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Indian Journal of Cryogenics

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B) This is the only Indian journal where articles on cryogenic engineering are encouraged. Editorial board encourages work on indigenous development as an import substitution.

C) Editorial board has decided to include at least one review article (by invitation) on each forthcoming issue in the field of Superconductivity, low temperature physics, cryogenic engineering or covering status of major cryogenic related project in India etc.

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FOREWORD

It gives us great pleasure to bring out the special issue of the Indian Journal of Cryogenics, Vol 38, which is a compilation of manuscripts of peer reviewed contributory papers presented at the Asian Conference on Applied Superconductivity and Cryogenics (ACASC-2011) held at Inter University Accelerator Centre during November 16–18, 2011 in Delhi, India. This conference was jointly organized by Indian Cryogenics Council (ICC), Inter-University Accelerator Centre (India), Variable Energy Cyclotron Centre (India), Institute for Plasma Research (India), Cryogenics and Superconductivity Society of Japan (Japan), Korea Institute of Applied Superconductivity and Cryogenics (Korea), Institute of Electrical Engineering: Chinese Academy of Sciences (China), Applied Superconductivity Commission: China Electro-Chemical Society (China) and Ankara University (Turkey).

This conference is the fifth in series, starting in 2001 as a joint workshop between Japan and Korea to collaborate work in the field of applied Superconductivity and Cryogenics. China joined this forum in 2003, India in 2007 and Turkey in 2011.Last ACASC was held in Matsue, Japan during December 6-8, 2009. We thank all the member countries for giving us the responsibility of hosting the conference in 2011 in India.

The focus of the conference was on the role of superconductivity in large scale applications like Fusion Reactors, Particle Accelerators, Power Applications like Fault Current Limiters, Superconducting Magnet Energy Storage, Superconducting Cables, Transformers, and Motors etc. The conference also highlighted the role of Cryogenics and Compatible Materials.

A total of 223 delegates from six Asian countries attended the conference and 141 presentations were made on recent R&D results in the field of applied superconductivity and cryogenics in either oral or poster form.

Out of these 141 papers, 27 papers were short listed and published in the Journal “Cryogenics” in Volume 52 (2012) and 37 papers contributed by Indian Authors are peer reviewed and now published in this issue of the Indian Journal of Cryogenics, Vol 38 (2013).

The next Asian Conference on Applied Superconductivity and Cryogenics (ACASC 2013) will be held in Turkey during October 22–24, 2013.

Amit Roy

R.K.Bhandari

R.G.Sharma

T.S.Datta

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Development of 440 V / 800 A High Temperature Superconducting Fault Current Limiter (SFCL)

Manglesh Dixit[1], Sandeep Kulkarni[1], Shubhangi Patil[1], Alok Gupta[2], PV Balasubramanyam[3]

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The addition of new generation capacity, interconnections and expansion of power network could increase fault current levels beyond the capacity of the installed circuit breakers. Conventional solutions to limit the fault levels are not effective measures when reliability and stability of power system are considered. High temperature superconductor fault current limiters (SFCL) are intelligent and self acting devices that can detect and limit fault currents within a quarter of the first cycle and without adding additional reactive power to the system. The benefits of utilizing SFCL include ability to connect new generation stations to the electric system, avoiding upgradation of existing networks and increase of network flexibility, sustainability and reliability. In India, Ministry of Power has initiated a National Perspective Plan (NPP) for R&D in Indian Power Sector, jointly funded with industries and research organizations. Under the NPP project, CG Global R&D is developing 440 V, 800 A, resistive type SFCL in Phase-I and 11 kV, 1250 A SFCL in Phase II. This paper presents the development and experimental results of 440 V, 800 A resistive SFCL utilizing second generation (2G) high temperature superconductor (HTS) tapes. SFCL performance parameters like response time, limited current, prospective current, recovery time and cryogenics are discussed. The reported data would be useful in developing commercial scale SFCL for the power grids.

Key words: Superconducting fault current limiter, resistive type, limited current, prospective current.

Investigation of multistage cable twisting pattern with a cable twisting model for 30kA CICC

Piyush Raj, Subrata Pradhan

Institute for Plasma Research, India

Superconducting cable with multistage twisted strands is an important component of the TF (toroidal field) magnets. A computational model describes the strands twisting pattern at each stage of the cabling. Modeling the pattern of a superconductor cable made of multistage twisted strands is necessary for indigenously developed 30kA NbTi strands CICC. The spatial structure of such superconducting cable is essential for appreciating the load and the performance of CICC at cryogenic temperature. This paper proposes cabling patterns of the strands and gives an approximate position of each stand during the twisting in various stages. These are proposed to be validated with currently developed 30kA CICC at IPR-BARC.

Key words: CICC, twist pitch, strands, trajectory

Hydraulic Modelling of Cable–in-Conduit Conductors (CICC): CFD Approach

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A practical design of cable-in-conduit conductor (CICC) cables, for different applications,involves calculation of pressure drop, friction factor and heat transfer. The flow analysis is expected to address the hydraulic issues relevant to the design of CICCs for safe and optimum operation. Flow analysis also yields the pumping power required to circulate the coolant (Supercritical Helium (SHe)). In the present work, a dual channel CICC with central spiral is considered for pressure drop analysis. The effect of mass flow rate on the pressure drop has been investigated. The computational domain is built and meshed in GAMBIT 2.0. The mesh was exported to FLUENT 6.3, a commercial CFD code, for further analysis. It is observed that as the mass flow rate through the conduit increases, the pressure drop increases appreciably. Friction factor in the CICC is calculated from the pressure drop obtained from FLUENT. This paper also presents the CFD methodology to find the pressure drop.

