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A yearly journal devoted to
Cryogenics, Superconductivity and Low Temperature Physics

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Proceeding of
Twenty Sixth National Symposium on Cryogenics and Superconductivity (NSCS-26)

Hosted by
Variable Energy Cyclotron Centre (VECC), Bidhan Nagar, Kolkata
February (22-24), 2017

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Indian Journal of Cryogenics

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PREFACE

There has been a steady growth of activities related to cryogenic technologies and applied superconductivity in the country. Cryogenic based Accelerator Technology development gained momentum when VECC, Kolkata went to build Superconducting Cyclotron. Around the same time other accelerators like Peletron at TIFR, Mumbai and IUAC New Delhi, Synchrotrons at RRCAT, Indore and other accelerators at BARC, Mumbai also came up. These accelerators used superconducting RF Cavities which were produced indigenously. Yet another ambitious fusion reactor programme, SST-1 using large superconducting toroidal and poloidal coils was initiated at IPR, Ahmedabad during 1990s. Consistent with these developments large cryogenic systems too were developed involving local industry. Considerable expertise has been developed in building magnets, fabricating RF cavities, the cryostats, laying cryogen supply lines and developing room temperature control systems.

The National Symposium of Cryogenics and Superconductivity (NSCS), held generally once in two years under the banner of the Indian Cryogenic Council (ICC), covers wide range of superconductivity, low temperature physics and cryogenic topics and provides opportunities for both formal presentations as well as informal discussions among the symposium participants on topics of interest to them. It provides a common platform for all academicians/professionals/ industrial partners & organizations for sharing knowledge, information about products & services in the area of cryogenics available in India. “NSCS-26” was hosted by Variable Energy Cyclotron Centre, Kolkata, one of the premier R&D organizations of Department of Atomic Energy in the area of nuclear physics, accelerators, cryogenics and superconductivity in India. The researchers, academicians, technologists, industrial houses, students involved in the R & D activities in cryogenics from across India were invited to actively participate in the symposium. The response had been overwhelming. There were some special invited lectures delivered by renowned scientists and technologists on the topics of interests in the present Indian scenario.

In a special session, ICC gave away the prestigious “ICC Life Time Achievement Award 2016” to three distinguished professors, namely, Prof. E.S.R. Gopal, Prof. Sunil Sarangi and Prof. Subhash Jacob. Three more ICC awards, the “ICC Leadership Awards” were given to Prof. Y.C. Saxena, Dr. Amit Roy and Dr. R. K. Bhandari. An exhibition of equipment, accessories, components etc., required in cryogenics and superconductivity was also organized at the venue. The participation of Industries and Manufacturers provided a forum for a strong interaction between the delegates and the industry for mutual benefit.

We thank all the invited speakers, participants and the exhibitors for their support to this symposium.

Dr. Sumit Som
Co-Chairman, Organizing Committee

EDITORIAL

It is a matter of great satisfaction that, year after year, we are able to bring out successive issues of our esteemed journal, the "Indian Journal of Cryogenics" on time. Volume no. 43 for the year 2018 is now out and in time. As per the policy of the ICC and the journal we encourage our young researchers to publish papers and many of them happen to be first timers. Very often, our distinguished reviewers have tough time and have to suggest many corrections and modifications in the manuscripts and ask for revision. I admire their endurance and stamina. This is all in the interest of the ICC, the Journal and our community. I thank all the referees profusely. Vol. 43 is the proceedings of the "26th National Symposium on Cryogenics and Superconductivity" (NSCS-26) held at the Variable Energy Cyclotron Centre (VECC) Kolkata during February 22 – 24, 2017.

This issue contains 32 papers in all out of a total of 54 papers submitted that were presented at the NSCS-26 at VECC, Kolkata. In keeping with our policy each paper of this issue was reviewed by two of our experts on our panel of referees from within and outside India. In case of conflicting reports the final decision on the acceptability of the paper is taken by the editorial board

Like the previous issues Vol. 41 and Vol. 42, this issue too begins with an invited review article written by Mr. Parag Kulkarni, Director and Chief executive Officer, INOX INDIA Pvt. Ltd., Vadodara, Gujrat. As you know Mr. Kulkarni is aveteran cryogenic engineer with vast experience in the design and manufacturing of small and large cryogen containers, storage tanks and large transport vessels. In this paper he has covered the development and manufacture of large vacuum insulated cryogenic containers for storage and transportation in the context of technology developments in recent years, and large scale use of industrial cryogenics. Apart from covering the design and manufacture of vacuum insulated containers, paper also describes the latest trends and applications associated with Liquefied Natural Gas (LNG). I thank him for having accepted our invitation to write this review and on a short notice. I am sure the cryogenic community and the Indian gas industry experts will enjoy reading this article.

