnetite was injected into the blood vessel of the pig. It was confirmed that the magnetite was successfully navigated and/or accumulated by the HTS magnet.

5:00pm

3LX04 - A superconducting joint technique for MgB2 round wires

***W.Yao**, J.Bascuñán, S.Hahn, Y.Iwasa, Massachusetts Institute of Technology*

The paper reports the progress in the development of superconducting splice between multifilament MgB2 round wires. The joints were made between reactivated conductors supplied by Hypertech Research, Inc. The preliminary result shows that at 4.2 K the joints can carry superconducting current of 40 A in its self field. Some technical details on the joints are discussed. Further development is being carried out in the areas of improving the critical current, and applying such superconducting splices in the construction of MgB2 magnet running in persistent mode.

3LY - Small Test Coils – II 4:00pm - 6:00pm

4:00pm

3LY01 - Recent Developments in 2G HTS Coil Technology

***D.W.Hazelton**, V.Selvamanickam, J.M.Duval, SuperPower, Inc.; D.C.Larbalestier, W.D.Markiewicz, H.Weijers, National High Magnetic Field Laboratory; R.L.Holtz, Naval Research Laboratory*

Recent developments in 2G HTS coil technology are presented highlighting the ability of 2G HTS wire to function under difficult operating conditions without degradation. The challenges of using 2G HTS wire in various coil constructions and applications are discussed. Several applications where the conductor is subjected to high stress levels include high field insert coils and rotating machinery. While these applications present different challenges, the ability of the conductor to operate under high stress levels has been demonstrated in both direct sample measurement and test coils. The high winding current density that is available with SuperPower's thin 2G HTS wire was utilized in a high field insert coil demonstration generating central fields in excess of 26.8 T [1]. This first test and later progress in moving to higher fields will be presented. The ability of the wire to be tailored (stabilization, insulation, ac losses) to fit various operating parameters will also be discussed

This work is supported in part by ONR contract N00014-07-C-0091. A portion of this work was performed at the National High Magnetic Field Laboratory, supported by NSF Cooperative Agreement No. DMR-0084173, by the State of Florida, and by the DOE.

4:15pm

3LY02 - YBCO coated conductor pancake coil with magnetic substrate and divertor

***E.Pardo**, J.Šouc, M.Vojenčiak, Institute of Electrical Engineering, Slovak Academy of Sciences, Dubravska 9, 841 04 Bratislava*

A small YBCO coated conductor pancake coil with a magnetic substrate is constructed, measured and numerically simulated. The AC loss and the voltage signal are investigated before and after covering the pancake by a thin ferromagnetic foil, which acts as a magnetic divertor. The coil is built as the secondary winding of a transformer, which voltage is measured by means of a contact-less loop embracing the transformer core. In order to understand the mechanisms involved, the measurements are compared with two different numerical calculations; one predicting the critical current Jc, simulating a DC experiment, and another one describing the AC loss, based on the critical state model. Both techniques assume an anisotropic field dependent Jc, inferred from in-field Jc measurements.

4:30pm

3LY03 - Progress in Wind-and-React Bi-2212 Accelerator Magnet Technology

***A.Godeke**, D.Cheng, D.R.Dietderich, C.R.Hanaford, S.O.Prestemon, G.Sabbi, Lawrence Berkeley National Laboratory; Y.Hikichi, J.Nishioka, T.Hasegawa, SWCC Showa Cable Systems*

We report on our progress in the development of the technology for the application of Bi2Sr2CaCu2Ox (Bi–2212) in Wind-and-React accelerator magnets. Presently, six superconducting subscale coils have been manufactured. The subscale coils have been reacted at the wire manufacturers. Selected coils are impregnated and tested, even though the coils exhibited leakage during the partial melt heat treatment. We report on the results of the current carrying capacity of the coils. Earlier work showed that leakage during the partial melt reaction is related to the degree of confinement of the superconducting cables. In parallel to the coil tests, we are therefore investigating methods to minimize the amount of leakage that occurs during the reaction and report our latest findings. The application of Bi-2212 in Wind-and-React accelerator type magnets, if successful, will open the road to higher magnetic fields, far surpassing the limitations of Nb3Sn magnet technology.

This work was supported by the Director, Office of Science, High Energy Physics, U.S. Department of Energy under contract No. DE-AC02-05CH11231

4:45pm

3LY04 - Quench Behaviour and Analysis of Bi-2212 Wind and React Coils

***Z.Melhem**, F.Domptail, G.Farmer, C.M.Friend, R.Harrison, P.Noonan, A.Twin, A.Van der Linden, Oxford Instruments NanoScience Ltd; S.Hong, Y.Huang, B.Czabaj, M.Meinesz, H.Miao, Oxford Superconducting Technology; Y.Yang, University of Southampton; J.Simkin, Vector Fields Ltd*

HTS materials have a unique combination of mechanical, electrical and thermal characteristics that makes it particularly challenging to deploy and model structures that include them. As part of our collaborative project on an Integrated Modelling Package for Designing Advanced HTS Material Applications (IMPDAHMA), we are using Bi2212 superconducting round wires as conductors for inserts in high field magnet applications. Quench behaviours of HTS insert coils fabricated as wind and react coils and integrated with an LTS coil have been captured and analysed. Various models of the integrated system have been developed and reviewed. In this paper we report on our progress on measurements of the quench behaviour and the associated modelling and analysis of the Bi-2212 coils.

This work is supported in part by the Technology Strategy Board (TSB) Programme of the UK, No. TP/5/MAT/6/I/H0647BT.

5:00pm

3LY05 - Development of React-Wind-Sinter Bi2Sr2CaCu2Ox Coil Technology

***X.T.Liu**, U.P.Trociewitz, J.Schwartz, National High Magnetic Field Laboratory of Florida State University; W.T.Nachtrab, T.Wong, Supercon, Inc.*

Bi2Sr2Ca1Cu2Ox/Ag (Bi2212) round wire is currently being considered for high field magnets due to its high Jc at high field and relative ease in winding and cabling into a wide variety of configurations. The processing requirements for Bi2212, however, are extremely stringent and Bi2212 is a brittle, strain sensitive material. To overcome these difficulties, a new technology for magnet fabrication, react-wind-sinter (RWS), has been proposed for Bi2212 round wire based on a split melt-process (SMP) which increases the critical current of Bi2Sr2Ca1Cu2Ox/Ag superconductor greatly. In this process, the temperature-critical reaction step is completed before magnet winding and then the reacted wire is wound and the magnet is sintered to complete the processing. The temperature control during sintering is less stringent than the reaction step, so RWS is an alternative approach for Bi2212 magnets. Here we compare small test coils made with wind-and-react manufacturing and conventional heat treatment processing, wind-and-react manufacturing with SMP, and RWS manufacturing. Index Terms—Bi2212, Superconducting magnet

This work was supported by the U.S. National Institute of Health SBIR Phase II Grant through Supercon, Inc.

5:15pm

3LY06 - Stress Analysis of a High Temperature Superconductor Coil Wound with Bi-2223/Ag Tapes for High Field LTS/HTS NMR Magnet Application

***S.Choi**, National Institute for Materials Science; S.Hahn, Massachusetts Institute of Technology; T.Kiyoshi, National Institute for Materials Science; M.Sugano, Kyoto University*

The maximum stress-strain level of an HTS insert should be strictly restricted below its allowable specification of conductor to avoid stress-originated coil damage in full operation of the magnet. For this purpose, it is important to precisely predict the stress distribution inside the winding with important stress-related parameters taken into consideration such as thermal stress-strain, winding tension, or effect of epoxy impregnation. A simplified equation to estimate the stress distribution, so-called JBR has been widely used for the sake of simplicity although JBR neglects the presence of a bobbin and the friction between each turn. The JBR method put a good guide for the worst situation in coil, but it could possibly overestimate the hoop stress in some coil configurations. In this paper, we present the analytical and experimental studies of stress-strain distribution inside a HTS test coil with taking account of winding tension, effect of bobbin, and friction between each turn. A test coil was wound with Bi-2223/Ag conductor on a 280 mm diameter GFRP bobbin and then the critical hoop stress on the HTS coil was measured by increasing currents in a background field up to 14 T. The experimental results were compared with those of two different calculation methods, JBR and numerical code based on force equilibrium equations.

This work was supported in the part by the Budget for Nuclear Research of MEXT.

5:30pm

3LY07 - Use of Second Generation HTS Wire in Filter Inductor Coils

***C.L.H.Thieme**, J.P.Voccio, K.J.Gagnon, American Superconductor (AMSC); J.H.Claassen, Naval Research Laboratory*

AMSC's process for manufacturing Second Generation (2G) YBCO High Temperature Superconductor wire provides the flexibility to engineer practical 2G conductors with various architectures. These wires, branded as 344 superconductors, are produced using the RABiTS-TM MOD approach and subsequently laminated to metal foils to tailor properties for specific applications and operating conditions. For applications with high frequency ac components, a stainless steel stabilizer is used to minimize eddy current losses. An example of such an application is the so-called Buck Inductor, a filter inductor which carries a DC current and a 5 KHz ac current superimposed. Previously we reported on the development and initial testing of the first 2G HTS toroid for this application [2]. We demonstrated a strong reduction of the ac losses with a DC bias current. In this work we present results on a toroid using higher current wire, and a different double pancake design with better cooling. This design allows operation of the double pancake in liquid nitrogen at high frequencies without heating effects. [1] M.W. Rupich et. al., IEEE Trans Appl. Superc. 17(2), 3379, 2007. [2] C.L.H. Thieme et. al." AC application of Second Generation HTS Wire", Conf. Proc. 2007 European Conference on Applied Superconductivity.

This work was supported by The Defense Advanced Research Projects Agency (DARPA) and Office of Naval Research (ONR)

5:45pm

3LY08 - Progress in Bi2212 Conductor and Coil Technology for High Field Magnets

***U.P.Trociewitz**, J.Jiang, E.E.Hellstrom, ASC/NHMFL, FSU; Y.Viouchkov, MST/NHMFL, FSU; T.Shen, X.Liu, M.LoSchiavo, T.Effio, J.Schwartz, D.C.Larbalestier, ASC/NHMFL, FSU*

Superconducting high-field magnets beyond 25 T are generally envisioned to require an inner section based on high-temperature superconductor technology. Bi2Sr2CaCu2O8+x (Bi2212) conductor and coil technology is the driving research program at the ASC/NHMFL to develop successful high-field Bi2212 magnets. A layer-wound insert magnet with a 30 mm free bore using Bi2212 round wire, manufactured applying the wind and react (W&R) approach, has been designed. A series of small test coils and versions of a full-size innermost shell of the insert have been manufactured and characterized. Various aspects of thermo-processing, effects on microstructure and in-field transport properties, compatibilities with conductor insulation and structural materials, and other basic technological issues have been studied extensively. Progress on these activities is reported.

THURSDAY, AUGUST 21, 2008

THURSDAY MORNING POSTER SESSIONS
10:00am - 12:00pm

4LPA - Accelerator Magnets – IV 10:00am - 12:00pm

4LPA01
Invited
Test Results of Superconducting Quadrupole Model for Linear Accelerator
V.S.Kashikhin, N.Andreev, J.DiMarco, V.V.Kashikhin, M.J.Lamm, M.L.Lopes, M.Tartaglia, J.C.Tompkins, A.V.Zlobin, Fermilab
The first model of superconducting quadrupole for Linear Accelerator was designed, built and tested at Fermilab. The quadrupole has a 78 mm aperture, a 36 T integrated design gradient, and a cold mass length of 700 mm. A superferric magnet configuration with iron poles and four racetrack coils was chosen based on magnet performance, cost, and reliability considerations. Each coil is wound using enamel insulated, 0.5 mm diameter, NbTi strand. The quadrupole package also includes racetrack-type dipole steering coils. The quadrupole design and results of model manufacturing and testing are presented. The magnet quench performance and results of magnetic measurements as well as specific issues related to the quadrupole magnetic center stability measurements, superconductor magnetization and mechanical stability are discussed.
**Work is supported by the U.S. Department of Energy*

4LPA02
Invited
Effect of superconductor magnetization on magnetic centre stability of quadrupoles for linear accelerators
M.L.Lopes, V.V.Kashikhin, V.S.Kashikhin, A.V.Zlobin, Fermilab
The development of superconductor quadrupoles for the International Linear Collider (ILC) Main Linac (ML) is in progress. The quadrupole design is based on a super-ferric magnet configuration with iron poles and four racetrack coils. The quadrupole package also includes dipole steering coils. This paper discusses the effect of superconductor magnetization in the steering coils on the stability of quadrupole magnetic centre. Two possible geometries for the steering coils, shell and racetrack types, were simulated. The results of 2D and 3D models are presented and compared.
**Work is supported by the U.S. Department of Energy*

4LPA03
Power switches utilising superconductors for accelerator magnets
S. A.March, CERN, University of Southampton; A.Ballarino, CERN; Y.Yang, University of Southampton
Power switches that utilise superconducting material find application in superconducting systems. They can be used for the protection of magnets as a replacement for warm DC breakers, as well as for the replacement of cold diodes in fast pulsed magnets. This paper presents a comparison of switches made of various superconducting materials having transport currents of up to 600 A and switching times of the order of a few milliseconds. The operating temperatures of the switches are in the range 4.2 – 77 K and utilise stainless steel clad YBCO tape, magnesium diboride bulk, and magnesium diboride tape with a nickel, copper, iron matrix. Results from simulations and tests are reported.

4LPA04
Electromagnetic efficiency of block design in superconducting dipoles
E.Todesco, L.Rossi, CERN
Semi-analytical scaling laws have been derived for the electromagnetic design of superconducting dipoles based on sector coils, i.e., near to cos theta. Here we discuss the different features of block coils designs used in the past, focusing on the field quality issues, and on the efficiency of the electromagnetic design (i.e. short sample field versus the quantity of superconductor) with respect to the standard cos theta design.

4LPA05
Electromagnetic design of open-midplane dipoles with sector coils
E.Todesco, J.E.Bruer, CERN
Some superconducting dipoles have to work in an environment with a heavy radiation in the coil midplane. For this reason, designs of superconducting dipole with an “open mid-plane” have been proposed in the past. Here we investigate the possibility of keeping the standard cos theta lay-out and replacing the coil sector near the mid-plane with a pretty large spacer (5 or 10 degrees). The constraints for the field quality are analyzed in this configuration and a comparison of the effectiveness of these options to a standard cos theta design is given.

4LPA06
A Novel Design of Iron Dominated Superconducting Quadrupoles with Circular Coils
V.S.Kashikhin, Fermilab
Linear accelerators based on superconducting technology use a large number of relatively weak superconducting quadrupoles. In this case an iron dominated quadrupole is the most cost effective solution. The field quality in this magnet is defined by iron poles; the magnet air gap is minimal as a coil ampere-turns. Nevertheless, it has long racetrack type coils, which must be rigid and fixed by a mechanical structure providing the needed mechanical stability. The novel concept of using circular superconducting coils in such a quadrupole type is presented, with a discussion of quadrupole parameters, and results of 2D and 3D magnetic designs. Variants of short and long sectional quadrupoles are presented.
*Work is supported by the U.S. Department of Energy

4LPA07
Design, Fabrication and Test of a Superconducting Quadrupole Magnet Based on Tilted Helical Solenoids
F.Trillaud, S.Caspi, D.Dietderich, P.Ferracin, A.Godeke, G.Sabbi, LBNL
It has been shown that by superposing two solenoid-like thin windings, that are oppositely skewed (tilted) with respect to the bore axis, the combined current density on the surface is “cos--theta” like and the resulting magnetic field in the bore is a pure dipole field. Following a previous test of such a superconducting dipole magnet, a quadrupole magnet was designed and built using similar principles. This paper describes the design, construction and test of a 75 mm bore 500 mm superconducting quadrupole made with NbTi wire. The simplicity of such a high field quality design, void of typical wedges, end-spacers and coil assembly, is especially suitable for high field insert coils using Nb3Sn and HTS wires.
Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

4LPA08

Design Study of a Curved Dipole Superconducting Magnet for Beam Transport

T.Obana, National Institute for Fusion Science; T.Ogitsu, A.Yamamoto, KEK High Energy Accelerator Research Organization; M.Yoshimoto, Japan Atomic Energy Agency; T.Orikasa, TOSHIBA Corporation

Superconducting magnets for beam transport from a particle accelerator to a target have recently received much attention in several applications such as high energy physics experiments, power generation and medical treatment, because of their compactness, light weight, and energy efficiency. In this study, a superconducting dipole magnet with a curved saddle shape (cosine theta) has been proposed as an efficient bending magnet for a heavy ion beam transport line. The superconducting magnet is designed to generate a vertical magnetic field of 3 T along an arc path of the beam line with a bending radius of 2.2 m and a bending angle of 60 degrees. Due to difficulties to optimize the curved coil shape that generates the good field quality, a new design method has to be developed. The developed method makes it possible to design the coil shape, which can generate the required integral field quality. The design study of the curved dipole superconducting magnet will be presented.

4LPA09

Parametric Analysis of Forces and Stresses in Superconducting Dipoles

P.Fessia, F.Regis, E.Todesco, CERN

Using the existing analytical approximation of the field in the coils for sector winding dipoles (near to cos theta), we give an estimation of the electromagnetic forces and of the related mechanical stresses. The distribution of the forces is investigated to better understand the stress in the retaining structure and the compression effect in the coil mid plane. The study has been carried out setting the magnet current at its critical value for Nb-Ti and Nb3Sn cables. Finally, the effect of an iron yoke on the magnetic field and forces is presented. The above approach allows carrying out a parametric analysis of the forces and stresses as functions of the geometrical layout.

4LPB - Other Accelerator Magnets II – Undulators
10:00am - 12:00pm

4LPB01

Development of the next generation superconductive undulators for synchrotron light sources

C.Boffo, M.Borelin, W.Walter, Babcock Noell GmbH; T.Baumbach, S.Casalbuoni, A.Grau, M.Hagelstein, R.Rossmanith, FZ Karlsruhe; E.Mashkina, B.Kostka, U. Erlangen-Nürnberg; A.Schörling, TU Bergakademie Freiberg; A.Bernhard, D.Wollmann, U. Karlsruhe

Superconducting insertion devices are very attractive for synchrotron light sources. For a given gap and period length they have higher fields compared to permanent magnet insertion devices allowing to reach higher photon fluxes. A new R&D program has been recently launched at ANKA aiming to the development of the next generation superconducting insertion devices for light sources. A cold bore superconducting undulator (14 mm period length, 100 periods long) is installed in the ANKA storage ring since three years. This will be replaced by an improved version with a more efficient cooling system and with a low tolerance design aiming to achieve reduced field errors. Under planning are two additional devices. One will allow to electrically switching the period length between 15 mm and 45 mm corresponding to an undulator and a wiggler mode, respectively. The other will be optimized for third generation light sources. It will be capable of tolerating higher beam heat loads up to 6 W while achieving very small field errors. The field error minimization will be obtained through the use of new shimming concepts which will correct inaccuracies due to manufacturing tolerances. This paper describes the technical concepts of the three projects.