Keywords: Cable-in-Conduit Conductors, Computational Fluid Dynamics, Porous medium,

Development of 10kA High Tc Current Leads

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A 10 kA High Temperature Superconducting (HTS) current Lead has been designed and currently under indigenous development for the first time to reduce the refrigeration power and hence the operation cost. The lead is designed to operate with liquid nitrogen. The HTS part of 10 kA lead consists of 62 stacks cylindrically arranged on a stainless steel tube. Each stack is composed of two Di-BSCCO tapes soldered throughout the length. The conventional part is a heat exchanger made of braided cable. The detailed description of the design of the lead is presented in this paper.

Key words: Current leads, high Tc superconductor and DI-BSCCO tapes

Technological advances in Superconducting magnet system of SST-1

Upendra Prasad, A.N.Sharma, Dipak Patel, Kalpesh Doshi, Pankaj Varmora, Yohan Khristi, Pradeep Chauhan, Surendra J.Jadeja, Pratibha Gupta and Subrat Pradhan

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Refurbishment of SST-1 has been taken up as a time bound mission to overcome the technological difficulties encountered during the last assembly and commissioning in October 2006. Various technologies related with sixteen toroidal field (TF) and poloidal field (PF) superconducting magnets have evolved by prototyping, laboratory validation and testing on spare TF coil. Low resistance inter-pancake (IP) joint and inter-coil(IC) termination fabrication, leak tight joint box implementation and its welding, insulation strengthening, joint box electromagnetic support, hydraulic manifold welding are the technologies related with TF and PF superconducting magnets. More than one hundreds of IP joints have been fabricated and tested at 5K with 10kA current. The electrical resistance of IP joint is found to be lesser than 0.5 nano-ohms (nΩ). Performances of electrical insulation integrity and leak tightness of joint boxes and hydraulic tubing have also been verified at 5K and DC transport current of 10kA. Joint fabrication, joint box welding and insulation were carried out under various strict quality control processes. TF coil fabrication related tasks begun in February 2010 and were completed in September 2010. Joint fabrication, joint box and associated welding, electrical insulation strengthening, 5K panel integration and their tests at room temperature and at 5K are discussed in this paper. QA processes related with all technologies are also discussed in this paper

Key words: SST-1, TF coils, PF coils, Low resistance joints, Joint Box

Room temperature pulsed magnet setup with a view to create 20 T facility at 77 K in future

Priyanka Jain, Anurag Gupta, T.K. Saxena, and Hari Kishan

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Extremely high magnetic fields up to 30 - 90T have been possible with pulsed magnet technique. This paper describes the challenge of handling high energy and fast measuring electronics for developing pulsed field setups. Following the basic design equations a room temperature pulsed magnet has been designed and experimentally tested for 1T and results are discussed. Fast read out electronics has also been developed for measurements in pulsed fields. A pulsed magnet of energy 8.6 kJ has been worked out to produce 20T field for 10ms at 77 K. The current required to generate 20T field is around 8.85 kA. A 60 mF capacitor bank, which can be charged with a 535 V DC supply, is required to store the energy.

Key words: superconductivity, pulsed magnet.

Thermopower of vanadium group of metals: A Revisit

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We have reinvestigated the thermopower of uncontaminated good quality samples of V, Nb and Ta in the temperature range 6-300K. The completely new features of significantly smaller magnitude, (negative) sign, phonon drag dip and influence of superconductivity of the thermopower data were studied quantitatively using the theoretical fittings. These give the Fermi energy of 10.94eV, 5.08eV and 1.86eV respectively. These are significantly smaller than those estimated from the free electron model, indicating strong and predominating s-d scattering over s-s scattering among the electrons, phonons and defects in the jungle-gym type Fermi surfaces of these metals. The poor fitting of the phonon-drag peaks leads to the much higher Debye temperatures than those obtained from other methods such as specific heat. Their details are discussed.

Keywords: vanadium group, thermopower, intrinsic properties.

I-V Characteristics, Minimum Quench Energy and Normal Zone Propagation Studies of forced flow gas cooled YBCO tape

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Fundamental investigations on self-field I-V characteristics as well initial quench induced normal zone propagation characteristics of second generation YBCO coated conductor has been carried out in forced flow nitrogen gas cooling (77 K) condition that simulates practical applications. A special forced flow facility laboratory set-up was developed in order to characterize the coated conductor in laboratory. Normal zone in conductor is initiated by a heater element glued to the conductor surface. The minimum quench energy (MQE) and normal zone propagation velocity (NZPV) have been estimated by monitoring voltage and temperature evolution along the length of the conductor. The minimum quench energy (MQE) value has been evaluated for a particular transport current by varying the heater energy. The minimum quench energy and the normal zone propagation velocity in the YBCO conductor under the forced flow nitrogen gas cooled condition is experimentally estimated to be 0.393 kJ/cc and 0.33 cm/s respectively under self-field criterion.