I take this opportunity to complement all the members of the Editorial Advisory Board for their help and cooperation. I thank Dr. RK Bhandari, Dr. TS Datta and Dr. SoumenKar who were always available for consultation and help which enabled us to bring out this issue (Vol. 43) of the IJC. I express my gratitude to the reviewers, who in spite of being deeply involved with their academic work always found time to review multiple papers. I thank all our authors who repose faith in IJC and cooperate in revising manuscripts if so desired by the reviewers. I also acknowledge the help from Ms. Richa Arora in keeping the line of communication alive with authors, the reviewers, the Journal HQ and the printer. I thank Mr. Satish Gupta of the New United Process for taking good care of printing.

We also acknowledge the support of the SERB (DST) for the publication of this journal

Finally, we remain open to suggestions from all the authors and reviewers which can add value to IJC.

R.G. Sharma

Chief Editor

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Development and manufacturing of large cryogenic containers for storage and transportation

Parag P. Kulkarni

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This paper covers the development and manufacture of large vacuum insulated cryogenic containers for storage and transportation in the context of technology developments over the years, and large scale use of industrial cryogenics. Apart from covering design and manufacture of vacuum insulated containers, paper also describes the latest trends and applications associated with Liquefied Natural Gas (LNG).

Key words: Vacuum insulation, Storage vessel, Perlite, Superinsulation, Liquefied natural gas (LNG)

Optimization of the performance of injection cooling system using genetic algorithm

Pritam Saha, B. Nitin and Pavitra Sandilya

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Injection cooling is a method to reduce the boil-off loss of cryogenic liquids, and has been applied in space launch vehicles. In this, subcooling due to liquid evaporation into the gas bubble causes a reduction in the liquid boil-off. Extent of evaporation depends on the gas-liquid interfacial area, and heat and mass transfer rates. Hence, gas flow rate, gas injection temperature and system configuration have profound effect on liquid subcooling. Optimum values of process variables are needed to maximize the process performance. The present study involves the development of an optimization strategy to minimize the evaporative loss of cryogenic liquid in injection cooling. Genetic Algorithm (GA) has been applied for this purpose as it enables the determination of global optimum values of various process variables. An in-house code has been developed to carry out optimization studies on the injection cooling.

Key words: Injection cooling, Heat and mass transfer, Optimization, Genetic algorithm

Performance characterization of a radiation shield baffle structure of a cryocooler based cryosorption pump for INTF

Milind Patel, Arun Kumar Chakraborty, Mainak Bandyopadhyay and Chandramouli Rotti

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To characterize Diagnostic Neutral Beam (DNB) for ITER, a test facility (INTF) is being developed at ITER-India laboratory, in Institute for Plasma Research, Gandhinagar. Operation of the beam source (BS) in INTF is based on the production of an H-- ion beam of energy 100 keV. To meet the requirement of high vacuum in INTF, twelve sets of cryocooler cooled cryosorption based cryopumps are planned of size 3.0m × 0.6m × 0.3m (L×W×D) to be installed in the INTF vacuum vessel. Each cryopump consists of Liquid Nitrogen (LN2) cooled 210 black TiO_2, Al_2O_3 ceramic coated V-shaped chevron baffles arranged in staggered way precisely as radiation shield around cryocooler cooled activated charcoal coated cryopanel, with temperature around 15 – 20K. Each LN2 baffle is connected to four LN2 distribution pipes at four corners of it, maintaining precious gap to ensure sufficient gas molecule transmission through it with negligible photon transmission to cryopanel. The manufacturing of cryopumps employs two important processes which are Black coating of chevron baffles and joining process of total 210 × 4 joints with the LN2 pipes. In the past, cryopumps for SST-1 have been manufactured by utilizing (1) plasma spray technique for black coating (2) TIG brazing for joining pipe to baffles joints. In the present case, while coating is applied using the same spray technique, the joining technology selected is vacuum brazing. The advantage of vacuum brazing is it makes it possible to join large number of baffles at one go, compared to TIG brazing technique which joins the baffles one of one. Emissivity of the black coating was found to be better than 0.9 exceeding the technical specification of 0.8. Adhesion of black coating with the substrate is found to be adequate. Vacuum brazing of coupons have been qualified for the requirements of the joints.

Key words: Cryopump, Vacuum brazing, Cryosorption, Cryocooler

Design development and studies on a liquid nitrogen based cryosorption pump

K. A. Shafi[1], Mathew Skaria[1], Rijo Jacob Thomas[1], K. Vasudevan[1], H. Mohammed Faizal[1], P. Vishnu[1], and Srinivasan Kasthurirengan[2]

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Cryosorption pumps are the vacuum pumping method for many high and ultra-high vacuum applications due to their reliability, cleanliness, and high pumping speeds. They are used in several industrial applications such as Semiconductor, Optical Coating, Particle Accelerators, Medical devices etc. and in Research and Development. These pumps generally use activated carbon as the sorbent material for pumping of various gases. Such a pump can be either cryocooler based or cryogenic fluid based. Supercritical liquid helium cooled cryosorption pumps are used in fusion tokamaks for pumping of helium and hydrogen. In our efforts towards the development of cryosorption pumps, we have designed, fabricated and studied cryosorption pumps cooled with liquid nitrogen (LN2). Specially developed activated carbon are adhesively bonded on the surface of copper panels and filled in a vessel made of stainless steel mesh. These are mounted in vacuum chamber. This chamber when cooled with LN2 forms the cryopump operating at 77 K. In this work, we report the performances of these pumps such as the ultimate vacuum.