4LPB02

Design of a Changeable Period Staggered Undulator

C.H.Chang, C.S.Hwang, J.C.Jan, F.Y.Lin, J.P.Chang, NSRRC

A conceptual design of changeable period staggered structure in a superconducting solenoid coil for generating a broaden synchrotron radiation is described. This special device is equipped with a changeable magnetic period via shifting magnet array in a superconducting solenoid coil. This undulator design is based on a permeable pole of the magnetic array could be shifted a pole position in longitudinal axis and the magnetic pole also could be separated into a half-period pole. A staggered magnetic structure equipped with 50 mm period or 25 mm period is designed for application of a 3 GeV storage ring of the Taiwan Photon Source. The magnetic characteristics of magnetic structure are calculated. Accordingly, the mechanical of shifting magnetic arrays is outlined. The superconducting solenoid is optimized to produce a highly uniform field over length. Finally, the field profile and the electron orbit trajectory with the end pole structures are presented.

4LPB03

Development of superconducting elliptically polarized undulator

S.D.Chen, National Chiao-Tung University; C.S.Hwang, J.C.Jan, National Synchrotron Radiation Research Center

A superconducting elliptically polarized undulator (SEPU) was developed to provide the photon wavelength for the Extreme Ultraviolet (EUV) lithography on a 1.5 GeV storage ring. Two layers structure - with and without rotated angle magnet arrays, were assembled together to produce the helical field. The vertical wound racetrack coil is chosen for the coil and pole construction of the SEPU. The elliptical field will be created when the up and down magnetic pole array with alternative directions rotated wire, respectively, in the horizontal plane. Meanwhile, an un-rotated wire magnet array is constructed together with the rotated wire magnet array on the same undulator will be used to switch the linear polarization on the horizontal and vertical plane as well as the circular polarization in right and left. A SEPU 2.37 with periodic length of 23.7 mm at magnet gap of 7 mm is designed and the helical magnet flux density Bx=Bz=0.55 T is obtained for the 13.5 nm wavelength of the application of EUV lithography. This device is also the main instrumentation for the Free Electron Laser (FEL) and the Energy Recovery Linac (ERL) facility. This paper will describe the design concept, the field calculation and field quality analysis, the performance of the prototype magnet testing.

Work supported by the National Science Council of Taiwan under Contract No. NSC 96-2112-M-213-006.

4LPB04

Design of a trim coil and a beam duct for the superconducting undulator

J.C.Jan, C.S.Hwang, C.H.Chang, F.Y.Lin, National Synchrotron Radiation Research Center

A trim coil was designed to correct the fluctuation of the magnetic field of a superconducting undulator (SU1.5) with period length of 1.5 cm. The trim coil was wound with NbTi wires (diameter 0.33 mm). In addition, the Teflon-insulated main arrays were rewound and tested. For the main poles we used Teflon insulation between wires and the iron pole to avoid degradation of SC wire when the coil was trained up to a large current. The main coil was wound with NbTi wires (rectangular cross section, 0.77 x 0.51 mm2). The trim coil was mounted directly on the main coil. The current through these trim coils was supplied with a constant voltage from a power supply; use of this constant-voltage mode saved the number of power supplies in the test. The gold-case resistances and a variable resistor were arranged in a parallel connection that prepared the current through the trim coil. In this work, we designed 10 trim coils on both the upper and lower arrays. A test beam duct was designed and manufactured to support the magnet arrays including the main coils and trim coils. A stainless-steel sheet (SS, thickness 0.3 mm) was welded on the SS frame and then glued together with the magnet arrays. The tests of the beam duct are also discussed herein.

4LPB05

Design of a Nb3Sn magnet for a 4th generation ECR ion source

S.Prestemon, F.Trillaud, S.Caspi, G.L.Sabbi, C.M.Lyneis, D.Leitner, D.S.Todd, Lawrence Berkeley National Laboratory

The next generation of Electron Cyclotron Resonant (ECR) ion sources are expected to operate at a heating radio frequency greater than 40 GHz. The existing 3rd generation systems, exemplified by the state of the art system VENUS, operate in the 10-28GHz range, and use NbTi superconductors for the confinement coils. The magnetic field needed to confine the plasma scales with the rf frequency, resulting in peak fields on the magnets of the 4th generation system in excess of 10T. High field superconductors such as Nb3Sn must therefore be considered. The magnetic design of a 4th. generation ECR ion source operating at an rf frequency of 56 GHz is considered. The analysis considers both internal and external sextupole configurations, assuming commercially available Nb3Sn material properties. Preliminary structural design issues are discussed based on the forces and margins associated with the coils in the different configurations, leading to quantitative data for the determination of a final magnet design.

4LPC - Superconducting RF – IV 10:00am - 12:00pm

4LPC01

Using Superconducting Crab Cavity to Generate Ultra-Short X-ray Pulse

H.Ghasem, IPM/NSRRC; G.H.Luo, NSRRC

Typical bunch length duration in synchrotron radiation facilities is around tens of pico-seconds. There are several novel methods to generate femto-seconds x-ray pulses for the applications in fast chemical reaction or phase transition and coherent vibration motion in atomics level. A superconducting crab cavity is used to create angle kick to rotate electron bunches in vertical direction, which can have the most high-average photon intensity in all methods. The short-bunch x-ray is generated from rotated bunches through insertion device. A second superconducting crab cavity is then to cancel the rotating angle of electron bunch in order to eliminate the interference to the rest of beamlines in the storage ring. An Quadruple-Bend-Achromat (QBA) lattice is designed for 3GeV Taiwan Photon Source (TPS) to generate high brightness x-ray. Various effects of the stored electron beam, due to the installation of superconducting crab cavities, were investigated. Optimal installation location and operation conditions of the superconducting crab cavities were found to the designed QBA lattice.

The authors wish to thank Dr. M. Borland and Drs. M. H. Wang for valuable discussions and appreciate the support from National Synchrotron Radiation Research Center.

4LPC02

FLUCTUATION SOURCE AND SUPPRESSION OF THE CESR-TYPE SUPERCONDUCTING RADIO-FREQUENCY CAVITY MODULE

M.C.Lin, C.Wang, M.H.Tsai, F.T.Chung, M.S.Yeh, T.T.Yang, M.H.Chang, L.H.Chang, National Synchrotron Radiation Research Center

A CESR-type superconducting radio-frequency cavity module, developed in the Newman Laboratory of Nuclear Studies, Cornell University, USA, is installed in the electron storage ring of NSRRC, Taiwan. During its operation starting from 2005 in NSRRC, a strong correlation of the cavity tuner movement with the temperature variations on the nitrogen-cooled parts is observed. With continuous studies and tests on a retired SRF module transferred from CESR, the double elbow waveguide section with nitrogen cooling channels is proven to be the source of temperature fluctuation. In this article, the test method to identify the fluctuation source is presented. And some operation methods to suppress the temperature fluctuation with promising results are proposed. Because the same SRF module has been also operated in some other facilities like CESR, CLS, DLS, and soon at SSRF, this study is thus important to benefit its application and improve the operation stability.

4LPC03

Experience with a 3.9 GHz Fundamental Power Coupler for Third Harmonic Superconducting RF Cavities

J.Li, E.R.Harms, A.A.Hocker, T.Khabiboulline, T.N.Kubicki, N.A.Solyak, Fermi National Accelerator Laboratory; T.Y.Wong, Illinois Institute of Technology

Third harmonic Superconducting RF (SRF) cavities were proposed to improve the beam quality for the Free Electron Laser in Hamburg (FLASH) project based on the TESLA Test Facility (TTF). A fundamental power coupler operating at the frequency of 3.9 GHz for this type of cavities has been successfully designed, developed, and tested at Fermilab. External quality factors of the coupler were measured and calculated at several different penetration lengths. The results are highly consistent with the simulation. High power vertical test of the coupler is a routine processing procedure before it is integrated in the cavity for horizontal test at cryogenic temperatures. All couplers passed this vertical test under ultra vacuum and clean environment. Only minimal vacuum and heating activities were observed during the whole test. All facets of the vertical test will be presented in this paper. Horizontal test of the coupler is very important as the cavity will be cooled down to superconducting state. The coupler must withstand a high temperature gradient and minimize the heat loss to the cryogenic environment. Coupler performance in the horizontal test will also be discussed in this paper.

We want to thank D.J. Nicklaus, D.R. Olis, P.S. Prieto, and J.S. Reid for their great contributions to this work.

4LPC04

High Intensity Neutrino Source Superconducting Spoke Resonator and Test Cryostat Design and Status

T.H.Nicol, G.Lanfranco, L.Ristori, Fermi National Accelerator Laboratory

Fermilab is in the process of constructing a 60 MeV linac as part of the High Intensity Neutrino Source (HINS) R&D program. Developments from this program could play a direct role in an upgraded injector for the existing Main Injector at Fermilab to support the ongoing neutrino physics program. In addition this same R&D could lead to breakthroughs in superconducting radio frequency (SRF) technology useful in any of several large-scale SRF accelerator projects being discussed around the world. The initial beam acceleration in the linac front end is achieved using room temperature spoke resonators combined with superconducting solenoids for focusing. At the end of the room temperature section, three cryomodules containing either 9 or 11 single spoke resonators operating at 4.5 K and 325 MHz, also with superconducting solenoids, accelerate the H- test beam to its final energy. Each spoke cavity will be tested individually in a cryostat that replicates conditions in the longer multi-cavity modules. This test cryostat has all the features of the longer cryomodules – magnetic shielding, 80 K thermal shield, multi-layer insulation, support post, and input coupler. The hope is that the use of common features will facilitate the eventual design of the longer cryomodules. This paper describes the design of the test cryostat, the mechanical design of the spoke cavities and their helium vessels, and includes a detailed status of the development work.

4LPC05

DEVELOPMENT OF 325MHz SINGLE SPOKE RESONATORS AT FNAL

T.N.Khabiboulline, G.Apollinari, I.V.Gonin, G.Lanfranco, R.Wagner, Fermilab

The High Intensity Neutrino Source (HINS) project represents the current effort at Fermilab to produce an 8-GeV proton linac based on about 400 independently phased superconducting cavities. Eighteen β=0.21 single spoke resonators, operating at 325 MHz, comprise the first stage of the linac cold section. In this paper we are presenting the current status of production and testing two of these cavities. Also we will present the design and prototyping of slow and fast tuning mechanism.

4LPC06

THERMAL BREAKDOWN LIMITATION IN SUPERCONDUCTING 3.9 GHz CAVITY

I.V.Gonin, H.T.Edwards, T.N.Khabiboulline, N.A.Solyak, Fermilab

Thermal breakdown is one phenomenon that limit achievable field in superconducting cavities. We present the analytical model of thermal breakdown based on measured niobium properties and electromagnetic fields obtained by HFSS simulations. Analysis of measured data for Kapitza resistance, thermal conductivity and surface resistance has been done. Also we compare the results of simulations and experimental data for quench limit for 3.9 GHz third harmonic superconducting cavity.

4LPC07

Vertical and Horizontal test results of 3.9 GHz accelerating cavities at FNAL.

T.Khabiboulline, H.Edwards, E.Harms, A.Hocker, A.Rowe, N.Solyak, FNAL

The 3rd harmonic 3.9GHz accelerating cavity was proposed to improve the beam performance of the electron/positron linear accelerators. In the frame of a collaborative agreement, Fermilab will provide DESY with a cryomodule containing a string of four cavities. Several 9-cell Nb cavities were tested and they did reach accelerating gradient up to 24 MV/m almost twice more than design value of 14 MV/m. Two of these cavities are with new HOM couplers with improved design. In this paper we present all results of the vertical and horizontal tests.

4LPD - Superconducting Magnetic Energy Storage – IV
10:00am - 12:00pm

4LPD01

Comparing different superconductors for medium-sized SMES systems

F.van Hövell, A.den Ouden, M.Dhallé, University of Twente

Based on an idealized toroidal model of a 3.6GJ-100MW SMES system, different technical superconductors are compared in terms of cost-effectiveness. With the advent of commercial HTS and MgB2, the superconducting materials portfolio has expanded significantly, especially by allowing operation also at higher temperatures. The paper seeks to make a first-order estimate of the impact of this development for medium-sized SMES systems. The engineering current density of the materials is used to calculate the required conductor volume as a function of operating field and -temperature. Unsurprisingly, the corresponding conductor cost increases with temperature. Cooling cost, however, can be approximated from AC loss estimates and heat leak considerations and decreases with temperature. Balancing these two cost factors yields an optimal working field and temperature for each superconducting material. Having established these optima, the analytical approach sketched above is refined with numerical estimates for more realistically achievable coil systems.

4LPD02

Dynamic Thermal Characteristics of HTS Coil for Conduction-cooled SMES

H.Kojima, X.Chen, N.Hayakawa, F.Endo, H.Okubo, Nagoya University

For conduction-cooled SMES, a dynamic thermal stability and a prevention of thermal runaway are one of the most significant issues in its operation. Although the recent development of HTS tape with high jc allows the size reduction of SMES coil, thermal characteristics due to the high current density in HTS coil might increase the thermal runaway risk. In this paper, we investigate thermal runaway characteristics of conduction-cooled BSCCO HTS coil and YBCO HTS coil with 4K-GM cryocooler system. We evaluate the static and dynamic characteristics of the HTS coil by measuring temporal evolution of temperature and voltage distributions for steady current and typical current patterns of load fluctuation compensation at different ambient temperatures. For the reason of that the n-value of the YBCO HTS tape is larger than that of the BSCCO HTS tape, the dynamic process of the thermal runaway will be different between the two HTS coils. We compare the dynamic thermal characteristics of the two HTS coils, and then we discuss the difference in thermal runaway properties with thermal analysis. From these results, we discuss key parameters for the evaluation of thermal runaway characteristics of conduction-cooled HTS coils.

4LPD03

Basic Insulation Characteristics of 2MJ class HTS SMES

J.W.Choi, H.G.Cheon, Gyeongsang National Univ. and Eng. Research institute ; H.J.Kim, K.C.Seong, Korea Electrotechnology Research Institute; S.H.Kim, Gyeongsang National Univ. and Eng. Research institute

The 2MJ class high temperature superconducting magnetic storage (HTS SMES) system is being developed by Korea Electrotechnology Research Institute(KERI). The system is operated in cryogenic temperature and high vacuum condition. The SMES magnet was cooled by conduction cooling method using cryocooler and others. Thus, electric insulation design at cryogenic temperature and high vacuum is a key and an important element that should be established to accomplish compact design is a big advantage of HTS SMES. This paper describes the basic insulation charateristics of liquid, solid and high vacuum for development of 2MJ class HTS SMES.

This work was supported by Electric Power Industry Technology Evaluation & Planning.

4LPD04

Temperature Characteristic of a Conduction-Cooled HTS SMES Magnet

J.Shi, Y.Tang, L.Ren, J.Li, S.Cheng, R&D Center of Applied Superconductivity, Huazhong University of Science & Technology

A 35kJ/7kW conduction-cooled HTS SMES is developed. The magnet of the SMES is solenoid type coil, made of Bi2223/Ag tapes, and cooled to about 20K by cryocooler through conduction-cooled method. To evaluate the performance of the 35kJ/7kW SMES, system characteristics such as the process of current carrying ability, power conditioning capability and dynamic operation for stabilizing power systems are tested. In this paper, temperature characteristic of the conduction-cooled HTS magnet for 35kJ/7kW SMES is investigated. Tests results verify that the thermal stability of the HTS magnet can meet the requirement of dynamic power compensation.

This work was supported by National High Technology Research and Development Program of China (863 program) under Contract No. 2006AA30Z209, National Basic Research Program of China-973 Program under Grand 2004CB217906.

4LPD05

Thermal Analysis of 600 kJ SMES Magnet during Charging and Discharging Period

J.Han, S.Y.Lee, B.W.Han, K.Choi, Korea Polytechnic University; W.S.Kim, C.Park, S.Y.Kwak, H.K.Jung, S.Han, Seoul National University; J.K.Lee, Woosuk University; J.H.Bae, S.K.Kim, K.D.Sim, K.C.Seong, Korea Electrotechnology Research Institute

A 600 kJ SMES system had been fabricated and tested by Korea Electric Research Institute (KERI) in Korea. It has an HTS magnet for magnetic energy storage which was wound with BSCCO-2223 tape and operated at the temperature of 20 K accomplished by conduction cooling with a GM cryocooler. The SMES magnet itself consumes no power to keep the operating current because of zero resistance of superconducting wire while it may generate small AC losses from a time-varying magnetic field during the period of charging or discharging. In the conduction cooling system, small loss could be the reason of a local temperature rise in the HTS magnet which may lead the magnet to a quench or burning out. In this paper, a thermal analysis during charging and discharging period has been performed for the HTS magnet fabricated for 600 kJ SMES system, and they were compared with the experimental measurement results.

This work was supported by Electric Power Industry Technology Evaluation and Planning.

4LPD06

Design of Cryogenic Cooling System for 2.5MJ Class HTS SMES

H.K.Yeom, D.Y.Koh, Y.J.Hong, S.J.Park, H.B.Kim, KIMM; K.C.Seog, KERI; T.B.Seo, Inha Univ.

To do a role of superconducting magnetic energy storage (SMES), it must be required cryogenic cooling system. The superconducting coil would be run below the critical temperature of its materials. Especially, working temperature of the HTS SMES system is around 30 K for increasing critical current. There are some applied examples of conduction cooling system in sub MJ class HTS SMES, but conduction cooling system has some problems to adapt in MJs class HTS SMES. In this study, we design the cryogenic cooling system for 2.5 MJ class HTS SMES. The HTS coil is immersed in liquid neon cryostat for cooling and evaporated neon gas is re-condensing by Cryocooler. To achieve this goal, evaluate the thermal load of cryostat and electric heat load of HTS coil, and design the re-condensing heat exchanger.

This work was carried out under the support of the Ministry of Commerce, Industry and Energy, Korea.