Key words: Coated Conductor, 'n' value, Minimum Quench Energy, Normal Zone Propagation Velocity

Automized Measurements of RT and I-V at Low Temperatures and High Magnetic Fields using LabVIEW

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A fully automized magnetotransport setup is developed for RT and IV characterization of superconducting samples in a temperature range T = 4.2 - 300 K and in magnetic field B = 0 - 7 T. A N_2 jacketed He cryostat, 7 Tesla magnet and variable temperature insert (VTI) are assembled to carry out the measurements. Based on LabVIEW and General Purpose Interface Bus (GPIB) an exhaustive software comprising of monitoring, control and data acquisition is developed. The software is versatile, for instance, parameters like increasing/ decreasing temperature and field, dynamic/ PID controlled temperature, pulsed current for IV and statistics of the measured data are user defined. The data is stored in Excel worksheet and displayed online as RT and IV graphs during measurements. The setup and software are tested on a NbN superconducting thin film at low temperatures and high fields.

Keywords: Magnetotransport Setup, Superconductors, Automation, Control and Data Acquisition

Thermoelectric response of $Fe_xSe_{1/2}Te_{1/2}$ (x=0.95, 1.00, 1.05 and 1.10) superconductors

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In the present work we have tried to explore the nature of charge carriers, Fermi temperature, T_F, and superconducting critical temperature, T_c, through the resistance and thermoelectric power measurements of $Fe_xSe_{1/}2Te1_{/2}$ samples. The polycrystalline samples have been prepared with nominal compositions $Fe_xSe_{1/2}Te_{1/2}$ (x=0.95, 1.00, 1.05 and 1.10) via two step solid state reaction route. X-Ray diffraction results reveal the formation of tetragonal structure in all the samples. The measurements of resistance as a function of temperature show that all the samples are superconducting. The observed superconducting transition temperatures are 12.60 K, 13.68 K, 12.42 K and 12.07 K for x= 0.95, 1.00, 1.05 and 1.10, respectively. The temperature dependent Seebeck coefficient also confirms the superconducting transition in all the samples. From temperature dependent Seebeck coefficient measurements, we have determined the Fermi temperatures and studied the nature of charge carriers. The variation of Seebeck coefficient with temperature gives us idea about the scattering mechanism and multiband character of the samples.

Keywords: Solid state reaction, superconductivity, thermoelectric power, critical temperature.

Iron-Oxypnictide Superconductors: Synthesis and Physical Property Characterization

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We had reported superconductivity in the SmFe1-xCoxAsO (x =0.0 to 1.0) and NdFeAsO0.8F0.2 systems[1,2]. These compounds were synthesized by a simple and versatile single-step solid state reaction route showing superconductivity with Tc of 14 K and 50 K respectively. The parent compounds SmFeAsO and NdFeAsO are nonsuperconducting showing spin density wave (SDW) like antiferromagnetic ordering at about 140-150 K. The partial substitution of Co3+at Fe2+site results in the appearance of superconductivity in SmFeAsO. Whereas in NdFeAsO0.8F0.2 system, the carriers are introduced by O2 site F1 substitution or by introducing the O1x oxygen vacancies, which in turn as a result of charge neutrality provide mobile carriers to the superconducting FeAs layer. In this paper we report the synthesis and physical property characterization such as electrical resistivity, magnetization, and specific heat measurements in zero and applied magnetic field, on the above two iron-oxypnictide compounds. A comparison in physical property characterization of the two systems is also discussed in detail.

Key words: Iron-Oxypnictide, Magnetization, Spin Density Wave (SDW)

Influence of cryogenic treatment on wear behaviour of Poly (tetrafluroethylene) – Teflon

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Polytetrafluoroethylene (PTFE) is well known engineering material. The PTFE when rubbed or slid against a hard surface, it exhibits a low coefficient of friction but a high rate of wear. This impairs its usefulness as an engineering material. Thus to overcome this situation the cryogenic treatment is carried out using liquid nitrogen in order to improve its wear resistance without sacrificing the low friction performance. Hence, in this paper investigations on the influence of cryo-treatment especially on structural and tribological properties of PTFE are presented. The selected material is treated at sub-zero temperature (-185 °C) for stipulated time period (4, 8, 12,16,20,24 hrs) in the cryostat and then tested at ambient temperature. The 'un-treated' and 'cryo-treated' PTFE samples are evaluated in a comparative manner for the wear property using pin-on-disc machine. The mechanism behind the enhancement in wear performance on cryo-treatment is studied through experiments included Tensile test (UTS), X-Ray diffraction (XRD), Scanning electron microscopy(SEM), Fourier transform infrared spectroscopy(FTIR). The SEM micrographs of material surface, worn surfaces, wear debris and transfer films advocates the reduction in wear loss. The change in % crystallinity and crystallite size are found to be the most important parameter responsible for improved wear performance.

Key words: Cryo-treatment; Polytetrafluoroethylene; Wear; Liquid Nitrogen.