Key words: Adhesive, Cryosorption, Panels, Activated carbon.

Structural and thermal analysis of dewar supports for low boil-off long duration storage of cryogenic liquids

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Design of a cryogenic liquid-storage system for various applications is unique and hence, is still an evolving field of research and development as newer applications of cryogens are being envisaged. The conventional way of storing cryogenic liquid is the use of dewars, which are double walled containers using evacuated insulation materials to reduce heat in leak from the ambient. Design of the dewar support system to store and transport cryogenic liquids on a mobile platform poses considerable challenge. The present study lays the foundation for addressing a long duration storage of cryogenic liquid under very high-stress levels. The study involves the evaluation of the structural and thermal performances of such vessels in order to ensure structural stability of the vessel while allowing minimal boil off loss of the stored cryogenic fluid. A FEM based numerical study is underway to compare support systems in terms of the stresses, and heat inleak.

Key words: Cryogenic storage, Dewar supports, FEM analysis

A prototype experiment on cryocooler based cryopump

Milind Patel[1], Arun Kumar Chakraborty[1],Mainak Bandyopadhyay[1],Chandramouli Rotti[1], Deepak Parmar[1], Hardik Shishangiya[1], Himanshu Tyagi[1], Ratnakar Yadav[1], Kartik Patel[2], Hiren Mistry[2] andKaushal Pandya[2]

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To characterize ITER Diagnostic Neutral Beam (DNB) in Indian test facility (INTF), ~ 106 l/s installed pumping speed is required to ensure low re-ionization losses and stripping losses of extracted negative hydrogen ions from the ion source in presence of ~ 14.6 Pa.m3/s hydrogen gas throughputs. Such large pumping speed will be provided using 12 cryopumps based on Cryo-sorption mode of operation and are dispersed symmetrically along the 9 m length of the test vessel. Each pump has a speed of ~ 1 x 105 l/s.The engineering configurations of the pumps are charcoal based Cryosorption type with cryopanel at 15K temperature, cooled by a cryocooler. The pumping surface is surrounded by Chevron shaped liquid nitrogen cooled radiation shield at 85K temperature. An experimental validation of the temperature distribution on the Helium surface has been carried out on a prototype using a 20 W @ 15 K cryocooler (Sumitomo make). The experiment establishes temperature uniformity within 0.5 K at the extremities of the Helium panel for heat loads that is a factor of 1.5 higher than the estimates, and closely corroborates the simulation data, thereby ensuring a reliable pumping performance. The results of the prototype experiment leads to a technical decision of incorporating 12 cryocooler based cooling for the Helium section, thereby obviating the need for a dedicated 15 K Gaseous Helium Supply System. The paper shall present a brief configuration of the Cryopump, the details of the prototype, the experimental results and the conclusions arrived at.

Key words: Cryocooler, Cryopump, Cryosorption

Design and development of an emissivity measurement set-up for use at 100 K

K. A. Shafi[1], Mathew Skaria[1], Rijo Jacob Thomas[1], K. Vasudevan[4], C. Krishnachandran[1], Arun Mudya Prakhyath[2], Manjunath Hatti[3], Srinivasan Kasthurirengan[4], UpendraBehera[4], Ranjana Gangradey[5] and Samiran Mukerjee[5]

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For the best performance of the Activated carbon based cryopumps, the activated carbon should be at the lowest possible temperature. For this, the heat load from the surroundings has to be minimized. Radiation heat load is significant and depends on the emissivity of surfaces. Since the emissivity data are scarce at cryogenic temperatures, we have developed an experimental setup based on the calorimetric method for the measurement of emissivity of various coatings or parts at these temperatures around 100 K. The setup consists of a heater located inside a vacuum vessel at 77K. When the heat transfer between the heater and the receiving surface is nearly by radiation, using the measurements of heat load and the temperatures, the emissivities of the different surfaces can be estimated. The design and fabrication of the experimental setup along with the preliminary results are presented in this paper.