4LPD07

Conceptual Design of the Cooling System Using Solid Nitrogen for HTS Superconducting Magnetic Energy Storage (SMES)

K.L.Kim, S.J.Hwang, H.G.Lee, Korea Univ., Seoul, Korea; D.Y.Koh, KIMM, Daejeon, Korea; H.M.Kim, K.C.Seong, KERI, Changwon, Korea; W.S.Kim, C.Park, Seoul National Univ., Seoul, Korea

Generally, conduction cooling through a cryocooler is mainly used to cool down the HTS SMES coil to the operation temperature. However, conduction cooling not noly consumes large electric power because of continuous cryocooler operation but also makes poor thermal stability and protection of the system. Introducing solid nitrogen (SN2), which has a large heat capacity, can enhance those disadvantages in the conduction cooling system. Particularly, large enthalpy with a minimal weight to the cold body of SN2 make a compact and portable system by increasing a value of recooling to recooling time period (RRTP). This paper presents a conceptual design of proto-type SN2 cooling system for a portable HTS superconducting magnetic energy storage (SMES).

This work was supported by Electric Power Industry Technology Evaluation and Planning, and also, was partially supported by MOCIE through EIRC program with YEPRC at Yonsei University, Seoul, Korea

4LPE - HTS Motors and Generators – IV 10:00am - 12:00pm

4LPE01

Performance Analysis of Superconducting Linear Driver to Propel Underwater Objects

L.Zhao, Y.Peng, C.Sha, R.Li, Q.Wang, Y.Xu, Institute of Electrical Engineering CAS

This paper applies the superconducting linear driver in electromagnetic underwater launch system to develop a novel direct-driven Superconducting Linear Electromagnetic Underwater Launch System (SLEULS) with high electrical power, compactness, lightweight and quietness. The SLEULS mainly consists of a tubular superconducting linear driver and a hydraulic unit including a plunger connecting to the linear driver, a pulse tank and a launch tube, and power supply and control units. In the linear driver, a DC resistive coil is placed coaxially in the warm bore of a high-temperature superconducting magnet. An electromagnetic force generates from the interaction of the current in the resistive coil with the radial component of the magnetic field, and drives the resistive coil and plunger moving together to push the water in the pulse tank into the launch tube. As a result, the weapon is ejected out of the launch tube with certain velocity. The mathematical model of the system was established and its performance characteristics were calculated and analyzed. The results show when field strength is 4T and the input power is 32kW, the tubular linear driver with a stroke of 0.25m can generate a propulsion force of 10kN and eject 30kg weapon out of the launch tube within 0.2s with the exit velocity of 8m/s.

4LPE02

Fundamental Study on Superconducting Linear Driver Waterjet Propulsion

L.Z.Zhao, Y.Peng, C.W.Sha, R.Li, Y.Y.Xu, Institute of Electrical Engineering of Chinese Academy of Sciences

Superconducting Linear Driver Waterjet Propulsion (SLDWP) is based on technologies of high-temperature superconducting magnet and linear drive, and offers a new method for ship propulsion with advantages of quietness, compact size, high pressurization, high efficiency and more agility. Compared with the MHD marine propulsion, it can be applied in both sea and freshwater. In the SLDWP system, a superconducting linear driver generates a large axial force and extrudes the working liquid in the hydraulic house to eject from the spout with certain velocity and pressure, thus driving the ship forward on. A mathematical model of the SLDWP system was developed and a SLDWP thruster was designed for YAMATO-1, and performance analysis of YAMATO-1 with SLDWP was carried out. The results indicate that with the same thrust force and speed of ship, input power can decrease from 3600kW down to 150.6kW, and its electrical efficiency increase from 2.9% up to 96.3% and thruster efficiency from 2.53% up to 61.7% when the superconducting linear driver's stroke is 0.6m and to and fro frequency is 274 per minute.

4LPE04

Torque Characteristics of a 10 kW Axial Flux Inductor Type HTS Motor

L.Liyi, Y.Tao, K.Baoquan, H.Junjie, W.Hongxing, Z.Chengming, H.Xuzhen, Harbin Institute of Technology

Axial flux inductor type HTS Motor has many advantages which traditional superconducting motor doesn`t have. This motor with novel topology doesn`t adopt the devices such as: hollow shaft, brush, slip ring, rotating cryogenic vessel, so it gains more advantages. This motor is an eight-pole inductor type synchronous motor with nine armature windings .The field and armature windings use the BSCCO HTS wires, and both of them are fixed in the stator, and the inductor plan is employed as the rotor. The iron cores are also adopted in the winding. It can effectively decrease the AC loss. Torque characteristics of a 10 kW axial flux inductor type HTS motor are introduced in this paper. The initial electromagnetic and structure design are also proposed in the paper. The motor output is 10 kW at the rated speed of 250 rpm. The effects on the torque characteristics of the motor of the armature winding current, field winding current ,air gap length, dimension and material of the inductor, position of the inductor mounted in the rotor are studied using 3D finite element method. With simulation results, a method to increase the motor torque and decrease the torque-ripple for motor optimization effectively has been acquired.

4LPE05

An Axial-Type HTS Motor with a Field-Pole Bi2223 Winding Without Iron Core

D.Sugyo, Y.Kimura, T.Sano, K.Yamaguchi, K.Tsuzuki, R.Taguchi, M.Izumi, M.Miki, Tkyo University of Marin Science and Technology; H.Sugimoto, University of Fukui; H.Fujimoto, Railway Technical Research Institute

In the previous work, we designed and studied several prototypes of HTS field-pole structured Double-Pancake-Coil (DPC) with Bi2223 superconducting wire. We studied these coils from the viewpoint of excitation efficiency. We have fixed a final design with a low loss up to 0.25 W upon 1.5 T excitation when apply the excitation current of 200 A at 30 K. In the present study, we developed a HTS motor of an axial type with the above mentioned core-less field pole coils. The dimension of the motor is 850 mm in diameter, 507 mm in length and weighting 1044 kg. Designed motor is 100 kW 230 rpm in rated output. The HTS windings without iron-core were cooled down by conduction cooling through rotor plate using liquid neon as cooling medium with a closed-cycle thermal siphon induced from GM cryocooler. Air-gap is in vacuum and the dimension of the present HTS motor is compact and light weight those will be practical.

This part of study was held by assistance of Japan Railway Construction, Transport and Technology Agency (JRTT).

4LPE06

Diamagnetic Rotor Immersed in two Opposite Stationary Magnetic Fluxes Produced by External Coils

J.S.Millan, A.Lopez, Universidad Autonoma del Carmen; L.A.Pérez, Instituto de Fisica, Universidad Nacional Autonoma de Mexico

In this work, a novel configuration of two pairs of external coils is analyzed in order to produce two opposite stationary magnetic fluxes with respect to the central point where a diamagnetic rotor is located. The Meissner effect causes a repulsion force with respect the magnetic field, and a pair force is induced on the rotor. We can reach this configuration joining two poles of each pair of external coils with aluminium (for example) which has higher magnetic permeability than the gaseous helium, which can be used like a refrigerant. The rotor could be constructed with a selected material with a high critical temperature superconductor added to its surface. The externals coils can be made of superconductor wire or conventional conductors. On the other hand, the size and form of the rotor`s plates and the magnitude of the magnetic field producing the pair force are restricted by the region between the coils where the flux can push the rotor`s plates. The field of velocities of the rotor's plates and the power reached are calculated as a function of the magnetic energy density stored within each coil. Methods and materials for the fabrication process are also discussed. Finally, we offer a discussion about this technical application for high and low power electrical motors design.

4LPE07

Characteristic analysis of Homopolar Machines using Superconductor in Field Winding

S.-H.Lee, J.-P.Hong, School of Automotive Engineering, Hanyang University; Y.-K.Kwon, J.-D.Lee, Korea Electrotechnology Research Institute

Superconductivity synchronous motors compared with conventional motor can reduce the motor size and enhance the motor efficiency for low speed and high torque applications under the space constraints for propulsion system. Especially, homopolar superconductivity synchronous motors (HSSMs) need less superconductor and lower magnetic flux density in superconductor field coil is lower than air-cored superconductivity synchronous motors (ASSMs). In addition, mechanical structure is simple and stability is increased because the superconductor field coil of HSSMs is not rotated. In this paper, we present the operational principles and the conceptual design of HSSM.

This work was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

4LPE08

Synchronous tube machine optimization for vehicle shock absorber using permanent or superconducting magnets

Dr. I.Vajda, Budapest University of Technology; I.Zador, S-Metalltech Ltd.; D.Kiraly, Budapest University of Technology

In today's vehicles shock-energy is converted into heat by a hydraulic shock absorber having a reacting force that is not controllable (passive suspension). The reacting force depends on the direction the piston is moving at, as well as the speed of displacement. At a piston speed of 0.5 m/s the maximum value is approximately 5000 N. Controllable suspension systems of a vehicle are semi-active and active suspensions (actuator). A permanent magnet (PM) and a high temperature superconductor (HTSC) magnet synchronous tubular machine were optimized for shock absorber use (maximal reacting force). Used as a motor, the machine is capable of acting as an active element in the suspension. An analytic and a FEM model was made, which was validated by prototype measurements. After the model validation an optimization was started. It contains geometrical, material, construction and shock absorber specific optimizations, which was shown that the performance of a conventional shock absorber may be reached with a tubular electric machine. It needs twice the volume, but it has several additional benefits (control, recuperation). With the model, it is possible to find the best geometry fitted to the available shock absorber space, which will give the maximum possible reaction force. HTSC magnets in contra-polar position, relaxation and the demagnetization were measured and were simulated on the rotor. A new HTSC construction was calculated from the same geometry, which was compared with the PM rotor machine.

4LPE09

Conceptual design of on-board cryocooler for low RPM 5 MW HTS motor

J.Jung, Korea Advanced Institute of Science and Technology; Y.C.Kim, T.S.Moon, H.J.Park, W.S.Kwon, Doosan Heavy Industry

It was known that a properly aligned cryocooler of linear compressor type does not have performance degradation in a rotating circumstance. Nevertheless, in order for an on-board cryocooler to be practical, the vibration produced by the cryocooler (mainly by the compressor) must not interrupt the rotor rotation. In other words, the on-cryocooler has to be made vibration free, or the produced vibration at the compressor must not be transmitted to the rotor. For a low RPM rotor, the latter case can be rather easily achieved by splitting the rotor and the compressor with flexible shaft coupling and tubing. In that case, the coupling and tubing permit torque and fluid transmission, but not vibration transmission. The rotor and the compressor are supported by their own bearings. If the installation of the compressor is perfect, a cold head of any type (pulse tube type, Stirling type or even GM type with proper flow rectifying circuit) can be applied. The development of a full scale on-board cryocooler of such configuration for 5 MW HTS motor is now under consideration.

This work was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

4LPF - Fault-Current Limiters – V 10:00am - 12:00pm

4LPF01

Use of superconducting fault current limiters within energy supply systems

A.Henning, M.Kurrat, A.Wehner, Technical University Braunschweig; Institute of High Voltage Technology and Power Systems; V.Schwanitz, EN|BS Energienetze Braunschweig GmbH

Fault current limiters (FCL) are being developed using high temperature superconductors. Possible applications of FCL are medium and high voltage energy supply systems. In this field conventional protection against high currents often causes high expenses. Using a superconducting FCL gives an economic advantage if a technical problem can be solved at lower costs or if its usage makes saving other equipment possible. This work deals with possible applications of a superconducting fault current limiter within a medium voltage auxiliary power network of a typical small cogeneration power plant. For possible installation locations in the existing energy supply system of Brunswick, Germany, calculations of shot circuit currents are being made. Thereby is kept track of the question, whether the power plant can be enhanced staying or becoming short-circuit-proof. One result of the work was that the auxiliary power system of the power plant is a especially interesting installation location for a FCL. Advantages of a FCL compared to conventional strengthening of the installations are discussed.

The help of en|bs Energienetze Braunschweig GmbH, the local utility, for obtaining the data for this work, is greatly acknowlegded.

4LPF02

New EMTP Equivalent Circuit Model of Core-Shielding Superconducting Fault Current Limiter Taking into Account the Flux Diffusion Phenomenon

M.Dione, F.Sirois, Ecole Polytechnique de Montreal

In order to successfully integrate superconducting fault current limiters (SFCL) into electric power system networks, accurate and fast simulation models are needed. This led us to develop a generic electric circuit model of an inductive SFCL, which we implemented in the EMTP software. The selected SFCL is of shielded-core type, i.e. a HTS hollow cylinder surrounds the central leg of a magnetic core, and is located inside a primary copper winding, generating an AC magnetic field proportional to the line current. The model accounts for the highly nonlinear flux diffusion phenomenon across the superconducting cylinder, governed by the Maxwell equations and the non-linear E-J relationship of HTS materials. The computational efficiency and simplicity of this model resides in a judicious 1-D approximation of the system geometry, together with the use of an equivalent electric circuit that reproduces accurately the actual magnetic behavior for the flux density (B) inside the walls of the HTS cylinder. The HTS properties are not restricted to the simple power law model, but instead, any resistivity function depending on J, B and T can be used and inserted directly in the model through a non-linear resistance appearing in the equivalent circuit. Measurements on a small prototype of this type of SFCL were performed in our lab. The resulting waveforms of voltage and current across the SFCL during a fault were simulated and compared with the experimental ones.

The authors kindly thank the FRQNT for its financial support of this project

4LPF03

Optimal Quenching Resistance Design using Probabilistic Method for Resistive FCL in Practical KEPCO 22.9kV Distribution System

J.Y.Yoon, S.R.Lee, KERI

KEPCO(Korea Electric Power Corporation) power system with 72GW generation capacity has been suffered from the serious fault current problem exceeding circuit breaker's breaking capability. It is caused by the high dense transmission loops and load density. HTS-FCL (Fault Current Limiter) was proposed by the powerful countermeasure for this fault current problem and developed by CAST (Centre for Applied Superconductivity Technology) as one of 21st frontier projects sponsored by government. In order to apply the HTS-FCL to practical KEPCO power system, HTS-FCL should be designed optimally to have the best performance including steady state and quenching behaviour with satisfying the system constraints such as protection problem. This paper designs the most important parameter, quenching resistance, for resistive type HTS-FCL using Monte Carlo technique. Also, this paper analyzes installation location and dynamic characteristics of HTS-FCL under various power system conditions. Various case studies for practical system with field parameters are performed to confirm the effectiveness of this model. Finally, in this paper, the reasonable quenching resistance is proposed to apply in practical 22.9kV system in near future.

This research was supported by a grant from the CAST(Center for Applied Superconductivity Technology) of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

4LPF04

HTS-FCL EMTDC Model Considering Nonlinear Characteristics on Fault Current and Temperature

J.Y.Yoon, KERI; H.S.Lee, Geo-Je Univ.

With the increasing capacity of distribution and transmission systems, the fault current is becoming a paramount issue. The issue becomes more important in applications where HTS-FCL technology is being utilized. The development of HTS-FCL is currently underway worldwide, and attempts to apply it to power systems are continuing. This paper describes the new dynamic Resistance Type HTS-FCL(High Temperature Superconductor Fault Current Limiter) EMTDC modeling, parameter tuning, and simulation study. In a practical concept, the characteristics of HTS-FCL are dependent several factors, such as the magnitude of fault current, the temperature of that, and etc. Thus, in this paper, the developed model is considering a quenching and recovery characteristics of a various type, a magnitude of the quenching and recovery starting current, a temperature dependence, a temperature coefficients, and etc. In simulation study, the developed dynamic R-Type HTS-FCL is applied the test power system of KEPCO system under various operational states. The test power system reflects exactly the actual system state for 154kV transmission lines, 22.9kV distribution lines, and other power equipments. As a simulation results, the proposed model shows a very exact characteristics, therefore, it has a capability to provide a basic information for a real development of R-Type HTS-FCL.

4LPF05

Superconducting Fault Current Limiter Design using Parallel-connected YBCO Thin Films

M.D.Ainslie, J.Baba, V.Salvucci, University of Tokyo; T.Nitta, Meisei University, CRIEPI; T.Fukunaga, M.Shibuya, Furukawa Electric; S.Torii, T.Matsumura, CRIEPI; T.Kumagai, AIST

Fault currents due to short circuit conditions that can develop from lightning strikes and other contingencies in electric power systems continue to increase, which increases the complexity of the system`s design. In order to reduce the mechanical and thermal damage that can be caused by these currents, various types of superconducting fault current limiters (SFCLs) are being actively researched. The resistive type SFCL using YBCO thin film has a simple and compact design and current research shows it has significant potential as a future protective device. However, due to limitations in current YBCO thin film manufacturing processes, it is not easy to obtain one large thin film that satisfies the specifications for high voltage/current applications. From an industrial point of view, the combination of standardized thin films using a combination of series and parallel connections has merit to reduce costs and maintain device quality. In this paper, the series and parallel connection of YBCO thin films is discussed in regard to optimizing SFCL design, including the role of a parallel resistor, the influence of individual thin film characteristics and a simple model of generated resistance, based on both theory and experimental results.

4LPF06

Quench and Recovery Characteristic of a Resistive FCL employing Bifilar Coil for Protection Coordination in Electric Power Grids

D.K.Park, Y.J.Kim, S.E.Yang, K.S.Chang, T.K.Ko, J.-W.Park, Yonsei University

Fault current limiters (FCLs) have been suggested to solve serious problems from excessive fault current in electric power grids. Many researches about FCL have been performed actively including quench and recovery characteristics of high temperature superconducting (HTS) materials. In this paper, quench and recovery characteristics of pancake type bifilar coil for FCL were simulated and analyzed by using finite element method (FEM), and the coil was fabricated and tested based on design considering protection coordination in a power grid. Short circuit tests and recovery time measurement tests were performed with the bifilar coil using coated conductors (CCs). Test results were compared with simulation results. Generated resistance and recovery time of the coil was determined by total amount of CCs and its temperature in fault duration. Optimal design of the bifilar coil was performed to fulfill the needs of electric power grids such as generated resistance and recovery time. And then, hybrid system including parallel extra impedance was suggested and tested for efficient fault current limiting and fast recovery.

This work was supported by MOCIE through EIRC program with Yonsei Electric Power Research Center (YEPRC) at Yonsei University, Seoul, Korea.

4LPF07

Multiphysical finite element modeling of inductive type fault current limiters and self limiting transformers

V.Tihanyi, A.Gyore, I.Vajda, Supertech Lab, Budapest University of Technology and Economics

A two-and-a-half dimension model of inductive type fault current limiter was developed for transient calculations. The model includes two dimensional finite elements for magnetic field directly coupled with network elements and sequentially coupled three dimensional finite elements for thermal calculations. A computersimulation was developed for implementing the model. Both iron and HTS nonlinearity are handled. The HTS model takes the E-J characteristic into account that depends on flux density and its orientation as wellas on the temperature. With 3D thermal calculation the model also handles material inhomogeneity along the perimeter of the HTS ring. The simulation results were compared with measurements performed on experimental models of inductive type fault current limiters and self limiting transformers.