Effect of submicron-sized Al_2O_3 inclusions on the superconducting order parameter fluctuation in $YBa_2Cu_3O_{7-™}$ superconductor

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The effect of submicron-sized Al_2O_3 particle addition on the crystal structure and superconducting properties of YBa2Cu3O7-d ceramics was systematically studied. A series of 1-x ($YBa_2Cu_3O_{7-™}$) + x (Al2O3) samples (x = 0.0, 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 wt.%) were prepared using the solid state reaction method . The microstructure and the morphology of the polycrystalline samples have been characterized by X-ray diffraction (XRD), Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) technique. The crystal lattice parameters and the orthorhombicity were decreased slightly with Al2O3 addition. No change in the structural symmetry state was obtained. Morphology of the surface of pure samples reveals a considerable number of randomly oriented and clean grain boundaries. While in the composites, grain boundaries were filled with submicron-sized particles with enlonged size. With the increase of Al_2O_3 addition, the superconducting transition temperatures (Tc) determined by standard four-probe method was decreased and dropped sharply with higher alumina content. Excess conductivity fluctuation analysis using Aslamazov-Larkin (AL) model fitting reveals transition of two dominant regions (2D and 3D) above Tc. The decrease in 2D-3D crossover temperature (TLD) (Lawerence-Doniach temperature) in the mean field region has been observed as a consequent dominance of 3D region to increase in wt.% of Al2O3 in the composite.

Keywords : YBCO, Al_2O_3 Nanoparticles, X-ray diffraction, Electrical properties

Mechanical and Dielectric Evaluation of Glass Fibre Reinforced Epoxy-Cyanate Composites

Priyanka Brahmbhatt, Subrata Pradhan

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The insulation system for the magnet winding pack is a fibre reinforced plastic (FRP) laminate, which consists of a S-glass fibre reinforcement tape, vaccum impregnated with epoxy-cyanate blend system. In order to evaluate the mechanical behavior of composites, different proportion of epoxy-cyanate blends were prepared to impregnate glass fibres. The insulation laminates were irradiated at room temperature using Am-Be source up to fast neutron fluence of 2.38×10^{12} n/m^2 (E> 0.1MeV) to investigate the radiation induced degration in mechanical strength of the insulation system. The short beam shear tests and ultimate tensile tests (as per ASTM standards) were performed at room temperature on the composites prior to and after irradiation to evaluate the inter-laminar shear strength and ultimate tensile strength of the composites. The objective of this paper is to evaluate the mechanical and dielectric properties of the glass fiber reinforced epoxy-cyanates composites without using kapton.

Key words: Epoxy, Cyanate ester, Ultimate tensile strength, Composite

Thermally Activated Flux Dissipation in (1-x) $YBa_2Cu_3O_{7-™}$ + x $BaTiO_3$ Superconductor

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The magneto-resistance of bulk polycrystalline (1-x) YBCO + x $BaTiO_3$ superconductor is reported. The onset of global superconductivity and transition temperature of the sample is observed to decrease with the application of magnetic field and $BaTiO_3$ incorporation. The resistivity showed remarkable broadening in the magnetic field as compared with zero field resistivity. The activation energy of the thermally activated flux flow was determined from the slope of Arrhenius plot. The dependence of the activation energy on temperature and magnetic field were obtained. The activation energy decreased in the presence of ferroelectric $BaTiO_3$ inclusion and magnetic field. This may imply an easier thermally activated flux flow due to the vortex decoupling across the non-superconductive grain boundaries. Morphological modification identified that $BaTiO_3$ resides in the grain boundary of the granular matrix of YBCO.

Key words: YBCO, Magnetoresistance, Activation energy, Flux creep

Recent progress and development of Cryogenics system towards refurbishment of SST-1

Vipul Tanna, Jignesh Tank, Rohit Panchal, Rakesh Patel, Gaurang Mahesuriya, Dashrath Sonara, Jayant Patel, Naresh Chand Gupta, Manoj Kumar Gupta, Dikens Christian, GLN Srikanth, Nitin Bairagi, Atul Garg, Manoj Singh, Ketan Patel, Rajiv Sharma, Hiren Nimavat, Pankil Shah, Pradip Panchal and Subrata Pradhan

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Under the SST-1 mission mandate, several cryogenics sub-systems have been enhanced and updated for cool-down of SST-1. Upgradation and new developments followed by stringent test procedures have increased the reliability of operation. After preventive maintenance of the helium plant, the facility has been extensively used for the TF / PF coils campaign in excess of 25 cycles. The tests have been carried out with and without using cold circulator in supercritical helium mode. New developments include, 80 K thermal shields along with its booster system, in-house development of vapor cooled current leads rated at 10 kA and their current feeders system, enhanced capacity of Helium recovery system, pneumatic services and 12 kA / 16 V DC Switch Mode Power Supply system. Other significant test programs include Octant cold test at 80 K, electrical isolators test for helium and nitrogen and testing of current leads. The above aspects will be briefly discussed in this paper.

Key words: SST-1, Embossed shields, Booster pumps, current leads and supercritical Helium

Design of outer vacuum chamber for long superconducting quadrupoles for fair super frs energy buncher

Javed Akhter, G. Pal, C. Nandi, S. Roy, U. Bhunia, A. Datta, C. Mallik and R.K. Bhandari

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The Superconducting Fragment Separator of the Facility for Antiproton and Ion Research at GSI in Darmstadt is a large-acceptance superconducting fragment separator to efficiently separate rare isotopes. Design of the outer vacuum chamber of the long superconducting quadrupole magnet is presented in this paper.

The stainless steel helium chamber for quadrupole magnet cryostat contains the SuperConducting magnet assembly and weighs about 23 tons. The helium chamber and thermal shield is enclosed in a vacuum shell using specially designed support links. The outer vacuum chamber has been designed for self weight, external pressure and loads due to magnet handling and transportation.