Key words: Emissivity, Calorimetric method, Cryopump, 77 K

Cryocooler based helium liquefier development- A practical usage

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A helium liquefier using a 1.5 watt at 4.2KGifford Mac Mohan (GM) cryocooler was developed at IUAC having a liquefaction capacity of 17.4 litres per day (lpd) at STP. This standalone setup could not be used for any other experimental facility which requires liquid helium for its functioning and so another portable experimental liquefier was designed and fabricated using the same technology, which can be used to hook up very easily using its liquid inlet line port. In the present experimental demonstration setup the cryocooler liquefier was hooked up to a commercial 100 l helium Dewar. The Dewar was cooled starting from room temperature with the cryocooler liquefier in 2 days and 50 litresof liquid helium was collected inside the Dewar. The measured production rate of liquefaction was 14.2 litres per day. Successful liquefaction of helium in such a portable setup opens up the door for using this technology for other experimental purpose requiring liquid helium.

Key words: GM Cryocooler, Liquefier, Heat exchanger

Development of an experimental set-up for effective thermal conductivity studies of insulations between 77K and 300K

Skaria Mathew[1], K. A. Shafi[1], Rijo Jacob Thomas[1], K. Vasudevan[1], D. Muhammed Anshad[1] and Srinivasan Kasthurirengan[2]

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Thermal insulation is an important aspect of any cryogenic system. The choice of a given insulation for a specific application depends on various factors, such as effectiveness of the insulation, the cost, easiness of application etc. The data on the thermal conductivities of several insulations at cryogenic temperatures are not available in the literature. Towards the above, we have designed and fabricated an experimental set up to determine the effective thermal conductivity of cryogenic insulations between 77 K and 300 K. In this set up, the insulation under study is positioned between a heater and a 77 K surface formed by a liquid nitrogen vessel, inside a vacuum chamber. The effective thermal conductivity of the insulation is determined by the measurements of temperature of the heater, applied heat load and the evaporation rate of liquid nitrogen from the LN2 vessel. The design, fabrication of the setup and the preliminary experimental results of thermal conductivities of some sample insulations are presented here.

Key words: Effective thermal conductivity, Cryogenic insulations

Stress analysis of cryogenic suspension system of superconducting MRI magnet cryostat

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Support system is one of the most critical components of any zero boil off MRI cryostat. We have designed and analysed twelve self-centring support structures for the warm bore horizontal cryostat for testing of 1.5T superconducting MRI magnet. The design has been optimized to have maximum tensile strength, minimum resonant frequency, heat load, maximum pretension force and with allowable accelerations. The dimensional constraints as well as requirements for structural stability has been established. The s-glass support straps with intermediate thermal intercepts at 60-80K and has been designed to suspend the five tons cold mass during assembly, shipment and normal operation of the MRI magnet. This paper briefly discusses the static and dynamic stress simulation of cryogenic support link of the MRI cryostat using ANSYS.

Key words: Zero boil off, Self-centring, Superconducting magnet, MRI cryostat

Design and analysis of a portable free piston stirling deep freezer

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A numerical study is conducted to study the feasibility of a free piston for a deep freezer using Sage software in which the free piston is modelled and optimized. The increased environmental hazards and energy consumption has led to the need for an alternative refrigeration technology. Hence the Stirling refrigeration using free piston which can even operate at the cryogenic temperatures, is a promising alternative. Since the design is concentrated on a cooler which can operate upto 193K a 14 L deep freezer is designed. A free piston using Helium as working fluid is designed and studied using the Sage software. Based on the operating conditions the energy flow in the free piston is obtained and dimensions for the freezer are determined. The heat from the refrigeration space is absorbed using a CO_2 capsule which acts as a thermos-syphon. These CO_2 capsules are kept in contact with the cold side of the free piston. The deep freezer is then tested for its efficiency and cooling capacity.

Key words: Free piston, Stirling cooler, Thermo-syphon

Design analysis and development of a thermoacoustic engine

V.K. Yadav, K.V. Yadav, S.K. Gupta and T.K. Nandi

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Thermoacoustic devices (TAD) deal with the conversion of thermal energy to acoustic energy and vice versa without any moving component. Combining a thermoacoustic engine (TAE) with Stirling-type pulse tube cryocooler results in an entire vibration free system and makes it suitable for long-term space applications.In this paper, a comprehensive design and optimization method of a TAE producing 50 W of acoustic power output is discussed. Based on the knowledge available in open literature, a TAE is designed and presented. The stack is placed inside a cylindrical resonator of 12.6 cm internal diameter. It is made of 0.2 mm thick stainless steel tubes with a inner diameter of 0.6 mm. The engine operates at 800 K at the hot end of the stack through electrical heater placed inside the resonance tube and the other end of the stack is cooled using air at normal temperature.