4LPF08

Analysis of quench development in superconducting fault current limiters

H.-R.Kim, S.-W.Yim, Korea Electric Power Research Institute; S.-Y.Oh, Chungbuk National University; O.-B.Hyun, Korea Electric Power Research Institute

We measured and analyzed the quench development in superconducting fault current limiters (SFCLs) based on Au/YBa2Cu3O7 thin films, taking temperature dependence of thermal parameters into consideration. The SFCLs were fabricated by patterning Au/YBCO films grown on 4 inch-diameter sapphire substrates. They were subjected to simulated AC fault currents for quench development measurement. The samples were immersed in liquid nitrogen during the experiment. The quench resistance data were analyzed quantitatively with the concept of heat transfer within the SFCLs and to the surrounding liquid nitrogen. A heat balance equation was derived, and solved taking into consideration temperature dependence of thermal parameters of sapphire substrates. Simple solutions with values of thermal parameters taken from the literature agreed well with the data. They explained the quench behavior both prior to and after completion of quench propagation. The dependence of quench development on applied voltages could be also understood quantitatively.

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

4LPF09

Study on the Quenching Phenomenon in 2G Superconducting Thin Films for the Design of SFCLs

V.Salvucci, Dept. of Electrical Engineering, University of Bologna; M.Ainslie, J.Baba, Dept. of Electrical Engineering, The University of Tokyo; A.Morandi, Dept. of Electrical Engineering, University of Bologna

The increase of power demand has increased the short circuit capacity of modern electric systems. As a consequence, a device able to limit the fault current below allowed values without influencing the system in normal operating conditions is strongly required. SFCLs may be a suitable solution. Among the various types of SFCLs, the resistive type based on YBCO thin films appears to be one of the most promising. To realize a resistive type SFCL, several thin films must be used in series and parallel connections in order to meet the voltage and current levels required for practical applications. In this paper, the quenching phenomenon in YBCO thin films is investigated in order to gain proper technical know-how suitable for the design of resistive type SFCLs. In particular, the origin of the quenching, as well the propagation dynamics within the thin film are investigated.

4LPG - MRI and Medical Applications – II 10:00am - 12:00pm

4LPG01

Design of High Magnetic Field Superconducting Coils for 500MHz NMR

Q.Wang, Y.Dai, Z.Zhao, S.S.Song, IEE, CAS; S.Chen, Z.Cao, L.Yan, Y.Lei, H.Wang, Z.Dong, IEE,CAS

A superconducting magnet is designed based on the 500MHz nuclear magnetic resonance. The superconducting coil is cooled by recondensed liquid helium with the clear-bore of 77 mm. In order to reduced the liquid helium evaporation, a two-stage 4K pulsed tube refrigeration is employed to provide cooling capacity. The superconducting magnet has a active shield with high pure copper shield to protect. The paper will present the electromagnetic design, and stress and protection in detailed.

**The work was supported by high technology project in part and NSFC No. 50577063*

4LPG02

Development of high-sensitive 600MHz NMR spectrometer with cross-bore, superconducting split-magnet, and superconducting solenoidal probe

M.Okada, T.Suzuki, K.Saitoh, H.Tanaka, S.Kido, H.Tsukamoto, K.Takeuchi, H.Kitaguchi, Hitachi, Ltd.

A new high-sensitive NMR spectrometer has been developed. Since 2003, we have been developing a novel NMR spectrometer having two special features; one is the superconducting split-magnet, and the other is the superconducting solenoidal probe coil. So far, we have successfully completed the magnet development with magnetic fields up to 14 Tesla. A cryogenic probe for the novel 600MHz NMR magnet is under optimization with showing a signal to noise ratio of over 5000. In this paper, we show the recent achievements on the development of this new NMR spectrometer.

This work is supported in part by Research Promotion Bureau, Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, under the contracts: Nos.17-260 and 18-489

4LPG03

Field homogeneity and stability of coils wound with HTS tape for NMR magnets

K.Akachi, Yokohama National University; N.Amemiya, Kyoto University

Very high field homogeneity and temporal stability are required in superconducting magnets for some applications such as NMR. To realize magnetic field over 30 T, high Tc superconducting tapes will be used for the insert coil of NMR magnets because they keep high critical current density even in a very high magnetic field. However, the magnetization currents flowing in them can generate field error, which is usually neglected in magnet design assuming uniform current distribution in superconductors. This field error may deteriorate field homogeneity. Moreover, the amplitude and the spatial distribution of the magnetic field vary with decaying magnetization currents, and temporal stability of the magnetic field may be affected. We have been developing a theoretical model and implementing it into numerical codes to calculate temporal evolution of magnetic field generated in coils wound with HTS tape where the magnetization currents are taken into account. The code uses the finite element method to calculate the current distribution in a superconducting tape wound into a coil, and then magnetic field in the coil is calculated from the spatially-distributed and temporally-changing current flowing in the superconducting tape. The Model employs the power law electric field – current density characteristic and the thin strip approximation in which the current component normal to the wide face of the tape is neglected.

4LPG04

Spatial and Temporal Variations of a Screening Current Induced Magnetic Field in a Double-Pancake HTS Insert for NMR Magnet

M.C.Ahn, MIT; T.Yagai, Tohoku University; S.Hahn, MIT; R.Ando, Hitachi, Ltd.; J.Bascuñán, Y.Iwasa, MIT

This paper presents experimental and simulation results of a screening current induced magnetic field (SCF) in an HTS insert for a low-/high-temperature (LTS/HTS) NMR magnet. The HTS insert, a stack of 50 double-pancake coils, each wound with Bi2223 tape, was operated in a bath of liquid nitrogen at 77K. A screening current was induced in the HTS insert by three different magnetic field excitations: 1) a self field induction of the HTS insert itself; 2) an external field induction by a cryocooler cooled 5-T background superconducting magnet; 3) combinations of both 1) and 2). For each field excitation, the spatial and temporal variations of an SCF along the HTS insert were measured with a search coil; a numerical simulation based on a critical state model was performed to compare its result with the measured SCF. We believe that SCF is an important design parameter for an LTS/HTS NMR magnet.

4LPG05

Numerical evaluation of stresses in ring bulk HTS during field-cooled magnetization

M.Tsuchimoto, Hokkaido Institute of Technology

Applications of a bulk superconducting magnet to nuclear magnetic resonance (NMR) were reported in several experiments. Uniform and high magnetic field was obtained by field-cooled magnetization (FCM) with ring shaped samples of melt-processed bulk high-Tc superconductor (HTS). Small sized and coolant free NMR apparatus with high sensitivity is expected by using the bulk HTS and refrigerator. In the present study, stresses in ring bulk HTS during FCM are evaluated numerically. Shielding current distributions are numerically obtained with an axisymmetric model, where the superconductive characteristic is evaluated in Iterative calculation with a standard critical state model. Distributions of the hoop and radial stresses are discussed with both disc and ring models. The maximum stress is also evaluated during the magnetization process.

4LPG06

Characteristics of the magnetic field distribution for compact NMR magnets with HTS bulk annuli

S.B.Kim, T.Nakano, R.Takano, Okayama University; S.Hahn, FBML-MIT

Recently, the performance of high temperature superconducting (HTS) bulks such as critical current density, size, and mechanical strength has been improved rapidly. So, various applications with HTS bulks such as motors, bearings, and flywheels are being investigated by many research groups; Compact nuclear magnetic resonance (NMR) magnet is one of new applications after a technique to enhance maximum trapped field of an HTS bulk more than 11.7 T, 500 MHz 1H NMR frequency, has been developed. This new compact NMR magnet out of HTS bulks is far less expensive than those conventional NMR magnets and expected to be widely used in food and drug industry. In design and manufacture of those compact NMR magnets, spatial field homogeneity of large trapped magnetic field in HTS bulk annuli is essential. This paper presents magnetic field distribution in single and three assembled HTS bulk annuli, measured by a 3-axis hall sensor, and experimental results of its spatial homogeneity improvement by mounting an iron ring inside or outside of the HTS bulk annuli.

4LPG07

Sensitivity of cryogenic probes for a split-type superconducting magnet with cross-bore

K.Kawasaki, Y.Fukuda, M.Tsuchiya, Hitachi Research Laboratory, Hitachi, Ltd.; H.Yamamoto, K.Saitoh, Advanced Research Laboratory, Hitachi, Ltd.; H.Tanaka, Mechanical Engineering Research Laboratory, Hitachi, Ltd.; M.Okada, H.Kitaguchi, Hitachi Research Laboratory, Hitachi, Ltd.

By using a split-type superconducting magnet with cross-bore, one can implement a solenoidal radio frequency (RF) coil for solution nuclear magnetic resonance (NMR). We expect the solenoidal RF coil to give us higher sensitivity than the ordinary saddle-shaped RF coil. We have developed both room temperature and cryogenic NMR probes utilizing a solenoidal RF coil for the split-type superconducting magnet. The fields of the magnets are 7 T and 14 T. The probes were evaluated by a sensitivity test with the standard 0.1% ethyl benzene in deuterated chloroform. Sensitivity tests with the room temperature NMR probes indicated that signal-to-noise ratios (SNR) are 416 at 300 MHz and 1487 at 600 MHz. Thus, based on these data, we obtained a sensitivity that is 1.5-2 times better than with a conventional saddle-shaped RF coil. The sensitivity test with the cryogenic probes on the 600 MHz magnet indicated an SNR of more than 5000.

Acknowledgement: This work is supported in part by Research Promotion Bureau, Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, under contract nos.17-260, 18-489 and 19-199.

4LPG08

Effects of Manufacturing Uncertainties on Spatial Field Homogeneity in Double-Pancake Type Inserts wound with HTS Tapes for High Field NMR Application

S.Hahn, M.C.Ahn, E.S.Bobrov, J.Bascuñán, Y.Iwasa, Francis Bitter Magnet Lab., MIT

In this paper, we present effects of manufacturing uncertainties on spatial field homogeneity in double-pancake type insert magnets wound with large aspect ratio (width/thickness > 10) HTS tapes for high field NMR application. Uncertainties in physical dimensions of individual double pancake coils such as outer diameter and height originates in manufacturing tolerance of HTS tapes, ~ 7%. These uncertainties destroy ideally designed field homogeneity and introduce large odd zonal harmonic errors such as Z1 or Z3. In this paper, a new stochastic approach is suggested to estimate the potential field errors of double-pancake type HTS inserts from manufacturing uncertainties. To verify the validity of the proposed method, manufacturing uncertainties from two HTS inserts are statistically investigated and compared with measured field homogeneity values: i) 50 MHz (H50) and ii) 100 MHz (H100) of which system configuration and operational details were previously published in our 350 MHz and 700 MHz LTS/HTS NMR magnet reports.

4LPG09

Non-linear Field Strength Behavior of Superconducting Shim Coils in LTS/HTS NMR Magnets

S.Hahn, M.C.Ahn, J.Bascuñán, W.Yao, Y.Iwasa, Francis Bitter Magnet Lab., MIT

In this paper we present operational issues of first and second order shims coils during a test of a 700 MHz low-/high-temperature (LTS/HTS) nuclear magnetic resonance (NMR) magnet comprised of a 600 MHz LTS background magnet and a 100 MHz HTS insert magnet. While performing the test it was found that i) the field strength of the superconducting (SC) shim coils, positioned radially outside the LTS magnet, were reduced to 50 – 70% of their strength when tested without the HTS insert and, ii) their magnetic behavior was non-linear, i.e., had strong hysteresis. It is believed that Screening Current induced Field (SCF) is one of the major sources for this irregular performance. In order to further understand the behavior of the SC shim coils, we designed and fabricate first-order room temperature (RT) shim coils, and operated them with two different HTS inserts: 50 MHz and 100 MHz. The effect of SCF on shim coils performance was investigated experimentally and analytically. The results are presented here.

4LPH - MRI and Medical Applications – III 10:00am - 12:00pm

4LPH01

Design of High Magnetic Field MRI Superconducting Magnet with Genetic Algorithm Optimal Methods

Q.Wang, Y.Dai, Z.Zhao, S.S.Song, IEE, CAS; S.Chen, Z.Cao, L.Yan, G.Xu, IEE,CAS

An optimization design method of short actively shielded superconducting MRI magnet is presented in this paper. Firstly, the section of the solenoid coil is simplified as a current loop with zero section in order to get a linear programming problem. And the coils' position and current can be calculated using linear programming method. Then the section of the coil is optimized with genetic algorithm to get appropriate section size. The method of linear programming, especially combining with genetic algorithm, reduces optimizing variables, which makes the design of magnet feasible. Based on GA method in the Matlab, we have written a code for the design of the super-short structure of 1 T MRI. The maximum length of the superconducting coil is smaller that 1.3 m. The superconducting magnet with warm bore of 900mm and length of 800mm is obtained on the basis of the two-step optimal methods.

**The work was supported by high technology project*

4LPH02

Operating characteristics of the linear type magnetic flux pump based on the theoretical analysis

Y.D.Chung, Yonsei Univ.; T.Nakamura, Kyoto Univ.; T.K.Ko, Yonsei Univ.

For the applications of superconducting magnet systems, in order to obtain a high magnetic field with stabilized property, the technology of maintenance of the persistent current mode has currently been recognized to be one of the most important problems. As a solution for the current decay in the hybrid NMR magnet, we designed the linear-type magnetic flux pump (LTMFP). The fundamentally operating characteristics of the fabricated LTMFP were investigated: the pumping performance depended on the driving frequency. These fundamental characteristics could be partially explained by the already reported analytical equation for flux pumps. In order to explain the operating characteristics of LTMFP in totality, new analytical equations that take into account the detailed behavior of the normal spot are necessary. From this reason, we suggested the modified theoretical equations in a wide range of driving frequency. In this paper, based on the phenomenon of enhancing normal spot under moving flux we induced the theoretical equations for pumping action of LTMFP. In order to verify the introduced theoretical equation, calculated results of pumping current by the theoretical equations compared with measured results.

This work was supported by Grant-in-Aid for exploratory research (No. 14655107) of JSPS, and the 21st Century COE Program (No. 14213201) in Japan.

4LPH03

A Novel Design Method of Shapes of Ferromagnetic Materials for the Superconducting MRI Magnet

Y.Murata, M.Abe, R.Ando, T.Nakayama, Hitachi, LTD.

A novel method is presented to optimize the shape of the ferromagnetic materials in order to generate the target static magnetic field. The design of a highly homogeneous magnet such as for MRI often requires not only getting a suitable magnetomotive force due to the several pairs of coils but also using ferromagnetic materials for fine tuning. In addition, it is necessary to optimize the shape taking into consideration the manufacturing constraints. Numerical search algorithms are mainly used to optimize the engineering design. However, they have a critical defect that fluctuations of random numbers which all stochastic search algorithms have avoid or delay gaining the optimum solution. In this study, the magnetizing current corresponding to an error field is solved as an inverse problem[1], and replaced with equivalent ferromagnetic materials. This enables us to obtain the optimum solution faster than by other iteration numerical optimization methods. The static field is calculated with FEM, and the update of the material shape is reflected on the mesh. It should be noted that when the differential of the material's volume becomes great, the convergence cannot be completed stably. Consequently, we propose a combined method: the initial shape of the materials is generated with the optimization algorithm, and then the shape is updated with the explicit method. This poster presentation shows that this method works well with the test problem of designing a 2D axisymmetric magnet. [1] M. Abe, et al., Phys. Plasmas, Vol.10, 4, pp.1022—1033 (2003).

4LPH04

The Cryogenics of an MRI limb imager based on HTS technology with minimum coolant inventory

W.Stautner, M.Xu, E.T.Laskaris, K.Amm, X.Huang, E.Budesheim, G.Conte, General Electric Global Research

The prototype of a limb imaging system for Healthcare applications is presented using high temperature superconductor technology with minimum cryogen inventory. Based on previous experimental findings with thermosiphon technology this new and advanced version of a limb imager considerably minimizes the footprint in an imaging suite and requires no operator intervention. The DI-BSCCO superconducting magnet is designed for 1.5 T (center field) and a homogeneity of 6 ppm. We will discuss the proposed cryogenic design and magnet features of this imaging system.

The project is supported by NIH and with collaboration of an HTS superconductor manufacturer.

4LPH05

Field Stabilisation of an MRI magnet operating in driven mode

A.Sinanna, S.Bermond, A.Donati, C.Hugon, J.F.Jacquinot, D.Sakellariou, T.Schild, P.Tixador, CEA Saclay; M.Lakrimi, Siemens Magnet Technology Ltd

In the framework of the Iseult/Inumac project, the development of a 500 MHz whole body MRI magnet has been launched in 2006. This magnet has outstanding specifications regarding usual MRI systems as the central field is 11.7 T with a warm bore of 900 mm. This magnet will operate in driven mode, i.e. the magnet is permanently connected to a power supply. As the field stability needed for MRI imaging requires a field drift of less than 0.05 ppm/h, it is hardly feasible to directly transpose this requirements in the power supply specification. As a first step, existing solutions for other applications has been found in literature. Two of them have been selected as potentially applicable to our project: one using a semi-persistent mode, and the other one using a short-circuited superconducting coil in the inner bore. For each solution, an experimental assessment has been done on a very small 7T magnet. The objectives of these tests are to get some experimental inputs for the achievable stability in order to design and to build reduced scale prototype of components required to apply these stabilisation methods on the full scale magnet. We will present the results of the two stabilisation methods and their extrapolations.

4LPH06

Field drift compensation using a superconducting current limiter for driven mode high magnetic field magnet

S.Bermond, A.Donati, T.Schild, A.Sinanna, CEA/Irfu; P.Tixador, CNRS/Institut Néel

High magnetic field magnets are often operated in driven mode, i.e. permanently connected to a power supply. In some applications as NMR or MRI, such magnets require a very low field drift, typically less than 0.05 ppm/h. Such requirement cannot be achieved by the power supply itself, limited in the range of 1 ppm/h. In literature, it has been proposed to improve stability by adding a small resistance connected in parallel to the magnet. Due to the low impedance of this resistance compared to the magnet impedance, all current variations due the power supply are going into the addition circuit. The current inside the magnet is then kept nearly constant. The additional circuit needs a superconducting switch in order to allow magnet energizing. In case of magnet quench, this switch will experience the voltage at the magnet ends. If the magnet is protected by an external dump resistor, this voltage can reach very high value, up to several kilovolts. The realization of such a switch can lead to technical problems; for example reliability regarding the ground insulation. That is why it is proposed to replace the usual thermal superconducting switch by a current limiter. In this paper, the designed requirements of such a limiter will be investigated. A design method is proposed. This solution has been tested on a small 7 T magnet. The results of this test will be presented in this paper.