The design of the outer vacuum chamber is based on the ASME Boiler and Pressure Vessel Code Section VIII code Division 2. Stress analysis was carried out using the allowable yield strength, ultimate strength and the buckling load defined in the code. This design ensures protection against the following failure modes: plastic collapse, local failure, collapse from buckling.

Key words: Cryostat, finite Element Analysis, Quarupole magnet.

Experimental Investigation and Analysis on Radiation Cooling of Cavities in Cryomodule for Superconducting Linac Accelerator

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Inter University Accelerator Centre. New Delhi

First phase of superconducting linac booster at IUAC with one linac cryomodule along with buncher and rebuncher was developed earlier and tested successfully. Recently another two linac cryomodules are added to complete the booster project. In each cryomodule, the cold mass at 4.2 K consists of cavities, liquid helium vessel and support structure is surrounded by the liquid nitrogen cooled thermal shield maintained at 100 K. Three stages of cooling namely, radiation cooling followed by liquid nitrogen pre-cooling and finally liquid helium cooling, are followed to reduce the temperature of cold mass from 300 K to 4.2 K. The temperature of cavity and helium vessel reaches to 220 K in 40 hours of time by the natural radiation from the thermal shield. Theoretical calculation on cooling rate and temperature profile for each component of cold mass is presented here along with measured data. Performance comparison with new modules is also discussed in this paper

Key words: Cryomodule, Cavity, Radiation, Thermal shield

PXI based data acquisition system for SST-1 TF test program

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SST-1 TF coil test program required data acquisition system (DAQ) for continuous monitoring of different sensors mounted on the coil for measurement of different parameters like voltage, pressure, temperature, strain, flow etc. Main design derivers for the system were ease of channel expansion capability, variable high/slow sampling rate, high accuracy, flexible GUI based configuration with reliable data storage and time synchronization with other acquisition systems. A PXI based data acquisition has been developed on Labview platform having these features. In present system, two NI-6225 Multifunction DAQ cards have been used,one dedicated for acquiring temperature data and other for acquiring voltages. GPS based time synchronization system has been used in this system. Application program provides flexibility of viewing online numeric data of selected channels in user defined groups and also the possibility to view online plots of four different groups in single window. This facilitated easy operator based actions during the test campaigns. Individual input channels have possibility to define sampling rate, gain, offset, multiplication factor and identification name. This data acquisition system has been successfully used for more than twenty coil test in the coil test campaigns and other small laboratory scale experiments. Present paper gives details of this system, application program and its performance during the tests.

Key words: PXI based system, Toroidal Field Coil, Tokamak, Labview, SST-1

Operation and Control Strategies in Pre-Series Testing of Cold Circulating Pumps for ITER

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Cryo-distribution system of ITER is responsible for the distribution and control of forced flow supercritical helium for cooling of the superconducting magnets and the cryo-pumps. The requirements of cold circulating pumps (CCP) for mass flow rates and performance are much higher than presently existing and commercially available one used at 4.0 K helium. Design up-scaling with pre-series test of CCP has been proposed including test infrastructure. Operation and control strategies for the test distribution box (TDB) of test infrastructure have been developed and analyzed using steady state and dynamic process simulation to cope with the functional requirements of CCPs. Off-normal scenario with CCP inlet pressure variation is an important concern, dynamic process responses during such scenario have been evaluated to verify the operability of CCP.The paper describes process simulation to cope with the functional requirements of CCPs along with evaluation of off-normal scenario to verify the operability of CCP.

Key words: Cold circulator supercritical helium

Quality Aspects in Support of the Refurbished SST-1 Magnet System

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Steady State Superconducting Tokamak (SST-1) magnet system consists of 16 superconducting Toroidal Field (TF) coils and nine superconducting Poloidal Field (PF) coils and a pair of resistive field coil inside the vacuum vessel.[1] A wholistic approach is adopted in Quality assurance (QA) and Quality Control (QC) of process and components used in the preparation of these magnets for SST-1 operation [2]. A Quality Control Plan (QCP) and Procedure Qualification Records (PQR) has been followed in the fabrication of superconducting magnet joints and manifolds. A pre-fabrication inspection comprised of visual inspection, dimensional measurements of copper blocks and jacket end caps and Destructive Tests (DT) of materials used for different component of these magnets like joints, manifolds, sleeves tubes etc. Fabrication inspection involved visual inspection, argon gas flow parameters and temperature monitoring, while the post fabrication inspection comprised of Non Destructive Tests (NDT) of the jointbox and manifold. This paper describes the individual QA and QC in detail.

Keywords: QA, QC, welding, Jointbox, manifold

80 K Liquid Nitrogen (LN2) Booster System for SST-1

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The 80 K thermal shields (double embossed type) in the Steady State Superconducting Tokamak (SST-1) at Institute for Plasma Research (IPR) are envisaged to be cooled to maintain a temperature uniformity of +/- 5 K against the heat load of 20 kW using forced flow single-phase liquid nitrogen at 6 bar (g), 80 K for a designated nominal flow of ~1 kg s-1. Single phase forced flow sub-cooled LN2 has been adopted to avoid uneven hydraulic distribution, pressure fluctuations, thermal runaway and vapor locking etc. The 80 K booster system consists of booster pumps, sub-cooler vessel, interconnecting vacuum jacket cryo lines and dummy load along with its ancillary components in a compact skid of 2.3 m (L) x 2.3 m (B) x 6 m (H). This paper describes the conceptual design, process flow diagram (PFD) along with process and instrumentation diagram (P & ID) of the 80 K booster system.