Key words: Thermoacoustic, Pulse tube, Thermal penetration depth, Acoustic power, Efficiency

Numerical analysis of miniature coaxial Stirling type pulse tube cryocooler with a modified reservoir

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A Numerical model of a compact coaxial Stirling pulse tube cryocooler with a cooling capacity not less than 2W at 80K is done. The performance characteristics with varying geometrical parameters are simulated. The Inertance Pulse Tube Cryocooler (IPTC) with a modified reservoir is suggested, where the reverse fluctuation of pressure in the compressor case is used instead of the steady pressure in the reservoir to shift the phase of the flow velocity at the hot end of the pulse tube. Therefore, the large reservoir volume of the cryocooler could be reduced, to make the cryocooler compact. The performance of the cryocooler was investigated and compared with the IPTC. The simulation results show that the cryocooler with modified reservoir can work as efficient as inertance type pulse tube cryocooler.

Key words: Cryocooler, Pulse tube, Inertance, Reservoir

Online quality factor measurement of the SRF cavity in injector cryomodule of VECC electron LINAC

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The ANURIB facility being planned at VECC will use a super-conducting electron linac (e-Linac) as photo-fission driver. The e-Linac will initially be of 30 MeV, 2 mA with an optional upgrade to 50 MeV planned in the future. An identical e-Linac is being built for the ARIEL project at TRIUMF, Canada. The 30 MeV e-linac is made using three 1.3GHz nine cell niobium cavities of Cornell-type, each cavity supplying 10 MV acceleration. The first 9-cell cavity is housed in a cryomodule called Injector Cryomodule (ICM) followed by an Accelerator Cryo-Module (ACM) comprising two 9-cell cavities. In the first phase, the ICM has been developed in collaboration with TRIUMF. The cavity operates at 1.3 GHz and 2 K. The paper highlights the online quality factor measurement of the ICM using calorimetric method.

Key words: SRF cavity, Cryomodule, TRIUMF

Fabrication of racetrack-type double pancake HTS coil for K500 extraction beam line steering magnet

Vipendra K Khare, Ankur Agarwal, Tamal Ghosh, Uttam Bhunia, Chinmay Nandi, Anindya Roy, Jedidiah Pradhan, Malay Kanti Dey and Sajjan K. Thakur

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A High Temperature Superconductor (HTS) based cryorefrigerator assisted steering magnet sunder development at VECC for the extraction beam line of K500 cyclotron. The magnet designed is specified for ± 3 degree horizontal correction and ± 1.5 degree of vertical correction of the beam of maximum rigidity of 3.3 T-m. The magnet is composed of two sets of double pancake racetrack coil – one set for vertical field (B_y) and other for horizontal field inside the return iron yoke. Double pancake coils are fabricated in-house using BSCCO-2223 HTS tapes by wet winding technique using cryogenic grade epoxy. The critical characteristics of the coils are tested at liquid nitrogen temperature in terms of critical current and index parameters. The paper describes the winding details of double pancake coils and test results at liquid nitrogen temperature.

Key words: HTS magnet, Racetrack coil, Conduction cooled

Thermal performance enhancement of liquid nitrogen distribution system of SST-1

Rajiv Sharma, Atul Garg,[1] Hiren Nimawat, Gaurav Purwar and V. L. Tanna

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The 80 K cryogenic system of SST-1Tokamak facilitates the liquid nitrogen system which consists of storage tanks and a distribution system, 80 K thermal shields, current feeders system, integrated flow distribution and control system, pre-cooling heat exchangers and purifier of helium plant. Huge frosting, condensation, LN_2 dripping and vacuum level of the order of 500 to 1000 mbar were observed on many sections of supply and return transfer line. The thermal cryogenic insulation as Polyurethane and Nitrile insulation has been installed. LN_2 process lines were evacuated to 10^{-3} mbar and replaced all 'O' ring sealings. The thermal performance of insulation material has been validated at 80 K, no frosting and condensation was observed on the applied insulated vent lines and evacuated supply transfer lines. In this paper, we present the detail and selection of cryogenic insulation, design calculation, applying techniques, performances tests and its results.

Key words: Cryogenic, Insulation, PUF, Nitrile

Design of nitrogen cryolines for ITER

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The ITER Cryogenic system is essentially one of the most complex systems in the world. It consists of cryoplant (source of cold power), cryodistribution system (for distribution of cold power) and cryolines (for channeling of cold power). These cryolines are of about 5 km in length having complex geometry (considering bends, angles, branch connections, etc.) and stringent criteria for design. The ITER cryolines are presently under preliminary or final design phases except the nitrogen cryolines which are under manufacturing phase after successful completion of final design. These nitrogen cryolines have length of around 600 m with pipe in pipe geometry and diameters of process pipes (PP) ranging from DN 15 to DN 250 with outer vacuum jacket ranging from DN50 to DN400. The sizing of these nitrogen cryolines has been optimized based on the specified pressure drop limit. In order to meet the specification of heat load as 2 W/m, the design of internal components such as internal sliding spacers, fix spacers has been performed and layers of multi-layer insulation (MLI) have been estimated accordingly. The paper describes the major input data, constraints for design of nitrogen cryolines, their design & analysis approach and result.