4LPH07

Experimental Layer-Wound Mockup Coil for HTS MRI Magnet Using BSCCO Tape

M.Xu, E.T.Laskaris, E.Budesheim, G.Conte, X.Huang, W.Stautner, K.Amm, General Electric, Global Research Center

Typical coils with BSCCO HTS tape are wound in a pancake or double-pancake style to minimize the strain in the tape by eliminating or minimizing the edge-wise bending of the tape. Stainless steel reinforced tapes are also preferred in the winding process to increase the strength and therefore reduce the strain due to winding tension and handling. However, an MRI magnet requires high current density in the winding pack to achieve high fields in the imaging volume and to reduce the size of the cryostat and the magnet volume. Due to the imaging volume and homogeneity requirements, layer winding is preferred both to increase the homogeneity of the fields in the large imaging volume and to reduce the number of joints that are sources of resistance in the circuit and hence sources of instability in the coil. We wound a mock-up coil using high-current-density BSCCO tape without stainless steel reinforcement. The coil is layer-wound which involved a few inline lap joints made inside the winding pack. Testing of the coil reveals a few issues that were expected. Investigations and analysis lead to a deeper understanding of the issues. We will discuss the lessons learned and potential solutions for using non-reinforced tape in a layer-wound coil. Insulation dimension control will also be discussed.

4LPH09

Research on Superconducting Properties of MgB2 Composite Superconductor and Main Magnet for MRI

D.Zhang, X.Li, X.Du, N.Song, L.Kong, M.Qiu, Z.Gao, X.Xu, S.Dai, Institute of Electrical Engineering, Chinese Academy of Sciences

Magnesium diboride (MgB2) shows a wide application prospect in the field of low field DC application for its relatively simple structure and rather high critical temperature. With the development of MgB2 composite superconductor manufacturing technology and cryogenic technology, developing conduction cooled superconducting MRI system with MgB2 composite superconductor is becoming increasingly feasible. This paper discribes superconducting properties of MgB2 composite superconductor for MRI, including the influence of Ni and Fe sheaths on the the properties of composite conductor, uniformity and n value fluctuations of MgB2 composite conductor, Shielding effect of sheath magnetic and the interaction in the self-field and external field. In addition several magnet structure of main magnet with MgB2 composite conductor are analysed and proposed.

NSFC(no. 50677067)

4LPJ - Maglev, Bearings and Flywheels – IV 10:00am - 12:00pm

4LPJ01

Levitation Experiment of Iron Block using Pinning Flux in HTS Bulk Material

R.Higuchi, T.Ishigoka, A.Ninomiya, Seikei University

By pinning flux in HTS bulk, a restoring force acts between iron and HTS bulk so as to keep the position between them constant. If we can utilize this force, it would be possible to realize a low cost magnetic levitation transport system without using high cost rare earth permanent magnets. In order to confirm this idea, the authors carried out an experiment to levitate an iron block in a space between two HTS bulks as a first step. And, the experimental result confirmed this levitation principle. The used HTS bulk is Gd-QMG material made by Nippon Steel Corporation. The levitated object is an iron sphere with a diameter of 10-30 mm, an iron cube with side length of 10×10×10 mm, and an iron rectangular bar with a side length of 10×10×30 mm. In this paper, levitation characteristics of these objects are presented.

4LPJ03

Accurate Position Control of Active Magnetic Levitation using Sphere-shaped HTS Bulk for Inertial Nuclear Fusion

Y.Ishigaki, H.Ueda, K.Agatsuma, A.Ishiyama, Waseda University

High-temperature superconducting bulk (HTS bulk) materials are expected to be used for superconducting flywheels, magnetic levitation systems, superconducting permanent magnets, motors, and so on. We have been developing an active magnetic levitation system using HTS bulk which can be applied to inertial nuclear fusion. The developed system is composed of a field-cooled disk-shaped or sphere shaped high HTS bulks and multiple air-core ring-shaped solenoid coils which are vertically piled up along the central axis of the solenoids. In this system, the levitation height of HTS bulk can be controlled by adjusting the operating current of each coil individually. One of the most important issues is to achieve stable vertical noncontact levitation and highly accurate position control of a capsule, which is covered with superconducting material, containing nuclear fusion fuel. In this study, we designed and constructed a model magnetic levitation system to realize the stable levitation of a sphere-shaped HTS bulk with a diameter of 5 mm by using the numerical simulation program based on the 3-D hybrid finite and boundary element method. Then, we carried out some experiments to investigate the stability of levitation and the position control characteristics.

4LPJ04

Analysis of dynamic characteristics of a superconducting spherical rotor in a given magnetic field

J.H.Liu, Institute of Electrical Engineering, Chinese Academy of Sciences

Aiming at dynamic characteristics calculation on a superconducting spherical rotor suspended by spherical coils, a numerical method which can avoid complicated and tremendous calculation is presented. The spherical coils are composed of six coils which aligned in a sphere. Sets of magnetic flux density are obtained by FEA method. Meanwhile the maximum offset of the rotor is got under the Meissner state with the given exciting circuit in the coils. Simplified expressions revealed the relationship between magnetic force and offset are achieved from these values. Dynamic characteristic and drift motion of the rotor are analyzed based on the simplified expressions. An applied dynamic equation of the magnetic suspended rotor is achieved.

4LPJ05

Enhancement of HTS Maglev vehicle system from three essential aspects

Z.Deng, J.Wang, J.Zheng, H.Jing, W.Liu, Y.Zhang, S.Wang, Applied Superconductivity Laboratory, Southwest Jiaotong University

In order to put the practice of high temperature superconducting (HTS) Maglev vehicle technology into people's life, the interaction between high temperature superconductor (HTSC) and permanent magnet guideway (PMG) as the basic model of HTS Maglev vehicle was carefully investigated and enhanced from three essential aspects, i.e., bulk HTSC material, PMG field and bulk HTSC magnetization. The Maglev measurement experiments were conducted with three kinds of bulk HTSC materials, two kinds of PMGs and two kinds of magnetization methods. It was found that three aspects are all very effective to improve its levitation capability and lateral stability. With better bulk material, more reasonable PMG configuration and magnetization method, the performance of HTS Maglev vehicle system was greatly advanced and closer to an economical and practical level.

This work is supported by the National High Technology Research and Development Program of China (2007AA03Z210), the National Natural Science Foundation in China (50677057) and the Innovation Foundation of Southwest Jiaotong University for Ph.D. Candidates, China.

4LPJ06

Studies on the lateral restorable range of high-Tc superconducting maglev above permanent magnet guideway

G.Ma, J.Wang, S.Wang, Q.Lin, M.Liu, Z.Deng, Applied Superconductivity Laboratory, Southwest Jiaotong University

The lateral restorable range is a key parameter for the stability in the design of high-Tc superconducting (HTS) devices, such as HTS maglev vehicle, superconducting magnetic bearing, and so on, but so far, there are few studies on this topic. In this paper, a simple device has been designed to study the lateral restorable range of the bulk YBCO array above permanent magnet guideway (PMG),and the dependence of lateral restorable on the field-cooling height (FCH) as well as levitation height (LH). Moreover, the experimental results are interpreted by the theory. In the end, the optimal FCH and LH of HTS maglev vehicle are obtained from the pointview of practical application.

This work is supported by the National Natural Science Foundation in China (No: 50777053)and the National High Technology Research and Development Program of China (No:2007AA03Z210).

4LPJ07

Influence of the permanent magnet guideway transverse slope on high temperature superconductor maglev system

S.Pan, S.Wang, Q.Lin, Q.He, J.Wang, Applied Superconductivity Laboratory, Southwest Jiaotong University

To optimize levitation performance of high temperature superconductor (HTS) Maglev vehicle, it is key to investigate the levitation and guidance performance of the HTS bulk above permanent magnet guideway (PMG). When the PMG transverse angle has been changed, levitation and guidance performances of HTS may be considered. So from 0° to 12°of the PMG transverse slope was investigated, the levitation and guidance experiments show that the transverse slope angle exceed 8°,the levitation and guidance performance reduces significantly. The transverse slope external magnetic field change was analyzed, which agrees to the experimental results.

This work is supported by the National High Technology Research and Development Program of China (2007AA03Z207) and National Natural Science Foundation in China (50677057).

4LPJ08

Performance improvement of high temperature superconducting Maglev system by eddy current damper

J.Zheng, Z.Deng, Y.Zhang, S.Wang, J.Wang, Applied Superconductivity Lab, Southwest Jiaotong University

An indirect method is presented to use eddy current damper for more practical high temperature superconducting (HTS) Maglev vehicle system in the paper. Different shapes and positions of inputted eddy current damper are studied in one HTS Maglev unit. Similarly to the direct optimization of the superconductor and permanent magnet guideway system, eddy current damper can help to improve the static and dynamic performances of HTS Maglev vehicle system. Further, effect of eddy current damper on speed shows the running stability (dynamic and thermal) of the HTS Maglev vehicle system by simulation. Thus, it will be another important performance improvement way for the future industrial application.

This work is supported by the National High Technology Research and Development Program of China (2007AA03Z210) and National Natural Science Foundation in China (50677057).

THURSDAY AFTERNOON ORAL SESSIONS 3:00pm - 5:00pm

4LA - Other Accelerator Magnets – III 3:00pm - 4:15pm

3:00pm

4LA01 - Test Results for the MICE Tracker Superconducting Solenoids

***S.P.Virostek**, M.A.Green, D.Li, M.S.Zisman, Lawrence Berkeley Laboratory*

This report describes the MICE tracker solenoids as built. Each tracker solenoid consists of five superconducting coils. Two coils are used to tune the beam going from or to the MICE spectrometer from the rest of the MICE cooling channel. Three spectrometer coils (two end coils and a long center coil) are used to create a uniform 4 T field (to 0.3 percent) over a length of 1.0 m within a diameter of 0.3 m. The three spectrometer coils are connected in series. The two end coils have a small power supplies to tune the uniform field region where the scintillating fiber tracker is located. This paper will present the results of the testing of the tracker solenoids.

This work was supported by the Lawrence Berkeley Laboratory and the Office of Science, U.S. Department of Energy under Contract No. DE-AC02-05CH11231

3:15pm

4LA02 - HINS Linac Front End Focusing System R&D

***J.C.Tompkins**, G.Apollinari, Fermilab; V.Aseev, Argonne; R.H.Carcagno, J.Dimarco, V.S.Kashikhin, V.V.Kashikhin, D.F.Orris, Fermilab; P.Ostroumov, Argonne; T.M.Page, R.Rabehl, C.Sylvester, M.A.Tartaglia, I.Terechkine, Fermilab*

This report summarizes current results from an R&D program to develop a focusing system for the front end of a superconducting RF linac. Superconducting solenoids will be used as focusing lenses in the low energy accelerating sections and superconducting quadrupoles are to be installed in the higher energy sections. The development of focusing lenses for the first accelerating section is in the production stage, and lens certification activities are ongoing at FNAL. The report will present information about the focusing lens design and performance, including solenoid, dipole corrector, and power leads and about cryogenic system design and performance. It will also describe the lens magnetic axis alignment technique as well as a discussion of the final acceptance/certification testing. Finally, the status of ongoing R&D to develop solenoid-based and quadrupole-based focusing lenses for the higher energy sections of the linac will be presented.

3:30pm
4LA03 - HTS 5 tesla synchrotron and neutron beamline magnets
***D.M.Pooke**, V.Chamritski, M.Fee, S.Gibson, B.T.King, HTS-110 Ltd; J. L.Tallon, Industrial Research Ltd; M.Meissner, R.Feyerherm, Hahn-Meitner Institut; S.Olsen, S.Kennedy, R.Robinson, The Bragg Institute*
Two world-first High Tc Superconducting (HTS) beamline magnets have been designed, manufactured and commissioned for synchrotron and neutron research facilities. One, for the Hahn-Meitner Institut, is for use with their high resolution diffraction and resonant magnetic scattering instrument MAGS at the Berlin electron synchrotron facility BESSY. The key features of this 5 tesla split-pair magnet include field performance within a given confined geometry, and low weight. Mounting in a 6-circle goniometer and employing conduction-cooled HTS coils, it operates through 90 degrees of rotation with respect to the beamline axis and scattering plane. The neutron beamline magnet is also a 5 tesla split pair, designed for both neutron reflectometry and small angle neutron scattering research at the new OPAL neutron facility of the Australian Nuclear Sciences and Technology Organisation. This much larger magnet offers wide neutron beam accessibility angles in both axial and transverse directions, large (50mm) sample capability, and mounts on tilt stages operating in two axes. Both magnets use pulse-tube refrigeration for the HTS coils, which have been constructed from high performance BSCCO wire, and both are compatible with separate commercial cryofurnaces providing sample temperatures from 1.5 K (MAGS) or 4 K (OPAL) to over 600 K.

3:45pm
4LA04 - Short period Nb3Sn undulator demonstration
*H.W.Weijers, **K.R.Cantrell**, NHMFL/FSU*
A superconducting planar undulator demonstration magnet is constructed and tested at the NHMFL. High current density PIT Nb3Sn conductor is applied on iron yokes, with a period of 14.5 mm. Upper and lower jaws consisting of two segments each are clamped around a mock beam liner. Very low resistivity joints connect the jaw segments. The projected field on the beam approaches 1 T based on a winding gap of 8.5 mm and a design average winding pack current density of 1800 A/mm2. The results of 4.2 K bath test are presented and discussed, leading to implications for a user magnet based on this technology.
This work is supported in part by the Advanced Photon Source, Argonne National Lab, under Contract 5F-00497.

4:00pm
4LA05 - A model superconducting helical undulator wound of a wind and react MgB2 multifilamentary wire
***M.Majoros**, M.D.Sumption, S.D.Bohnenstiehl, E.W.Collings, The Ohio State University; M.Tomsic, M.Rindfleisch, J.Phillips, D.Lyons, J.Yue, Hyper Tech Research, Inc.*
A short model helical undulator, 250 mm long, with a period of 14 mm was designed, fabricated and tested in liquid helium bath. The helical coil was wound with stabilized multi-filamentary MgB2 strand, 0.5 mm in diameter, in a wind and react mode with S-glass insulation followed by vacuum epoxy impregnation. Beam aperture of the coil is 7 mm, winding bore diameter 8 mm, coil winding OD=18 mm and 1010 Fe pole (flange) OD=19.05 mm. The coil was measured for Ic and magnetic field in the bore at 4.2K in liquid helium bath. The bore field as a function of depth was also determined near the critical current at 4.2 K. The load line of the coil was compared to short sample Ic values. A comparison of the magnetic field maps with those obtained from numerical modeling using finite element method, was also made.

4LB - Fault-Current Limiters – VI 3:00pm - 5:00pm

3:00pm
Invited
4LB01 - First Commercial Medium Voltage Current Limiters Based on BSCCO 2212 Bulk Components
*S.Elschner, Hochschule Mannheim; R.Dommerque, **D.Maier**, Nexans SuperConductors; M.Noe, Forschungszentrum Karlsruhe; F.Steinmeyer, M.Stemmle, J.Bock, Nexans SuperConductors*
Superconducting bulk coils cut from melt cast processed BSCCO 2212 tubes are an already proven material option for resistive current limiters. Two distinct basic concepts are followed, electrical protection with a continuously contacted metallic shunt and quench homogenisation via magnetic trigger field with a parallel coil wound around the superconductor. The metallic shunt concept has already demonstrated its reliability in a field test within the CURL 10 project. Since then, the further development including new shunt materials has brought a substantial increase of performance with respect to higher powers and larger electric fields. Different commercial applications with a protected power in the range of 20 MVA are going to be installed within 2008. The contribution presents the progress of development including high voltage and cryogenic issues. The field triggered concept has several advantages especially with respect to the required amount of superconducting material and thus the occurring AC-losses. Although this concept has in principle shown its functionality, the manufacturing process for the needed large quantities still needs further optimisation. Actual progress of the corresponding material development and perspectives for applications in the transmission level are discussed.
The work was partially supported by the German Government (BMBF/VDI) under Grant 13N8868.

3:30pm
4LB02 - Introduction of 35kV/90MVA live-grid operated superconductive fault current limiter
***Y.Xin**, W.Z.Gong, X.Y.Niu, Innopower; Y.QGao, Q.Q.Guo, Tianjin M&E Industry Group, Co.; Z.J.Cao, H.Hong, Z.H.Li, X.M.Hu, B.Tian, J.Y.Zhang, Y.Wang, J.Z.Wang, Innopower; J..Cui, S.Z.Ding, Tianjin M&E Industry Group, Co.*
We developed a saturated iron-core type 35kV/90MVA superconductive fault current limiter and installed the device in a transmission network at Puji substation of China Southern Power Grid for live-grid operation. Innovative design in the iron-core structure ensures the device having low impedance in normal power transmission and sufficient high impedance in a fault current limiting action. A dc magnetization control circuit enables the iron-cores to be saturated or de-saturated depending upon the functional requirement. An energy release and voltage-surge suppressing unit can promptly discharge the magnetic energy in the iron-cores and to suppress the induced and surge voltages on the dc circuit in the current limiting process. This device is to reduce the magnitude of a fault current by 50%, so the breaking capacity of the existing circuit breakers in the transmission network is not exceeded. Structural and functional specifications are presented in this article. Up-to-date live-grid operation data of the device will also be reported.

3:45pm

4LB03 - Electrothermal phenomena about current limitation using coated conductors

***P.Tixador**, Grenoble INP; T.Nguyen, Y.Cointe, G2Elab; C.Villard, CNRS*

The superconducting (SC) fault current limiter (FCL) is very attractive to enhance the security and the power quality of the electricity grid, which explains its great interest throughout the world. Most of SC FCL uses the quench of a SC element and the thermal phenomena are fundamental. To study them we follow two approaches: experimental and modeling. For the experiments, we have developed temperature sensors deposited directly on coated conductors to achieve the best thermal coupling and a very short time response. The sensors are micron size copper meanders (typically a section of 90 µm by 0.2 µm). A very thin polymer layer provides the necessary electrical isolation. The sensor response is satisfying both in terms of time response and accuracy. The measurements, especially the hot spot temperature, are in good agreement with temperature calculations, performed using the current data during limiting experiments. The voltage data gives informations about the quench homogeneity. The recovery phase is very important and has been studied using the temperature measurements. They are in good agreement with some calculations. Several tests carried out on different samples will be presented and analyzed. These works are important for a better understanding of the complex phenomena occurring during a limitation and for the design of a conductor suitable for FCL. They validate at last our models.

Works supported by ANR.