Key words: Forced-flow, Booster Pumps, Thermal Shields, Single phase, LN_2 and SST-1

Integrated Leak testing of 80 K Thermal Shields of SST-1 in RT and Cold condition

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SST-1 has implemented bubble type 80 K thermal shields cooled with single-phase liquid Nitrogen around the superconducting magnet system. These panels have been designed to maintain temperature uniformity within ± 5 K with pressure drops below 1.5 bar for nominal flow conditions. Another extremely critical criterion towards the functionality of these thermal shields is the leak tightness of these panels under any normal and offnormal scenarios. Integrated helium leak testing on each of these panels as well as group of assembled panels both at room temperature (RT) as well as at cold temperature of 80 K have been carried out to ensure leak-tightness. All the panels have been tested in component levels before and after thermal shocks between RT and 80 K three times. As per defined groups, these assembled panels around SST-1 vacuum vessel modules and sectors have been tested inside a dedicated high vacuum (HV) chamber having vacuum < 5.0 × 10–5 mbar. The panel temperature was obtained to be 80 K with inlet pressure of 1.83 bar (a). Before cool down and after achieving 80 K, these panels were leak tested by pressurizing helium gas at 8.0 bar (g). RGA spectra does not show traces of helium gas indicating the leak tightness of integrated system.

Key words: SST-1, Bubble panels, Leak tightness, RGA spectra

Use of piezoelectric actuators in cold condition for phase locking of superconducting Quarter Wave Resonators

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The need of the rf control system of superconducting resonators is to provide amplitude and phase stability. As the superconducting(SC) cavities often have a high Q (>108), the fluctuation of resonant frequency acts as the main disturbance to the stabilization process. The existing phase locking scheme of the quarter wave resonators (QWR) in the first operational module of the superconducting heavy ion linear accelerator consists of electronic and mechanical tuners. The mechanical tuner uses pure helium gas to flex the Niobium tuner bellows for tuning the frequency in slow time scale. The helium gas operated slow tuner turns out to be complicated, somewhat unreliable and expensive for long term operation of the linac. In an alternate scheme to handle the slow time part of the phase control, the tuner bellows is deflected by using a piezoelectric crystal for fine adjustment of the frequency. The piezoelectric actuator is used in closed loop along with dynamic I-Q based electronic tuner inside the cryostat to phase lock the superconducting cavities. The stiffness and stroke of piezoelectric actuators in cold condition was found to be sufficient to control the maximum frequency variation around the master oscillator.

Key words: Superconducting cavity, Phase control, Piezoelectric actuator, P-I control

"Validation of SST-1 components at low temperature under vacuum environment"

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Steady-state superconducting Tokamak (SST-1) is currently under refurbishment in a mission mode at Institute for Plasma Research. In this mission, leak tightness of all the cryogenic components of SST-1 under all operational scenarios is evaluated. Cryogenic components include TF coils, 80 K thermal shields, Helium and Nitrogen Manifolds, Isolators, Tubing,Headers etc. Toroidal field (TF) magnets of SST-1 have been refurbished and have been tested in cold condition with current. Leak tightness of the entire superconducting magnets winding-pack including joints and helium manifolds were necessarily to be ensured at room temperature (RT) as well as in cold (~ 5 K) with and without current. Nearly twenty five campaigns involving SST-1 TF coils have been made where the vacuum leak tightness was monitored and ensured including those of the partial pressure of the residual gases. This paper will elaborate these experiments including methods adopted at ensuring leak tightness in cold. This paper will elaborate these experiments including methods adopted at ensuring leak tightness in cold condition and Partial pressure measurement during all the campaigns of Coils and other component testing.

Key words: SST-1, Leak tightness, TF coils, thermal shields, helium manifolds.

Conceptualization and Development of a Helium Liquefier at BARC, Mumbai

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Indigenous development of helium liquefiers is regarded as a high priority area at BARC, Mumbai. A pre-cooled Collin's cycle based helium liquefier conceived to work between pressure limits of 0.105 and 1.3 MPa(a) and with mass flow rate of 62 g/s is reported in the present paper. The system is designed to achieve a liquefaction rate of about 57 l/hr with the lowest temperature as 4.86K. Effect of different heat exchanger effectiveness and turbine efficiency values on the liquefier performance has also been theoretically studied and reported here. Design and development methodology of the liquefier cold box has been dealt with. The present paper also describes the current state of installation and commissioning activities of the above described helium liquefier at BARC, Mumbai. First trial runs are expected soon after the completion of the transferline circuit from the liquefier cold box to the liquid helium receiver vessel.

Key words: Helium liquefier, Cold box, Expansion turbine, Compact brazed plate and fin heat exchanger

Experimental studies of cryocooler based cryopump with indigenous activated carbon cryopanels

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A Cryosorption pump is the only possible pump that can be used to pump helium and hydrogen isotopes in fusion devices. In our attempt to develop cryosorption pumps and to benchmark the performances of indigenous activated carbon based cryopanels, we have experimentally evaluated the performances of the indigenous activated carbon panels in comparison with that of the commercial one used in CTI Cryosorption pump (model Cryotorr 7). The panels are mounted at the second stage cold head of the GM cryocooler, which reaches 11 K, with the first stage reaching ~ 50 K. With no gas influx, an ultimate pressure of 2.3E-7 mbar is reached. The pumping speeds of different gases such as nitrogen, argon, hydrogen and helium have been studied both for the commercial and indigenous charcoal based cryopanels. These studies serve as guidelines for benchmarking the indigenous activated carbon based cryopanels towards their performance improvements.