Key words: Design approach, Nitrogen Cryolines, ITER

Thermal conductivity studies of epoxy-aluminium composites (300 K – 4.5 K) for the development of cryosorption pumps

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Cryosorption pumps are the only solution to achieve ultra-high vacuum in nuclear fusion environment. An important aspect in their development is the proper adhesion of the activated carbon granules onto the metallic cryopanel and their cooling to the lowest possible temperature by using high thermal conductivity adhesives. Hence, the thermal conductivity data of the select adhesives and activated carbons down to 4.5 K are quite essential, but they are not available in open literature. This paper deals with the studies on thermal conductivity of epoxy-aluminium composites to enhance the pumping speed of cryosorption pump. The thermal conductivity data for pure epoxy and epoxy-aluminium composites from 300 K to 4.5 K have been presented in this paper. The above studies will enable to make the right choice of adhesives for the development of cryosorption pumps.

Key words: Thermal conductivity, Epoxy, Aluminium, Composite, Cryosorption pump

Numerical investigation on the pressure drop characteristics for steady and pulse flow along a compact regenerator

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The regenerator is the most important component in pulse tube refrigerator. Ideally, regenerator with zero pressure drop and unit effectiveness are desirable.The present study aims at evaluating the pressure drop characteristics of flow along a compact regnerator.When there is a flow through a channel, the pressure drop will naturally occur due to the frictional factor and the boundary layer effects. The pressure drop characteristics along a regenerator for steady and unsteady flows are compared. A regenerator having cylindrical channels of porosity 0.62 is considered. The working fluid used is helium gas. The regenerator material used is stainless steel. The analysis is done in ANSYS FLUENT 14 software by providing suitable boundary conditions, both steady and unsteady flows are simulated through the regenerator channels at constant Reynolds number and their pressure drop characteristics are compared. The effect of the change in the compressor frequency from 40 to 80 Hz and the Reynolds number ranging from 2820 to 5650 on the pressure drop along the regenerator is investigated.

Key words: Regenerator, Pressure drop, Pulse flow

Analysis of the effect of liquid volume fraction of liquid helium chamber with wall heat flux for K 500 SC

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An analysis was carried out with the partially filled helium cryostat of Superconducting Cyclotron (SC) and the processes of insulation vacuum failure to cryostat. In this work, the helium vessel was assumed to be filled up with different liquid level for different cases as initial condition. Specific interest is calculation of the pressure-time and void fraction-time history of the container under this condition. Maximum required mass expulsion rate from the cryostat was determined for cases typical for the operation with this helium cryostat.

Key words: Liquid helium chamber, Vapour space, Wall heat flux

Numerical investigations on direct contact condensation (DCC) of oxygen vapour in a staged combustion cycle based rocket engine

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Numerical simulations are performed for 60%, 100% and 105% thrust conditions at the inlet duct to the main LOX pump in SCE-200, a staged combustion cycle based semi-cryogenic rocket engine, indigenously being developed in India. A two-fluid Eulerian multiphase model has been implemented for investigating the direct contact condensation of oxygen vapor jets in subcooled flowing liquid oxygen. For predicting the condensation effects, thermal phase change model has been applied with two resistance model to capture the heat transfer effects on the liquid and vapor side. The governing equations along with the constitutive relations are solved using the unsteady coupled solver available in the commercial CFD package ANSYS CFX®. Plume shapes and heat transfer coefficients are plotted for different thrust conditions for a time period of 50 ms and the results are analyzed.

Key words: Semi-cryogenic, Direct contact condensation, Oxygen, Plume shapes, Heat transfer

Effect of bottom heating on thermal stratification and self-pressurization in a cryogenic tank

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The aerodynamic side wall heating is an inevitable phenomenon happening in a cryogenic propellant tank during a space mission. The side wall heating leads to thermal stratification and self-pressurization of propellant tank. The rise in propellant temperature may also leads to cavitation in pump which has to be avoided. So modeling of stratification in cryogenic tank is essential as the liquid propellant must meet the pump inlet condition. Self-pressurization in a cylindrical tank which is partially filled with liquid hydrogen is investigated numerically under constant side wall heating and varying bottom heating. The Volume of Fluid (VOF) method is employed as well as a phase change model. The model is validated with experimental data reported in the literature. Numerical results indicate that considerable amount of side wall heating goes into raising the temperature of the fluid inside the boundary layer which enhances the stratification. By providing controlled bottom heating, some agitation is introduced, which disturbs the formation of free convection boundary layer. Due to the absence of well-defined free convection boundary layer flow in the tank, most of the side wall heating goes into raising the temperature of the bulk liquid, resulting delayed stratification.