4:00pm

4LB04 - Evaluation of Fault Current Limiters for Power Utilities using EMTP-RV

***J.R.Cave**, O.Saad, IREQ Hydro-Québec*

Using the software EMTP-RV (Electromagnetic Transient Program) that includes comprehensive models of superconducting materials such as YBCO thin films, 2G tapes, bulk materials and MgB2 wires the performance of resistive fault current limiters can effectively be evaluated in typical network conditions. These models include the electromagnetic and thermal behavior of the superconducting composites and connected materials. The superconductor's resistivity depends on the evolution of the transport current and self-field, and in certain configurations an additional control field. Also, the modular nature of many resistive limiters implies careful control of the interconnects between series and parallel superconducting elements. This is to keep the current flow distributed uniformly and this is modeled by using repeated modules within EMTP. Not only can this approach model the device behavior in the power network but also can be used to investigate local current pathways in the superconducting materials. In this article an evaluation of the performance of resistive current limiters in typical power network situations will be presented.

4:15pm

4LB05 - Assessment of small bend diameter magnesium diboride wire for superconducting fault current limiter applications.

***A.Oliver**, A.C.Smith, M.Bailey, Y.Feng, Manchester University; M.Husband, Rolls-Royce Plc*

The paper examines the suitability of three samples of Hyper Tech Research Inc. magnesium diboride wire wound onto a 2cm diameter ceramic former, for use as an element in a resistive fault current limiter. Sample 1 is a monofilament magnesium diboride wire with CuNi sheath; sample 2 is monofilamentary with a CuNi sheath, doped with SiC and Mg; sample 3 has 18 Mg doped filaments with Cu stabilisation in a CuNi sheath. The wire diameter of all samples was 0.83mm. A fully controllable low current supply was used to determine the variation of the coil impedance with frequency and temperature. The frequency characteristic enabled the calculation of coil inductance and superconducting resistance. Critical temperatures measured were in the range of 34K – 39K. A high current supply was used to test the coils current limiting properties in the temperature range 25-32K in self field at 50Hz. Good current limiting properties were observed with quench currents in the range 130-390A. No detectable damage being caused to the wire during the quench process. The main objective of the paper is to demonstrate the suitability of magnesium diboride wire for fault current limiting applications in terms of manufacturing costs, coil fabrication technique i.e. material handling (particularly at low bend diameters) and quench behaviour.

The authors thank Hyper Tech Research Inc, Scientific Magnetics, Rolls-Royce Plc and the UK Department of Trade and Industry.

4:30pm

4LB06 - Introduction of an SFCL Operation Test in KEPCO`s Test Line with Artificial Faults

***O.-B.Hyun**, H.-R.Kim, S.-W.Yim, T.-H.Kwon, D.-MKim, Korea Electric Power Research Institute; K.-B.Park, J.Sim, B.W.Lee, I.S.Oh, LS Industrial Systems*

This report describes Korea's effort for a Superconducting Fault Current Limiter (SFCL) operation test in the KEPCO's 22.9 kV test line with artificial faults. First, we have redesigned the previously developed hybrid SFCL so that it can meet the 0.5 s reclosing requirement by fast auto-reset including the recovery of the superconducting part from quench. The rated current may be varied from 350 A to 630 A depending on the fault current. The test line, which can generate artificial faults by an automatic fault generator, carries various relays and recloses for protection scheme study. There are two major test targets; (1) long term operation test of the SFCL, (2) protection coordination test using artificial faults. For the latter part, efforts will be focused on how to make the SFCL and other protection devices work together. We will also discuss various problems associated with an SFCL such as inrush current during reclosing.

This work was supported by the grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea.

4:45pm

4LB07 - Test requirements and standardization issues for resistive type superconducting fault current limiters

***B.W.Lee**, J.Y.Koo, Hanyang University/Division of Electrical Engineering and Computer Science*

Among the various types fault current limiters, superconducting fault current limiters are the most preferable choice for high voltage and high current electric power systems due to the excellent current limiting characteristics of superconductors. However, there has been no superconducting fault current limiter installed into actual high voltage electric systems until now. In order to promote the development and application of the superconducting fault current limiter, it is necessary to grasp the electric power utilities' requirements and suitable test method and some specifications should be prepared. This paper focuses on the matters of test requirements and standardization issues that were pre-requisites for commercialization of superconducting fault current limiters. The performance and test results by some developers' stand points are reviewed and other standards including circuit breakers, transformers, reactors, power fuse, and fused circuit breakers were compared and considered for the basic steps to setup novel specification of superconducting fault current limiters. Furthermore, the lists of test methods were suggested for evaluating the performances of superconducting fault current limiters considering the installation sites such as bus-tie section, outgoing feeders, incoming feeders and the protection of main transformer.

THURSDAY LATE AFTERNOON ORAL SESSIONS 5:30pm - 7:30pm

4LX - Stability and Protection IV – LTS 5:30pm - 7:15pm

5:30pm

4LX01 - Transient Stability of Impregnated and Non-Impregnated Nb-Ti Rutherford Cables

***G.P.Willering**, University of Twente; A.P.Verweij, CERN; A.den Ouden, H.H.J.ten Kate, University of Twente*

The quench behaviour of Rutherford cables, especially if operated at 60-90% of their critical current, is very sensitive to even the smallest heat releases. Consequently, thermal-electromagnetic stability against transient heat deposition in cable strands is a key factor in the design of superconducting cables. Due to the complex phenomena contributing to stability such as helium cooling and inter-strand current and heat transfer, the level of stability and the margins associated are hard to assess. An important mechanism to model and quantify in detail is the transient cooling by helium. In order to experimentally verify this issue we have prepared two identical Nb-Ti cable samples for performing transient stability measurements using point-like heaters. One cable sample is impregnated, hence eliminating the helium inside the cable voids as well as drastically reduce heat transfer to the surroundings. The second cable sample is non-impregnated, so that the helium in the cable voids is in good contact with the strand surface. We clearly demonstrate that the reduced stability at the cable edges, as we have observed in all our experiments on Rutherford cables, is due to the reduced amount of helium in the voids. By comparing the results obtained on these two cable samples with the simulation model, we are able to better discriminate the various heat flows, and more specifically, better quantify the heat transfer from the cable to the helium. Furthermore, the experiment provided a valuable validation of our CUDI simulation software.

5:45pm

4LX02 - Measurements of Ac Loss in Cored Nb3Sn Rutherford Cables: Interstrand Contact Resistance as Function of Cable Deformation

***E.W.Collings**, M.D.Sumption, LASM, MSE, The Ohio State University; E.Barzi, D.Turrioni, R.Yamada, A.V.Zlobin, Fermi National Accelerator Laboratory; Y.Ilyin, A.Nijhuis, Low Temperature Division, Faculty of Applied Physics, University of Twente*

Calorimetric and magnetic measurements of AC loss have been performed on Nb3Sn based cored cables. Five cables were measured, three with cores and two without. The cored cables each with a 9 mm wide core, and were given either standard (S), heavy (H), or light (L) compactions, with cable thicknesses of 1.78 mm, 1.72 mm, and 1.84 mm, respectively. The two uncored cables represented the heavy and light compactions. The cables, fabricated at Fermilab from RRP-type strand, were wrapped with S-glass tape impregnated in most cases with a ceramic binder (applied before reaction HT). The HT/pressurization sequence of the cables was made to mimic as closely as possible the expected (LARP) accelerator magnet-fabrication schedules. Contact resistance values were extracted from known loss expressions.

This work was supported by the U.S. DOE, HEP, under Grant No. DE-FG02-95ER40900

6:00pm

4LX03 - Current Sharing and AC Loss Measurements of Cable-in-Conduit Conductor with Nb3Sn Strands for the High Field Section of the Series-Connected Hybrid Outsert Coil

***I.R.Dixon**, M.D.Bird, National High Magnetic Field Laboratory; P.Bruzzone, B.Stepanov, EPFL-CRPP*

Performance verification of the Nb3Sn cable-in-conduit conductor (CICC) for the Series-Connected Hybrid magnets at the National High Magnetic Field Laboratory (NHMFL) and Hahn-Meitner Institiut (HMI) is performed through short sample testing. The superconducting outsert coil consists of three CICC configurations, graded for the applied magnetic field. The CICC for the high field section of the coil is tested in the SULTAN facility at CRPP. The CICC is representative of the cable pattern, twist pitch, void space, and dimensions of what is planned for the magnet systems. Measurements of the current sharing temperature at field current combinations comparable to what is expected in the magnet are made. Electromagnetic cycling is performed with a repeat of the current sharing measurements to investigate the Nb3Sn strand sensitivity to transverse electromagnetic loading. In addition, measurements of AC loss and pressure drop along the conductor are made and discussed.

6:15pm

Invited

4LX04 - Self field instability in high-Jc Nb3Sn strands with high RRR

***B.Bordini**, L.Rossi, CERN*

High critical current density (Jc) Nb3Sn conductor is the best candidate for next generation high field (> 10 T) accelerator magnets. Although very promising, state of the art high-Jc Nb3Sn strands suffer of magneto-thermal instabilities that can severely limit the strand performance. Recently it has been shown that at 1.9 K self field instability is the dominating mechanism that limits the performance of strands with a low (

6:45pm

4LX05 - Magnetization, Low Field Instability and Quench of RHQT Nb3Al Strands

***R.Yamada**, Fermilab; M.Wake, KEK, Japan; A.Kikuchi, NIMS, Japan*

Practical copper stabilized Nb3Al strands are now being produced over the length of 1 km for the application of high field accelerator magnets and others. Several different types of the RHQT Nb3Al strands were developed at NIMS and they have been studied. As the RHQT Nb3Al strands are heated up to 2000 degrees centigrade during strand production, pure Niobium or Tantalum is used as the matrix element for Nb3Al strands. Because these materials are superconducting at 4.5 and 2.2 Kelvins respectively, they cause some characteristic magnetization, and disturbance at low field regions. In the past we have made and tested the Nb matrixed and Ta matrixed Nb3Al strands. We have observed anomalously large magnetization with Nb matrixed strand at the operation of 4.5 K. This problem was eliminated with the Ta matrixed strand at the operation of 4.5 K. But with this strand a similar anomalous magnetization was observed at 2.2 K operation. We investigated these phenomena with computer simulation. At the low field the interfilamentary coupling currents in the outer layers of subelements make a shielding current, reducing the inside field and standing against higher outside field. At higher external field eventually the superconductivity of the matrix elements collapses and releases a large energy, causing the quench at that point. Depending on the size of the energy the strand or the cable starts the quench operation. The minimum quench energy MQE is calculated and it is confirmed with the computer simulation.

7:00pm
4LX06 - Effect of cable edge deformation on RRR and magnetization of strands extracted from Nb3Sn-type Rutherford cables
***M.D.Sumption**, E.W.Collings, V.Nazareth, LASM, MSE, The Ohio State University; D.Dietderich, H.Higley, Lawrence Berkeley National Laboratory*
Modern high-Jc Nb3Sn strands and cables used in high field accelerator magnet models suffer from flux jump-related instabilities at low magnetic fields, these instabilities are exacerbated by enhanced magnetization and/or reduced RRR. Such instabilities and their response to deff and RRR in individual strands have been widely reported. In this work, we look at the influence of strand deformation during cabling on RRR and magnetization for strands extracted from Nb3Sn Rutherford cables; these results are compared to those for isolated strands given individual deformation. Four separate cables types were used for this study, two rectangular and two keystone cables, These cables were used to wind both race-track and quadrupole magnets. Longitudinal variations of RRR were estimated from multiple-tap measurements along the length of strands extracted from the various cables and then reacted in a special fixture. Magnetization measurements were then performed on cable sections to examine the effect of edge deformation. The implications of these measurements for stability are discussed.
This work was supported by the U.S. Dept. of Energy, Division of High Energy Physics, under Grant No. DE-FG02-95ER40900 and Contract No. DE-AC03-76SF00098.

4LY - Fault-Current Limiters – VII 5:30pm - 7:30pm

5:30pm
Invited
4LY01 - Development of Resistive Fault Current Limiters Based on YBCO Coated Conductors
***H.-W.Neumueller**, W.Schmidt, H.-P.Kraemer, Siemens Corporate Technology; A.Otto, J.Maguire, J.Yuan, D.Folts, W.Romanosky, B.Gamble, A.P.Malozemoff, American Superconductor; N.Lallouet, F.Schmidt, Nexans; S.Ashworth, J.O.Willis, Los Alamos National Laboratory; S.Ahmed, Southern California Edison*
All over the world there is a growing need for current limiting devices in electrical networks with steadily increasing power demands and fault currents. Initiation of production of YBCO coated conductors (CCs) paves the way for economically viable superconducting fault current limiters (FCLs) both in power distribution and transmission networks. In a collaboration between AMSC and Siemens, the limiting capability of YBCO CCs has been investigated and was demonstrated in a successful laboratory test of a 2.2 MVA medium voltage FCL. This device is based on bifilar coils with CCs as switching elements and corresponds to one phase of a 3-phase FCL designed for the 13 kV-class distribution voltage level. In more than 40 switching tests at voltages up to 7.7 kV the device showed excellent limiting performance. Presently this collaboration has been expanded and has entered a new DOE funded joint project that encompasses the design, construction and test of a 115 kV FCL for power transmission within a time frame of 4-5 years. AMSC as the project leader is responsible for wire manufacturing, system integration and cryogenics. Siemens` main task is switching module development, Nexans contributes the high voltage terminations and Los Alamos National Laboratory investigates AC losses. Installation and testing are planned for a Southern California Edison substation. A project overview and progress under the first phase will be reported.

6:00pm
4LY02 - Design and Experimental Results of three-Phase Superconducting Fault Current Limiter using High-resistive YBCO Tapes
***T.Yazawa**, K.Koyanagi, M.Takahashi, M.Ono, M.Sakai, K.Toba, H.Takigami, M.Urata, Toshiba Corporation; Y.Iijima, T.Saitoh, Fujikura Ltd.; N.Amemiya, Yokohama National University; Y.Shiohara, ISTEC*
As one of the programs in the Ministry of Economy and Trade and Industry (METI) project regarding R & D on coated conductor, three-phase 6.6kV superconducting fault current limiter (SFCL) has been developed and some evaluation tests have been implemented. The developed SFCL is mainly comprised three-phase set of current liming coils in stalled in a sub-cooled nitrogen cryostat with a GM cryocooler, circuit breakers and a sequence circuit. The whole system is installed in a panelboard. Two tapes were wound in parallel in each coil to obtain the rated current of 72Arms. AC characteristics of each coil were measured and relevant performances were obtained. After developing the whole SFCL system, short circuit experiments were implemented with a short circuit generator. In a three-line ground fault test, the SFCL successfully restricted the short circuit current over 1.6kA to about 800A by the applied voltage of 6.6 kV. The SFCL in installed in a user field and connected with a gas engine generator. The paper also describes the test results obtained in the field.
This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

6:15pm
4LY03 - Comparison between the behaviour of HTS thin film grown on sapphire and coated conductors for fault current limiter application.
***L.Antognazza**, M.Therasse, M.Decroux, University of Geneva; M.Abplanalp, ABB Corporate Research Centre; O.Fischer, University of Geneva*
Due to their lower price, coated conductors (CC) have been recently tested for current limitation applications. One weakness of these CC is their very low electric fields, typically below 1V/cm as compared to 40V/cm observed in YBCO films grown on sapphire. The limitation of this electric field in CC comes certainly from the very low propagation velocities of the dissipative state, a property which might be correlated with the poor thermal behaviour of the architecture of these materials. We have then investigated the thermal and electrical behaviour and the propagation velocities in CC during constant current pulses above Jc and constant voltage pulses. The comparison with the results obtained on YBCO films grown on sapphire shows two major differences. In CC, the flux flow resistivities are 2-3 orders of magnitude higher than in film grown on sapphire and quench propagation velocities at least 3 orders of magnitude lower (of the order of cm/s) are confirmed. Measurements of the CC's temperature in the normal state during current or voltage pulses indicate that the DyBCO/Ag bilayer is in a quasi adiabatic regime. The observed velocities can be explained, within an adiabatic model, only if we assume a very low thermal conductivity for the bilayer. This could come from the different grain interfaces present in CC which might strongly decrease the thermal conductivity of the bilayer.

6:30pm
4LY04 - Switching test of 500 V/200 A fault-current-limiting modules made of large MOD-YBCO thin films with high-resistivity Au-Ag alloy shunt layers
***H.Yamasaki**, National Institute of Advanced Industrial Science and Technology (AIST); K.Arai, K.Kaiho, Y.Nakagawa, M.Sohma, W.Kondo, I.Yamaguchi, T.Kumagai, AIST*
We recently proposed a new design for YBCO thin-film fault-current limiter (FCL), which uses high- resistivity Au-Ag alloy shunt layers instead of pure gold layers conventionally used. Because of their much larger resistance the FCL elements withstand very high electric fields (> 30 Vrms/cm), which leads to a dramatic cost reduction through much reduced amount of expensive large-area YBCO films. In this presentation, switching test results of the FCL modules are reported. Two YBCO thin films (27 mm wide and 200 mm long), prepared by a low-cost MOD method, were connected parallel with using Ag-sheathed Bi-2223 superconducting tapes. An ac current of ~380 Apeak flowed without quench for 5 cycles (50 Hz), which is about 1.15 times larger than inductively estimated critical current of 330 A, and the rated current of 200 Arms was achieved. The effective FCL length of ~170 mm was divided into three parts (~57 mm, room temperature resistance of ~1.9 ohm), and an outer resistor (0.35 ohm, made of noninductively wound Manganin wire) and a capacitor (120 micro-F) were connected parallel for each part for the protection against the hot spots at the time of quenching. The rated voltage of this module is 500 Vrms, and it was tested successfully up to ~450 Vpeak, limited by our power supply. We will also present the result of a higher-voltage switching test to confirm the voltage specifications.

6:45pm
4LY05 - An investigation into an Inductive Shielded Type SFCL incorporating YBCO Coated Conductor Cylinders
***F.J.Mumford**, AREVA T&D, Technolgy Centre, Stafford, UK; A.Usoskin, EHTS, Alzenau, Germany*
Because of its self-triggering and rapid switching capability in the presence of over- currents, the superconducting fault current limiter (SFCL) is recognised as potentially the most attractive device for protecting electric power systems from damaging short circuit currents. Three main types of SFCL are presently under investigation; the resistive type, the inductive-shielded type and the inductive-saturated iron core type. The first two operate as switches utilising the intrinsic rapid superconducting to normal state (S-N) transition capability of superconductors. The third type does not lose superconductivity even under current limiting scenarios. All three devices generally incorporate specific HTS conductors each with individual (cost, performance) merits. In this paper, the inductive shielded type of SFCL utilising YBCO coated conductor cylinders is investigated and its merits determined.