Key words: Cryocooler based Cryopump, Indigenous charcoal panel, Pumping speed, Fusion devices

Comparative performance of two different designs of heat exchangers for the Vapor Cooled Current Leads

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The performance of vapor cooled conventional current leads is a strong function of the heat transfer coefficient between the coolant and the available metallic surface. Designers always look for the best-optimized design concept of heat exchanger for the higher ratio of wetted area to current carrying cross-sectional area along with acceptable pressure drop and liquid helium consumption. At IPR, two different design configurations of heat exchangers have been adopted for comparison in which one of them is shell and rods with baffles and other one is rods in tubes. A (+/-) pair current leads has been tested and characterized for different current values up to 10kA. Test results show that, the shell and rod heat exchanger with baffles configuration is ~ 20% more efficient as compared to tube and rod heat exchanger, which is a good margin on a cryogenic system.

Key words: Current lead, Liquid Helium, super conducting magnet, heat exchanger

Design of Still for Dilution Fridge

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In view of indigenous development of a dilution fridge at VECC, Kolkata, we have designed a 3He distillation chamber (Still) of 40 cc volume for efficient evaporation of 3He from the dilute solution. To ensure the requisite cooling power of the dilution fridge we have chosen, manganin wire heater (~400Ω) is glued to the exterior to the Still body. The Still is made of OFHC Cu. To reduce the 4He film flow, the diameter of 2.5 mm is used for the exit path in the pump-out line. The estimated Still power is of~ 0.6 mW. RuO temperature sensor is tightly fitted with the still in an appropriate boring. A typical circulation rate of 15 µmol/s of 3He is considered for the fridge (estimated cooling power ~10 µWatt @100 mK). This paper presents the detailed mechanical design along with analytical results of Still with film flow suppressor.

Key words: Still, Superfluid, Superfluid film flow, Cooling power.

Dynamic Simulation of Helium Liquefiers using Aspen Hysys®: Problems, Solutions and Prospects

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Cryogenic Engineering Centre, Indian Institute of Technology Kharagpur, India *This paper deals with the application of dynamic simulation of helium refrigerators and liquefiers by a general purpose process-simulator Aspen Hysys®. A standard helium liquefier for capacities of 100 L/hr and 50 L/hr with and without liquid nitrogen pre-cooling respectively, have been chosen for validation of the code of Aspen Hysys®. To obtain an accurate simulation result we need appropriate equation of state, accurate transport properties of helium and thermal properties of metal, actual equipment specifications and cool-down sequence with appropriate control. In the present work, the limitations of Aspen Hysys® in simulating helium systems have been identified and techniques to overcome these problems have been discussed. The dynamic simulation has been performed following the above techniques in order to obtain cool-down profiles. The cool-down process has been simulated from 300 K to 8 K showing similar trends in the temperature variations at different state points. However, it has not been possible to get below the level of 8 K and the solution diverges at this temperature. The reasons for this divergence are under investigation and future efforts would be made to achieve a complete cool-down process simulation. To conclude, it may be said that, despite the limitations of Aspen Hysys® and non-availability of many vital specifications of equipment of plant, we are optimistic about the applicability of Aspen Hysys® as dynamic simulator for simulation of helium systems down to its liquefaction point.*

Key words: Dynamic simulation, Helium refrigerator and liquefier, Aspen Hysys®, Parameter estimation.

Performance of Helium Recondenser for Quadrapole Magnet Cryostat

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A superferric superconducting quadrupole doublet magnet cryostat is currently under fabrication at our institute. This cryostat will be located far off from the existing cryogenic distribution facility and hence the cryostat design is done based on the cooling capacities provided by a two stage GM cryocooler. Cryocooler 1st stage cooling power will be used to cool the copper shield to 60 K and HTS leads and the second stage cooling power will be used to recycle the cold helium gas through a liquid helium recondenser heat exchanger apart from the radiation load from 60K shield and instrumentation wiring. A helium recondenser with a surface area of 0.15 m2 in a compact volume has been designed, fabricated and tested. To have maximum enhanced area per unit volume fin like straight grooves were cut into an OFHC copper block deep down. A detailed thermal analysis of the recondenser has been carried out both theoretically and experimentally. LHe production rate achieved was 0.88 liter per day (lpd) and the measured refrigeration capacity in the setup was maximum 2.26 watt at an equilibrium pressure of ~56537 Pa inside the refrigeration chamber. Also study was conducted to measure the recondensation capacity at various input power in liquid helium against the stabilized chamber pressure and at the same time temperature at various points was measured. This paper will discuss the design aspect of the heat exchanger, and the performance w.r.t. refrigeration capacity at various pressure and temperature.

Key words: Recondenser, Cryocooler, Superconductor magnet, Cryostat, UHV Vacuum vessel

Thermal Performance evaluation of Multi-Stream Plate Fin HXs using Finite Difference Technique

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A new methodology for thermal performance analysis of multi-stream plate fin (MSPF) heat exchanger (HX) based on finite difference technique is proposed in the present paper. The heat exchanger is partitioned into a number of smaller element along the flow direction. In addition to this, fins in every channel are discretised also along the direction perpendicular to flow direction. Governing steady state heat transfer and energy balance equations for separating plates, fins and fluid are solved simultaneously to find the temperature profile inside the HX core and predict its thermal performance. An algorithm is developed to solve all the equations simultaneously with given boundary conditions. A thermo physical property software is coupled with the developed program to capture real fluid properties at each node while best fit curve is used for thermal conductivity of metal.