Key words: Thermal stratification, Self pressurization, Bottom heating

Two phase helium cooling characteristics in Cable-in-Conduit Conductors

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Cable-in-Conduit Conductors (CICCs) are validated base conductors for fusion grade superconducting magnets. In practice, the CICC acts as a narrow cryostat that provides adequate cryostability with the direct contact of coolant fluid to conductor from inside. The superconducting magnets are cooled using forced flow (FF) supercritical helium or two phase (TP) helium, which flows through the void spaces of the CICC. Thermo-hydraulics studies using supercritical helium in single phase flows are well-known and established. On the other hand, the TP cooling with helium is still an area of active research. There are perceived risks of the TP cooled CICC running into flow chocking and possible thermo-acoustic oscillations leading to flow instabilities; and hence traditionally are not favoured. This research work addresses the fact that TP cooling is an exciting cooling and operation regime with inherent parametric benefits. Our present study is an analytical study of forced flow two phase helium cooling in CICC wound superconducting magnets. The TP flow provides greater cryostability by the latent heat of helium compared to enthalpy, as in case with supercritical helium cooling of CICC. Analysis carried out predicts significant gains with TP cooling on a prototype CICC, which is circular in cross-section and appropriate for fusion devices for high magnetic field applications. These formalisms are general and extendable to any CICC wound magnets. This paper describes the analysis and advantages of the TP cooling over single phase cooling of a CICC.

Key words: Two-phase flow, Helium, Thermo-hydraulics and CICC

HTS based 400 mm level sensor for liquid nitrogen

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High Temperature Superconductor (HTS) tapes are commercially available with lowest width of 3 mm. An attempt to use these types of tapes for cryogen level sensor is discussed in this paper. The output voltage curves versus liquid level shows the linear behavior when a constant current of 1 ampere is used as an excitation in a four probe method. An attempt to develop the liquid level sensor of 400 mm of length for use in cryostat of LOX tank and the calibration of level sensor against the secondary standard (capacitance type level sensor) is presented here. The calibration was carried out using liquid Nitrogen. The superconductor type level sensor weighs less than 1 kg can be used in cryostage to reduce the payload of the flight. The continuous online data logging was done using the program developed in LabVIEW 11.0 software.

Key words: HTS, Calibration, Superconductor, Level sensor

Ethernet based instrument-device-servers & IoT to replace PLC, CAMAC, VME based Cryogenic CDAQ systems

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Ethernet is one of the most widely accepted communication interfaces today. The power of Ethernet is being realized by the automation Community in the recent past for control & data acquisition applications due to the advancement in technologies like the Internet of Things (IoT) where the Ethernet is the backbone. Traditionally, Automation engineers bought commercially off-the-shelf meters that came with processed analog outputs and then they used these voltage/current outputs to transport each signal to a series of central crate-based digital hardware like CAMAC or VME or PLC for control &data acquisition. A new crate-less model of large number of inter-connected distributed hardware device-servers, each of which has been programmed with embedded control functions, where analog back-end and digital front-end electronics are built together, is designed and developed to replace conventional control & data acquisition systems. The embedded i/o server implemented using ARM processor tcp/ip stack ensure global interconnections. Many of such devices, with very low-bandwidth requirement per node, are connected together to create a low collision network of WEB-compatible instruments compatible to the future IoT applications where signals need slow update- rate. However, the suggested model is also suitable to be used with fast sensors, where each sensor is interfaced directly via UART, SPI, CAN etc. and then only the final processed results are simply transmitted through RPC variables over slow HTTP connections to servers & clients. In this paper, we report successfully built web-compatible instruments using web-based tools which are made fault-tolerant to replace existed Crate–based systems at IUAC Cryogenics automation activities for accelerators. The design is based on ARM® mbed™ IoT Device Platform which provides the operating system, cloud services, tools and developer ecosystem.

Key words: Ethernet, COTS, HTTP, IoT, Cryogenics, LAN, Sensor, Actuator

Design and characterization of a low noise amplifier operating at cryogenic temperature

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This paper presents the design and test results of a low noise amplifier indigenously developed for VECC cryogenic Penning ion trap facility. The amplifier is built in two stages of which the first stage provides signal amplification whereas the second stage offers an output impedance of 50 Ω. The voltage gain as well as input voltage noise density of the amplifier is measured at room temperature and 130K. In this paper, we have demonstrated that cooling the amplifier down to 130K increases the voltage gain by a factor ~ 1.5 and decreases the input voltage noise density by a factor ~ 1.7.

Key words: Cryogenic amplifier, LNA

Capacitance level sensor with integrated cold electronics

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Capacitance type level sensors are extensively used for level measurement both for cryogenic and room temperature applications. The measurement of capacitance was carried out using various commercially available electronic circuits. All these circuits are designed to operate at room temperatures. A cold Electronics based level measurement circuit is designed which operates from 300 K down to 4.2 K. The frequency of the cold electronic oscillator is a function of the liquid level due to the change in capacitance value of the level sensor. The details of the calibration setup are discussed. Liquid Nitrogen was used as cryogen for the calibration. The details of developed cold electronics and its performances are discussed in this paper.