7:00pm
4LY06 - Conceptual Design of 6.6 kV Class Superconducting Fault Current Limiter with YBCO Thin Film Elements
***T.N.Nitta**, Meisei University; T.M.Matsumura, Nagoya University; J.B.Baba, The University of Tokyo; S.T.Torii, Central Research Institute of Electric Power Industry; T.K.Kumagai, Advanced Industrial Science and Technology; T.F.Fukunaga, The Furukawa Electric Co., Ltd.; M.S.Shibuya, The Furukawa Electric Co., Ltd*
A cubicle-type superconducting fault current limiter (SFCL) for 6.6 kV and 400 A was conceptually designed. The SFCL consists of parallel- and series-connected superconducting YBCO elements and limiting resistor. Adopted superconducting element has a rectangular shape of 30 mm width and 210 mm long, where YBCO thin film of about 200 nm in thickness is coated on sapphire substrate with cerium oxide (CeO2) interlayer by metal-organic deposition (MOD) method and covered by a protective metal coat. The over-current carrying experiments were carried out to derive the data required to design the SFCL, such as a voltage-current characteristic and withstand voltages of the superconducting elements. Furthermore, the parallel and series connecting methods of superconducting elements and the limiting resistor were theoretically and experimentally discussed. The single-phase prototype FCL was constructed and it is fount out from the fundamental tests that the prototype FCL has satisfactory performances.

7:15pm
4LY07 - Testing and Demonstration Results for the Transmission-Level (138kV) 2G Superconducting Fault Current Limiter at SuperPower
***J.C.Llambes**, C.S.Weber, D.W.Hazelton, M.Marchevsky, Y.Y.Xie, V.Selvamanickam, SuperPower, Inc.*
Development of SFCLs has been pursued for decades. In the past the Achilles heel of these devices was typically the reliability of the brittle, ceramic superconducting material. However, within the last 1-2 years a newer, more robust type of superconductor known as 2G HTS wire, has become available in sufficient quantity and lengths for developers to build prototype devices and test its capabilities. This new material has re-invigorated the worldwide race to develop a successful SFCL device that will meet the stringent demands of the electric utility application. SuperPower is pursuing the development of a transmission level (138kV) SFCL based on its proprietary 2G HTS wire and SFCL technologies. This paper will discuss why 2G HTS wire is the material of choice for SFCL developers, as well as how this material can be custom designed to meet the needs that utility engineers deem most desirable for an SFCL. We will also discuss the latest developments in SuperPower's SFCL program
This work is supported in part by the US Department of Energy (DoE) and the Electric Power Research Institute (EPRI).

FRIDAY, AUGUST 22, 2008

FRIDAY MORNING ORAL SESSIONS
10:00am - 12:30pm

5LA - IEEE Session on Very High Field Magnets,, sponsored by the IEEE Magnetics Society and the IEEE Council on Superconductivity 10:00am - 11:45am

10:00am
Invited
5LA01 - The NHMFL Hybrid Magnet Projects
***M.D.Bird**, T.Adkins, S.Bole, K.Cantrell, I.R.Dixon, A.V.Gavrilin, J.Lu, T.A.Painter, J.Toth, R.P.Walsh, H.W.Weijers, T.Xu, Y.Zhai, NHMFL*
The National High Magnetic Field Laboratory is developing resistive-superconducting hybrid magnets both for internal use and for installation at the Hahn-Meitner Institute in Berlin. The NHMFL magnet will have a vertical field and provide 36 T in a 40-mm bore with 1-ppm homogeneity over a 10-mm diameter spherical volume. The HMI version will provide a horizontal field of 25 T in a double-conical configuration suitable for neutron-scattering experiments. The two magnets will use copies of the same ~14T Nb3Sn CICC coil for the superconducting outsert. The resistive insert magnets will be different configurations operating at different power levels. In designing the magnet we have developed a new numerical model to predict the critical current of Nb3Sn CICC's, tested several conductors in-house and abroad, designed cryostats and refrigeration systems, and developed new resistive magnet technology. An overview of the innovations and present status is presented.
The authors are greatly indebted to John R. Miller and Alessandro Bonito Oliva who played major roles in these projects.

10:30am

5LA02 - Investigation of cooling schemes for a superconducting outsert of the Series Connected Hybrid magnet

H.Bai, M.D.Bird, K.R.Cantrell, I.R.Dixon, ***A.V.Gavrilin****, National High Magnetic Field Laboratory*

A large powered high-field magnet system, Series Connected Hybrid, being presently designed at the National High Magnetic Field Laboratory in Tallahassee, Florida will consist of a resistive insert and superconducting outsert. The main coil of the latter will be wound with a CICC with niobium-tin cable inside. The design has evolved to provide a helium inlet and outlet to each of 19 layers of the outsert main coil so as to reduce the time of evacuation of heat deposited due to rather high AC losses during cyclic operation of the magnet (ramping up and down, cycle after cycle) and to improve the cooling conditions as much as possible at a limited mass flow rate. Hydraulically, the main coil winding presents a system of parallel cooling paths connected through manifolds of finite volume going to/from the magnet cryogenic system. To analyze even a part of such a network, including also valves, transfer lines, buffers, etc., for the case of cyclic operation when reverse and unequal flows occur in the winding cooling paths is a cumbersome task. We use a combination of the codes Gandalf and FLOWER by CryoSoft for the modeling, aiming to find the best cooling options and schemes. The results are discussed.

This work is supported in part by the National Science Foundation under Grant DMR0412169 and the State of Florida.

10:45am

5LA03 - Design of a 30 T Superconducting Magnet using a Coated Conductor Insert

K.Koyanagi*, M.Ono, S.Hanai, Toshiba Corporation; K.Watanabe, S.Awaji, T.Hamajima, Tohoku University; T.Kiyoshi, H.Kumakura, National Institute for Materials Science*

A development program of a 30 T superconducting magnet with new concepts is now in progress at the High Field Laboratory for Superconducting Materials (HFLSM), Tohoku University and the Tsukuba Magnet Laboratory (TML), National Institute for Materials Science. In this study, a 30 T superconducting magnet comprised of HTS insert and LTS outsert has been conceptually designed. For the high-field insert, YBCO coated conductor was adopted because of its superconducting characteristics in high magnetic field and its mechanical strength. Due to the prominent mechanical property, relatively high tolerance limit of hoop stress in the coil winding can be assumed in the coil design. Critical current density of the YBCO tape was predicted using the percolation model as a function of temperature and magnetic field. The LTS outsert is composed of CuNb/Nb3Sn and NbTi coils. The CuNb/Nb3Sn coil was designed using high-strength cable consisted of internally reinforced Nb3Sn strands with CuNb reinforcing stabilizer with the repeated bending treatment. From the results of this design study, a potential for compact high-field magnet was confirmed adopting an insert coil of YBCO coated conductors.

11:00am

5LA04 - Superconducting Outsert Design for the Nijmegen 45 T Hybrid Magnet

J.H.Schultz*, MIT Plasma Science and Fusion Center; S.Wiegers, J.Perenboom, University of Nijmegen; J.V.Minervini, P.Titus, A.Zhukovsky, A.Radovinsky, MIT Plasma Science and Fusion Center*

The High Field Magnet Laboratory at Nijmegen is upgrading its capabilities in advanced spectroscopy by building a 45 T Hybrid Magnet with a 32 mm bore. The superconducting outsert magnet has a warm clear bore of 600 mm with a field in excess of 14 T and field uniformity better than 10^-3 in the test space. Two design options are being considered. One is a Rutherford cable, using Nb3Sn in the inner subcoils and NbTi in the outer. Each subcoil has a steel reinforcing shell on the outside and vertical cooling channels on the inside. The second option is Cable-in-conduit (CICC), similar to those used in the US National High Magnetic Field Laboratory. However, the cables would have stagnant supercritical helium in the cable space for stability and transient cooling, but liquid helium, using natural convection in vertical channels at the inside of each subcoil. The paper describes the designs of the coils, cryostat, and cooling systems, along with analysis and tradeoffs between the two options.

This work is supported by the University of Nijmegen

11:15am

5LA05 - Coupled Analysis Method for High-Field Magnet Coil Using Coated Conductor Based on J-E Characteristics as a Function of Temperature, Magnetic Field Vector and Mechanical Strain

K.Higashikawa*, T.Kiss, M.Inoue, Kyushu University; T.Nakamura, Kyoto University; H.Fukushima, Y.Yamada, Y.Shiohara, Superconductivity Research Laboratory*

Using analytical formulation of the nonlinear current transport characteristics in coated conductor as a function of temperature, magnetic field vector and mechanical strain, we have carried out coupled analysis on the electromagnetic-, thermal- and mechanical-properties in a coil for high-field magnet. The current transport characteristics are intended for long coated conductor being fabricated in Japan. In the analysis, the distributions of heat generation and electromagnetic force in the coil are calculated by electromagnetic analysis. Then, the distributions of temperature and mechanical strain are correspondingly estimated by thermal analysis and by structural analysis. Furthermore, they are fed back to the electromagnetic analysis for the calculation of heat generation. These analyses are based on finite element method, and are repeated until the convergence. We will discuss the influence of temperature distribution and strain distribution on the transport performance of the coil, and then will propose some guidelines on the coil design for high-field magnet using coated conductor.

11:30am

5LA06 - Stability of Second Generation HTS Pancake Coils at 4.2 K for High Heat Flux Applications

C.Thieme*, K.Gagnon, American Superconductor (AMSC); H.Song, J.Schwartz, NHMFL/FSU*

For the manufacture of Second Generation HTS YBCO wire, AMSC's process provides the flexibility to engineer 2G performance, architectures and stabilizer materials towards a variety of applications. These so-called "344 superconductors" are produced using the RABiTS (TM) MOD approach. They are also of interest for High Energy Physics applications as the critical current at high fields can be substantial [1]. The potential for heat load stability at high fields appears excellent due to the wire's high thermal margins. In this study we started the exploration of this high field stability using both short conductors and small pancake coils. A 50 m length of wire was carefully characterized for performance along the length in self-field at 77 K and in 10 m lengths at 75 K and a 0.5 T field oriented parallel and perpendicular to the face of the conductor. Short lengths of conductor were tested at 4.2 K and 0-25 T in parallel and perpendicular fields, demonstrating an overall critical current of 450 A/mm2 in a parallel field of 25 T. Ic was also measured as a function of field angle at 4.2 K and 7 T. Subsequently, these characterized lengths were made into small pancake coils provided with a central heater, voltage taps and thermocouples. We report on the properties and stability measurements of these coils at 4.2 K and 27 K as a function of background magnetic fields. [1] E. Barzi, et. al "Study of HTS Conductors for High Field Solenoids", CEC-ICMC 2007, Chattanooga TN.

This work was supported by the US DOE, Office of High Energy Physics.

5LB - Stability and Protection V – HTS 10:00am - 11:45am

10:00am

5LB01 - Hot spot stimulated transition in YBCO coated conductors: experiments and simulations

G.Celentano, G.M.Polli, A.Angrisani Armenio, A.Augieri, V.Galluzzi, A.Mancini, A.Rufoloni, A.Vannozzi, ENEA Frascati, Italy; A.Saggese, S.Pace, CNR-INFM, University of Salerno, Italy; ***U.Gambardella****, INFN Frascati National Laboratory, Italy*

The use of YBCO tapes in extensive applications claims for a comprehensive knowledge of their behaviour in every possible condition of operations. In particular, one of the main topics to explore is the tape stability against heat and current disturbances, in terms of minimum quench energy and normal zone propagation velocity (NZPV). In this work we present results on NZPV measured in a 35 cm long YBCO coated conductors manufactured by SuperPower. The tape is cooled by means of a cryocooler and kept insulated under vacuum in order to achieve near-adiabatic conditions. Two independent heaters are positioned on the tape: One on the YBCO side and the other on the substrate side. The quench is monitered by recording the voltage and temperature evolution along the tape. It has been observed that the NZPV increases with the energy which triggers the quench. The NZPV, at 77 K, reachs a value larger than 2.5 cm/s for a bias current I= 50 A which represents the 56% of the critical current value. The quench properties of the tape are discussed with the help of a simulation program based on the finite difference discretization of the Fourier's heat equation: the model is capable to correctly reproduce the experimental response behaviour.

10:15am

5LB02 - Influence of Inter-Layer Contact Resistances on Quench Propagation in Coated Conductors

P.J.Masson*, CAPS/Florida A&M University; C.A.Luongo, NHMFL*

Superconducting power devices are considered for airborne applications. For the devices of interest the operating temperature needs to remain around 70 K in order to minimize the weight and volume of the associated cooling system. The use of second generation coated conductors allows for operation at fairly high temperature (65-77K) while maintaining high current carrying capabilities. Unfortunately, when a hot spot is created in a coated conductor wound magnets, the quench propagates so slowly that it cannot be detected using conventional methods and therefore those magnets may remain unprotected. In order to address this quench detection issue, we have to better understand the physics of the quench and what phenomena drive it so it can be accurately simulated. We have modeled YBCO tapes using Finite Element Analysis in order to assess the role of the contact resistance between the different layers composing the tape. Indeed, if the temperature rises, the YBCO layer becomes highly resistive and current has to redistribute into the stabilization layers. The contact resistance between the YBCO layer and the copper should then play a very important role in terms of current sharing length and voltage difference between the layers. This paper presents the model implemented in COMSOL Multiphysics, simulation results and comparison with experimental data available in literature.

This research was partially supported by the Air Force Research Laboratory through Universal Technology Corporation

10:30am

5LB03 - Numerical and experimental studies of the quench propagation in coated conductors for Fault Current Limiters

F.Roy*, B.Dutoit, EPFL; M.Decroux, L.Antognazza, Universite de Geneve; F.Sirois, F.Grilli, Ecole polytechnique de Montreal*

A fundamental understanding of the quench phenomena is crucial in the future design and operation of HTS Fault Current Limiters (FCLs). The key parameter that quantifies quenching process in superconductors is the normal zone propagation (NZP), which is defined as the speed with which the normal zone expands into the superconducting volume. Theoretical predictions and recent experimental measurements in YBCO tapes have shown that the NZP in these materials is extremely slow (in the order of 0.1 to 1 cm/s). Due to these low velocities, we developed a pulsed current setup to measured with accuracy the NZP on several YBCO tapes in order to compare experimental data with a FEM magneto-thermal model developped in our group recently. Our measures were made with voltage taps disposed along the conductors in which a default (constriction)was made to initiate the NZP. Combined with our FEM model, we have shown that the thermal stability of YBCO tapes depends strongly of the substrate properties.

This work was partly supported by the Swiss National Science Foundation through the National Center of Competence in Research "Materials with Novel Electronic Properties" - MaNEP and partly by the Natural Sciences and Engineering Research Council of Canada - NSERC.

10:45am

5LB04 - Quench Onset and Propagation in 2G HTS Conductors

E.A.Young, M.K.Al-Mosawi, University of Southampton; C.Friend, Oxford Instruments; ***Y.Yang****, University of Southampton*

The prospect of medium/high field superconducting magnets using 2G HTS tapes is approaching to reality with continued enhancement in performance of these conductors. While the cryogenic stability and quench propagation are fundamental issues for the design and safe operation of superconducting magnets, there are insufficient understanding and experimental data for 2G HTS conductors, in particular for the high field scenario at low temperature (<< 77K) where the current sharing range is much larger than in low temperature superconductors. The present work includes a systematic characterisation of the relevant thermal-electrical properties, which are used for the computer simulation of the quench behaviour. Direct measurements of 1d adiabatic quench initiation and propagation of the 2G conductors have been carried out with spatial-temporal recording of temperature and voltage following the deposition of various local heat pulses to samples at different temperatures between 4K and 77K carrying different transport currents. The minimum quench energy, minimum propagation zone (MPZ) length and the propagation velocity are determined as a function of temperature and transport current. Features unique HTS such as increasing MPZ with transport current have been identified. The experimental results are compared with those from computer modelling, and analysed to determined the influence of current share over a large temperature range.

11:00am
5LB05 - Quench behaviors of YBa2Cu3Ox coated conductor at 4.2 K
***H.Song**, U.Trociewitz, J.Schwartz, Applied Superconductivity Center, National High Magnetic Field Laboratory; C.L.H.Thieme, American Superconductor Corporation*
Second Generation HTS technology based on YBa2Cu3Ox coated conductor, has great potentials for use in high magnetic fields. Demonstrated critical currents at 4.2 K are very high in magnetic fields of at least 25 T when the magnetic field is oriented parallel to the conductor. American Superconductor Corporation "344 coated superconductors" are produced with different stabilizers to meet the needs of various superconducting applications. The stability at low temperatures and high magnetic fields, however, needs exploration. Due to high transport currents and lower heat capacities the superconductor is expected to demonstrate very different quench behaviors at 4.2 K than that measured at 40-77 K, where slow quench propagation velocities have been reported. Here we report on quench measurements at 4.2 K and magnetic field up to 8 T, including normal zone propagation velocity, minimum quench energy and quench onset times. Normal zone propagation velocity is dependent on transport current and the quantitative relationship is determined. From the point of magnet detection, the minimum quench energy can be redefined based upon a quench onset time; this concept is discussed and experimental results are interpreted within this framework.
The authors would like to thank Tim Effio for assistance and useful discussions and the Air Force Office of Scientific Research for support.

11:15am
5LB06 - Simulation and Measurement of AC loss in 2G YBCO tapes
***A.V.Velichko**, R.Pei, Z.Hong, T.A.Coombs, Cambridge University*
Superconducting Fault Current Limiters (SFCLs) are expected to improve the reliability and stability of power delivery networks. Among other superconductors, second generation (2G) HTS tapes seem to be one of the best candidates for this role. For successful implementation of the 2G tapes studying their electrical and thermal properties in AC fields is required. In our simulation we have studied the effects of surface layer and external shunt, as well as influence of defects on the ac performance of YBCO tapes. The results show that both kind of shunts lead to a comparable increase in the rated current and reduce the overall temperature rise of the tape. As far as defects are concerned, only defects with an area of more than 10% of the tape cross-sectional area are found to noticeably increase ac loss. Experiment have shown that a typical level of AC loss at 1 A on commercial YBCO tapes is around 10^-9 J/cm/cycle. Here copper-stablised tapes usually exhibit 20-25% lower Ic, than those stabilized by stainless steel, and AC loss more than an order of magnitude higher. In the near future we plan to study the effect of stress in YBCO tapes produce by mechanical stretching and/or bending. Studying the effect of deoxygenation and, consequently, smeared current-voltage characteristic, is also on the way.
We would like to acknowledge support from the EPSRC.