Key words: Multi-stream plate fin HX, Cross layer conduction, Finite difference technique

Investigations on performance improvement of standing wave type thermoacoustic prime mover using acoustic amplifier

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Thermoacoustically driven pulse tube cryocooler is gaining significant interest in the recent time due to its key advantage of complete absence of moving components from the entire system. Design and development of a thermoacoustic prime mover is a challenging work which requires thorough understanding of thermoacoustic phenomenon. The system performance, mainly in terms of pressure amplitude is significantly influenced by the operating parameters like heat input, temperature of heat input and charging pressure, geometrical parameters like stack length, stack position, resonator length etc. and the type of working gas. Reduction in length of the device results in higher frequency and lower pressure amplitude of thermoacoustic oscillations. The disadvantage of lower pressure amplitude of thermoacoustic oscillations is offset to some extent by using the acoustic amplifier.In the present work experimental investigations are carried out on a standing wave type thermoacoustic prime mover having parallel plate type stack with around 300 Hz frequency of oscillations. The improvement in pressure amplitude of thermoacoustic oscillations using the acoustic amplifier is studied. The results obtained are compared with the results of theoretical modeling. Effect of charging pressure and stack length is studied for nitrogen and helium gas.

Key words: Thermoacoustic engine, Standing wave, Acoustic amplifier

Effect of length scale on miniature Stirling cycle cryocooler

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Miniature cryogenic coolers operating on the reversed Stirling cycle are used for cooling IR detectors in satellites, imaging cameras in battle tanks and super conductor filters. These coolers should be of low weight, compact size, trouble free operation high reliability and high endurance limit. The performance of the Stirling cooler depends on the effectiveness of the regenerator used in the system. In the present study, the influence of length scale on each individual loss associated with the regenerator is investigated. For fixed cycle parameters and regenerator length scale the system produces net refrigeration for a specific range of hydraulic diameters only. There is an optimum value for hydraulic diameter which gives maximum net refrigeration. It was also found that the optimum value of ratio between hydraulic diameter and regenerator length decreases when the regenerator length increases. Among the different regenerator materials investigated, material with minimum thermal conductivity gives maximum net refrigeration.

Key words: Stirling cycle, Regenerator, Length scale

Performance Estimation of Miniature Inertance Tube Pulse Tube Cryocooler.

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The work is focused in modelling and performance comparison of in-line model of Inertance tube Pulse tube cryocooler a detailed analysis of the flow and temperature variation in various components of the above mentioned models under oscillating flow conditions is carried out. The components of inertance tube pulse tube cryocooler are compressor, transfer line, aftercooler, regenerator, cold heat exchanger, pulse tube, hot heat exchanger, inertance tube and the buffer. The mathematical model consists of the full set of compressible conservation equations with the assumption of axisymmetry. The regenerator is modelled using porous approximation. Studies are conducted with a different L/D ratio of the inertance tube. The performance of different L/D ratio for pulse tube is also analyzed. The no-load temperature achieved in the cold heat exchanger in all the cases is compared The simulations reveal interesting time dependent flow patterns that develop in the pulse tube due to fluctuation caused by the piston and the presence of inertance tube.

Key words: cryocooler, pulse tube, inertance tube.

Numerical Investigation by CFD on Thermoacoustic Twin Prime Mover

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Thermoacoustic prime movers and refrigerators, due to their simple structures and the absence of moving components would serve as desirable systems for several applications. Towards their development, a standing wave thermoacoustic prime mover has been built, in which the prime movers are located at either ends of resonator. This system has been designed based on the procedures outlined by Swift [1] and Tijani [2]. Experimental studies have been conducted to evaluate its performance characteristics with respect to several parameters such as the working fluids, operating pressures etc. We have attempted the modeling using the procedures of CFD, and the analysis has been carried out for different fluids such as argon, helium and 80% Helium - 20% Argon mixture under various pressures. The theoretical predictions were compared with the experimental studies.

Keywords: CFD, Thermoacoustics, Stack, Resonator, Primemover

Optimization of a Moving Magnet Linear Motor for Opposed Piston Two Stage Stirling Cryocooler

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A two stage Stirling cooler is composed of a compressor unit, cooler electronics and two stages of Stirling coolers; i.e., two sets of regenerator and displacer body. A moving magnet linear motor is designed for an input power of around 120W to achieve cryogenic temperature at the cold end of the cooler. The two pistons, mounted on the opposite ends of the same shaft, are driven by the linear motors. The cooling capacity in the cold head is generated by the combined motion of the displacer and a pressure wave developed by the pistons. The temperature reduction is achieved in two stages viz., in first stage 90K with 1W and in second stage 30K with 200mW heat lift. The optimization analysis of various electromagnetic and geometrical parameters of the moving magnet linear motor for the system is required to achieve the desired objectives as the active magnet height varies periodically with respect to time. The present work is dealt with the optimization analysis of the linear drive to power the pistons.

Key words: Stirling cooler, Two stage, Electromagnetic