Key words: Capacitance level sensor, Calibration, Cold electronics, Planar inductor

Quench analysis of 1.5 T superconducting MRI magnet

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A national project on indigenous development of whole body 1.5 T superconducting magnetic resonance imaging (MRI) system has been initiated by Meity, Govt. of India. This MRI magnet will have multi-coil solenoidal structure to be operated at a current density of 140 A/mm². The total stored magnetic energy will be 4.5 MJ. This high stored energy of the magnet makes it crucial to design an efficient quench protection system for the magnet to prevent any damage due to either localized temperature rise or any voltage arcing during the quench. This paper presents the details of the quench characteristics of the MRI magnet simulated using OPERA. The transient thermal mapping of the magnet is also discussed in detail in the paper. A comparison has been made of the quench behavior of the magnet using different types of quench protection systems.

Key words: MRI magnet, Quench

Wear properties of Polytetrafluroethylene (PTFE) at cryogenic temperature

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Conventional lubricants like oil and grease cannot be used for cryogenic applications, since they tend to solidify at low temperatures. For these applications, solid lubricants like Polytetrafluroethylene (PTFE) and its carbon composites are extensively used. In this experimental study, the tribological properties of cryotreated and untreated PTFE and its composites are studied at room and cryogenic temperatures. A dedicated pin on disc type cryotribometer has been designed and developed to study the wear. Results of tribological experiments carried for fixed time duration of 10 minutes, constant speed of 400rpm and track diameter of 60mm under the applied load of 10N are studied and analysed.

Key words: Tribology, Wear, Coefficient of friction, Frictional force, Cryotreatment

Effect of cryogenic temperature on electrical parameters of copper coil used in SMES

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With the inclusion of renewable energy sources, the variability of the power supply has increased. To reduce this variability, energy storage equipments such as superconducting magnetic energy storage (SMES) are required. The energy is stored in SMES coil, making its design very crucial. This paper presents the effect of cryogenic temperature on the resistance and inductance of air core solenoid. The experiment is performed on the copper wire wound over teflon and copper formers. The published mathematical model for the calculation of the coil inductances is taken and results are compared with measurements performed with an LCR meter. The difference between the measured and calculated inductance value for both coils is found to be less than 10% at 300 K. The cryogenic temperature is maintained by first using a liquid nitrogen bath and later by cryocooler.

Key words: Cryogenic temperature, Resistance, Inductance, Copper coil, SMES system

Development of a lab-scale High-T_c superconducting power cable

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High Temperature Superconducting (HTS) cables for power transmission applications are gaining prominence all over the world as the efficiency of power transmission is higher as compared to that of conventional cables. In view of the benefits that can be obtained from usage of HTS cables in future power transmission systems, Applied Superconductivity Laboratory, IIT Kharagpur, in collaboration with Central Power Research Institute (CPRI), Bangalore and Bruker HTS Gmbh, Germany has developed a lab-scale superconducting cable carrying 800 A (DC) current at low voltages. The HTS cable containing 2G YBCO HTS tapes (of width around 4 mm and thickness of 0.1 mm) as current carrying conductors, wound helically around a copper former is tested for superconductivity in an open liquid nitrogen bath-type cryostat using a DC power supply (0-1000 Amps) and necessary measuring instruments (nano voltmeter, temperature monitor etc.) at Corporate R & D, BHEL, Hyderabad. In the present paper, the Voltage – Current characteristic of the HTS cable along with its development procedure is presented.

Key words: High Tc superconductor, Cryogenics, Liquid nitrogen, Power cable, YBCO

Analysis of mechanical stress due to winding pretension in a 1.5 T superconducting MRI magnet

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The paper presents the analysis of stresses due to winding tension in a 1.5 T MRI magnet with a clear bore of ~1 m and an outer diameter of ~1.8 m. The magnet has four pairs of symmetric coils arranged over a length of ~1.5 m. The stringent requirement of field homogeneity makes it critical to design a structurally stable magnet system. It is essential to evaluate the 3-dimensional stresses that would be generated in the magnet during winding, cool down and operation. The bobbin structure also has to be designed so as to reduce the relative movements of theeight superconducting coils, which otherwise can adversely affect the field homogeneity at the Field of View (FOV). The bobbin will be made of aluminium 5083 alloy, while the magnet winding will be a composite structure which consists of NbTi, copper and polyester insulation. The paper discusses the stress distribution over the aluminium bobbin and the coil caused due to winding tension applied during magnet winding. The article also discusses the element death and birth method in FEA to accurately simulate the winding process.

Key words: Magnet stress analysis, Winding stress, Pretension, Element Death and Birth

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