11:30am
5LB07 - DI-BSCCO Magnet with Directly Conduction Cooling for AC use
***T.Sanami**, T.Hayashi, K.Ohkura, T.Okazaki, K.Ohmatsu, Sumitomo Electric Industries, Ltd.*
Usually, it is preferable for the magnets with superconducting (DI-BSCCO Bi-2223/Ag) tapes to be used under DC operation. Their cooling method is LN2 cooling or directly conduction cooling, and we can choose either them depending on the application. However, under AC operation, the size of cooling system becomes lager when LN2 cooling. Because AC loss is generated under AC operation, the total loss is significant and large LN2 circulation system is required. We cannot choose LN2 cooled AC magnet without enough spaces. So, we tried to apply directly conduction cooling to AC magnets. The design problems are following; (1)Optimizing coil design for decreasing AC loss (2)Optimizing structure of cooling path (3)Suitable material of cooling path for decreasing eddy current loss We approach above problems with CAE (Computer Aided Engineering) and verification experiments by using the small model magnet system which assumed actual machine. This report introduces the small model magnet system, the results of CAE and experiments, and the design of AC magnet with directly conduction cooling.

FRIDAY AFTERNOON ORAL SESSIONS 12:30pm - 2:30pm

5LX - Accelerator Magnets V - Memorial to Paul Reardon 12:30pm - 2:30pm

12:30pm
5LX01 - Overview for LARP Magnet R&D
***P.Wanderer**, Brookhaven National Lab*
The talk will summarize work by the LARPL LHC accelerator Reseach Program Collaboration to develop NB3SN quadrupoles for upgrades of the LHC.

12:45pm
5LX02 - Test Results of LARP 3.6 m Nb3Sn Racetrack Coils Supported by Full-Length and Segmented Shell Structures
***J. Muratore**, M. Anerella, J. Cozzolino, J. Escallier, G. Ganetis, A. K. Ghosh, R. C. Gupta, P. P. Joshi, P. Kovach W. Louie, A. Marone J. Schmalzle, R.Thomas P. Wanderer, BNL; G. Ambrosio, E. Barzi, R. Bossert, S. Feher, F. Nobrega, D. Turrioni, FNAL; S. Caspi, D. Cheng, D. R. Dietderich, H. Felice, P. Ferracin, A. R. Hafalia, C. R. Hannaford, A F. Lietzke, A. D. McInturff G. Sabbi, LBNL*
As part of the LHC Accelerator Research Program (LARP) to build a high performance quadrupole magnet with Nb3Sn conductor, a pair of 3.6m-long Nb3Sn racetrack coils has been made at Brookhaven National Laboratory (BNL) and installed in two shell type support structures built by Lawrence Berkeley National Laboratory (LBNL). These magnet assemblies have been tested at 4.5K at BNL to gauge the effect of extended length and prestress on the mechanical performance of the long structure compared to earlier short models. This paper presents the results of quench testing at different ramp rates, summarizes the shell strain measurements, and compares the overall performance of the 4 m support structure with that for the 1 m model, also tested at BNL. The variation of quench current with ramp rate is analyzed with regard to thermal margin. In addition, the effectiveness of the quench protection schemes used to minimize the risk to the magnet during spontaneous quenches is discussed. Index Terms—LARP, Nb3Sn, racetrack, superconducting magnets
This research is funded by U.S. DOE Office of High Energy Physics.

1:00pm

5LX03 - Quench performance of a 4-m long Nb3Sn cos-theta dipole coil

***G.Chlachidze**, G.Ambrosio, N.Andreev, E.Barzi, R.Bossert, R.Carcagno, V.S.Kashikhin, V.V.Kashikhin, M.Lamm, F.Nobrega, I.Novitski, D.Orris, C.Sylvester, M.Tartaglia, Fermilab; J.C.Tompkins, D.Turrioni, G. Velev, R. Yamada, A.V. Zlobin - Fermilab*

Fermilab is developing Nb3Sn accelerator magnets with cos-theta style coils made by the react-and-wind method. Several 1-m long small-aperture dipole and large-aperture quadrupole models were fabricated and successfully tested. A technology scale up phase has started the fabrication and testing of 2-m and 4-m long dipole coils in a 'mirror configuration' in which one of the two coils is replaced by a half-cylinder made of low carbon steel. This approach allows for shorter fabrication times and extensive instrumentation while preserving almost the same level of magnetic field and Lorentz forces in the coils as in a complete dipole model magnet. The 2-m long coil made of 'Powder-in-Tube' (PIT) Nb3Sn strand reached its short sample limit at a field level of 10 T. A 4-m long coil made of advanced Nb3Sn strand, based on the "Restack Rod Process" of 108/127 design, has been recently fabricated and tested at Fermilab. Coil test results at temperatures of 4.5 K and 2.2 K will be reported and discussed

1:15pm

5LX04 - Assembly and Test of the Nb3Sn quadrupole magnet TQS02b

***H.Felice**, B.Bingham, S.Caspi, P.Ferracin, R.Hafalia, A.Lietzke, J.Lizarazo, G.L.Sabbi, X.Wang, Lawrence Berkeley National Laboratory; M.Bajko, M.Karppinen, J.C.Perez, A.Siemko, E.Todesco, CERN*

Insertion quadrupoles with large aperture and high gradient are required to achieve the luminosity upgrade goal of 10^35 cm^-2s^-1 at the Large Hadron Collider (LHC). Although improved designs based on NbTi are being considered as an intermediate solution, Nb3Sn conductor is required to meet the ultimate performance goals for both operating field and temperature margin. As part of the development of this technology, the 90-mm aperture Nb3Sn quadrupole TQS02b has been tested at CERN. The transverse coil support structure is composed of an aluminum shell over iron yoke and loading pads, and is assembled using water-pressurized bladders and interference keys. Four aluminum rods bolted to a stainless steel endplate provide the axial support. The main goal of the TQS02b test is to evaluate the magnet performance under different axial and azimuthal loading conditions. This paper reports on assembly, cool-down and quench behavior, as well as magnetic and strain gauge measurements. This work was supported by the Director, Office of Science, High Energy Physics, U.S. Department of Energy under contract No. DE-AC02-05CH11231

1:30pm

5LX05 - Fabrication and Test of LARP Technological Quadrupole Models of TQC Series

***R.C.Bossert**, G.Ambrosio, N.Andreev, E.Barzi, G.Chlachidze, S.Feher, V.S.Kashikhin, V.V.Kashikhin, M.Lamm, A.Nobrega, I.Novitski, M.Tartaglia, A.V.Zlobin, Fermi National Accelerator Laboratory; G.Sabbi, S.Caspi, Lawrence Berkeley National Laboratory; R.Carcagno, D.Orris, Fermi National Accelerator Laboratory; D.Dietderich, P.Ferracin, A.R.Hafalia, Lawrence Berkeley National Laboratory*

In support of the development of a large-aperture Nb3Sn superconducting quadrupole for the Large Hadron Collider (LHC) luminosity upgrade, several two-layer technological quadrupole models of TQC series with 90 mm aperture and collar-based mechanical structure have been developed at Fermilab in collaboration with LBNL within the framework of the US LHC Accelerator Research Program (LARP). This paper summarizes the results of fabrication and test of TQC02, the second TQC model based on RRP Nb3Sn strand. The test results presented include magnet strain and quench performance during training, as well as quench studies of current ramp rate and temperature dependence from 1.9 K to 4.5 K.

1:45pm

5LX06 - Development of LARP 3.7 m Long Nb3Sn Quadrupole Models

***G.Ambrosio**, N.Andreev, Fermilab; M.Anerella, BNL; E.Barzi, R.Bossert, Fermilab; H.Felice, P.Ferracin, D.Dietderich, LBNL; A.Ghosh, BNL; F.Nobrega, Fermilab; S.Peggs, BNL; G.L.Sabbi, LBNL; J.Schmalzle, P.Wanderer, BNL; A.V.Zlobin, Fermilab*

The U.S. LHC Accelerator Research Program (LARP) has started the fabrication of 3.7-m long Nb3Sn quadrupole models. The Long Quadrupoles (LQ) are "Proof-of-Principle" magnets which are to demonstrate that Nb3Sn technology is mature for use in high energy particle accelerators. Their design is based on the LARP Technological Quadrupole (TQ) models, developed at FNAL and LBNL, which have design gradients higher than 200 T/m and an aperture of 90 mm. The plans for the LQ R&D, testing both shell-based and collar-base structures, are presented and discussed in this paper together with the main LQ design features and assembly procedures. Some practice coils have been fabricated and inspected. The fabrication at BNL and FNAL of the set of coils for the first Long Quadrupole has almost been completed. The coil fabrication procedures, based on the TQ experience with some improvements and modifications due to the longer length, are presented with the inspection results.

Work supported by the U.S. Department of Energy

2:00pm

5LX07 - Design of HQ - a High Field Large Bore Nb3Sn Quadrupole Magnet for LARP

***S.Caspi**, D.Cheng, D.Dietderich, H.Felice, P.Ferracin, R.Hafalia, R.Hannaford, A.F.Lietzke, G.L.Sabbi, LBNL; M.Anerrela, P.Wanderer, BNL; G.Ambrosio, R.Bossert, V.V.Kashikhin, A.V.Zlobin, FNAL*

In support of the Large Hadron Collider luminosity upgrade, a large bore (134mm) Nb3Sn quadrupole with 15 T peak coil field is being developed within the framework of the US LHC Accelerator Research Program (LARP). The 2 layer design with a 15 mm wide cable is aimed at pre-stress control, alignment and field quality while exploring the magnet performance limits in terms of gradient, forces and stresses. In addition, HQ will determine the magnetic, mechanical, and thermal margins of Nb3Sn technology with respect to the requirements of the "Phase 1" luminosity upgrade at the LHC.

Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

2:15pm

5LX08 - Assembly and Test of HD2, a 36 mm Bore High Field Nb3Sn Dipole Magnet

***P.Ferracin**, B.Bingham, S.Caspi, D.W.Cheng, D.R.Dietderich, H.Felice, A.Godeke, A.R.Hafalia, C.R.Hannaford, J.Joseph, A.F.Lietzke, J.Lizarazo, G.L.Sabbi, F.Trilluad, X.Wang, LBNL*

We report on the fabrication, assembly, and test of the Nb3Sn dipole magnet HD2. The magnet, aimed at demonstrating the feasibility of Nb3Sn superconductor in high field accelerator-type dipole magnets, features a 36 mm clear bore surrounded by block-type coils with tilted ends. The coil design is optimized to minimize geometric harmonics in the aperture and the magnetic peak field on the conductor in the coil ends. The maximum expected bore field of 15 T at 4.5 K is determined through critical current measurements of extracted strands. The coils are horizontally pre-stressed during assembly using an external aluminum shell pre-tensioned with water-pressurized bladders. Axial pre-loading of the coil ends is accomplished through two end plates and four aluminum tension rods. The strain in coil, shell, and rods is monitored with strain gauges during assembly, cool-down and magnet excitation, and compared with 3D finite element computations. Magnet's training performance, quench locations, and magnetic field quality are then analyzed and discussed.

Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

5LY - Fusion - ITER III 12:30pm - 2:30pm

12:30pm
Invited
5LY01 - Recent Results from Full-Size ITER TF Conductor Samples
TheSultan Working Group*, ITER Project*
Prior to the launch of the ITER Toroidal Field (TF) conductor procurements, the six Domestic Agencies involved (China, Europe, Japan, Korea, Russia and US) are required to manufacture and test Conductor Performance Qualification Samples (CPQS) at the SULTAN test facility. The procedures for sample preparation, test and test data analyses must be agreed upon and identical for the 6 DA's and their definition is one the main charges of the so-called SULTAN Working Group set up by ITER International Organization. This paper reviews the test results from recent ITER TF conductor samples and details the recommendations made by the SULTAN Work Group on the CPQS procedures.

1:00pm
5LY02 - Methods, Accuracy and Reliability of ITER Conductor Tests in SULTAN
P.Bruzzone*, B.Stepanov, R.Wesche, Y.Ilyin, R.Herzog, M.Calvi, M.Bagnasco, F.Cau, EPFL-CRPP*
In the last decade, a large number of high current, force flow superconductors have been tested as short length samples in the SULTAN facility. The object of the test ranged over transient stability, thermal-hydraulic behaviour, AC losses, joint resistance and proof-of-principle for innovative conductor design. Recently, with the ITER cable-in-conduit conductors (CICC), the basic DC transport properties have been again the focus of the SULTAN test. The demand for high accuracy and reliability increases at the time where the design verification overlaps with the manufacturer qualification. The performance degradation in Nb3Sn CICC makes extremely sensitive the assessment of the test results. In a context where the outcome of SULTAN tests moves from the scientific evidence to the commercial certification, the methods and the reliability of the test procedures have been critically reviewed. The critical steps of the sample assembly and instrumentation are discussed, with emphasis on the application of the temperature sensors, verification of signal treatment chain and calibration. The post-processing and the data reduction are focussed on the assessment of the current sharing temperature, Tcs: the conventional method of electrical field threshold detection by voltage taps is compared with the power threshold detection by gas-flow calorimetry. Eventually, the value of a certified conductor test is discussed in the frame of the quality control for the ITER magnets.

1:15pm
5LY03 - Electromagnetic Analysis and Interpretation of the Voltage - Temperature and Voltage - Current characteristics of ITER TF conductor samples
M.Breschi*, University of Bologna; F.Bellina, University of Udine; P.L.Ribani, University of Bologna*
Recent tests of the performance of the ITER TF cable-in-conduit conductors, carried out in the SULTAN facility at Villigen, PSI, Switzerland, have showed peculiar behaviors of the voltage traces measured on the jacket of these conductors. In particular, in the re-test of the European and Japanese conductor samples TFPRO2 and JATF2, voltage ramps have been measured during the current ramp-up using circular arrays of voltage taps located at different positions along the jacket. These voltage ramps are particularly remarkable for the arrays located in the proximity of the joints and terminations. In order to assess the conductor performance from the voltmetric measurements, the mechanisms at the origin of these voltage ramps must be understood and interpreted. This interpretation can also be useful to apply adequate corrections to the measured results in order to determine the current sharing temperature of the conductor. The paper presents an electromagnetic analysis of the peculiar features of these voltage traces and a comparison with experimental results from different ITER TF conductor samples.
ITER

1:30pm
5LY04 - Summary of ITER Nb3Sn strand testing under axial strain, spatial periodic bending and contact stress
A.Nijhuis*, W.Abbas, W.A.J.Wessel, Y.Ilyin, University of Twente*
Numerous manufacturers and different strand processing techniques are involved with the production of the Nb3Sn strand material required for ITER. The superconducting transport properties of brittle Nb3Sn layers strongly depend on the strain state. Hence, the thermal compression and the large transverse load in combination with the key choice for the cabling pattern of the ITER CICCs, will determine their performance. Knowledge of the influence of axial strain, periodic bending and contact stress on the critical current (Ic) of the used Nb3Sn strands is therefore inevitable to gain sufficient confidence in an economic design and a stable operation. We have measured the Ic and n-value of ITER Nb3Sn strands from various manufacturers in the TARSIS facility, when subjected to spatial periodic bending and contact stress at a temperature of 4.2 K and in a magnet field of 12 T. The same strands have been subjected to uni-axial applied strain in compressive and tensile direction. The Ic and n-values have been determined for strain varying from -0.8 % up to +0.3 %, at temperatures between 4.2 K and 10 K and magnet fields ranging from 6 T to 15 T. The strain sensitivity varies appreciably for different strand types but since the electromagnetic force is the driving parameter for strand bending in a CICC, the stiffness of the strands may also play an important role. We present an overview of the results obtained so far.
This work is supported by the ITER Organisation and the EU under the contract of Association between EURATOM/FOM.

1:45pm
5LY05 - JT-60SA Toroidal Field Coils: Evolution of Design
P.Barabaschi*, JT-60 SA European Home Team; A.Pizzuto, ENEA Frascati; L.Zani, D.Ciazynski, CEA Cadarache; A.Cucchiaro, A.della Corte, A.Di Zenobio, J.-L.Duchateau, ENEA Frascati; P.Hertout, B.Lacroix, CEA Cadarache; L.Muzzi, ENEA Frascati; S.Nicollet, CEA Cadarache; L.Petrizzi, ENEA Frascati; F.Rondeaux, A.Sharma, CEA Cadarache*
The upgrade of JT-60U to JT-60 Super Advanced (JT-60SA), a fully superconducting tokamak, will be performed in the framework of the Broader Approach (BA) agreement between Europe (EU) and Japan. In particular, the Toroidal Field (TF) system, which includes 18 coils, is foreseen to be procured by France, Italy (for the magnet itself) and Germany (for the current leads). This work covers activities from design and manufacturing to shipping to Japan. Recently some optimisation design evolutions have taken place in the design, largely prompted by cost. The work was jointly performed by all participating contributors. The paper describes the revised conductor, structure, and integrated analyses of the magnet system, including both electromagnetic, mechanical, and thermo-hydraulic assessment.

2:00pm

5LY06 - JC(B,T,ε) Parameterization for the ITER Nb3Sn Production

***L.Bottura**, CERN*

A number of models for the critical parameters of Nb3Sn, and in general A15 superconductors, have been developed in the past years. This paper compiles the latest scaling laws, using consistent notation, thus allowing a direct comparison of the various terms. The scaling laws appear dissimilar at first sight, but are in reality all based on a fit of the dependence of the normalised pinning force on the reduced field, and have similar scalings for the critical field and critical temperature. The main differences among the models are in the fits of the Ginzburg-Landau parameter, of the strain functions, and in the way that strain is assumed to affect the overall scaling. In this paper we analyse the differences, advantages and disadvantages of the various parameterization, and we settle on a generic scaling that is suitable for the characterization and production follow-up of the ITER Nb3Sn strands. The accuracy of the scaling is estimated from the fitting residuals on various sets of IC(B,T,ε) data available in literature.

This work is performed within the scope of the CERN-ITER collaboration in magnets

2:15pm

5LY07 - Test Results from the PF Insert Coil and Implications for the ITER PF System

*D.Bessett, ITER Organization, Cadarache, France; **L.Bottura**, CERN; A.Devred, ITER IO; N.Mitchell, ITER; K.Okuno, JAEA; C.Sborchia, Max-Planck-Institut fuer Plasmaphysik*

In this paper we give the interpretation of the main test results on the Poloidal Field Insert coil (PFI) for the International Thermonuclear Experimental Reactor (ITER), built jointly by the EU and RF ITER parties, and recently installed in the CS Model Coil facility, at JAEA-Naka. The main aims of the test are (a) to verify the DC and AC operating margin of the NbTi Cable-in-Conduit Conductor in conditions represenative of the operation of the ITER PF coils, (b) validate the concept of the intermediate conductor joint, a (c) observe any change in AC loss properties of the conductor once subjected to a significant number of charge/discharge cycles. We compare the results obtained to expectations from strand and cable characterization, which were studied extensively earlier. WE finally compare the performance of the PFI to the envelope of operating scenario for ITER and we discuss the implications for the ITER PF system.