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

Published by
Indian Cryogenics Council

Proceeding (Part-A) of
Twenty Fourth National Symposium on Cryogenics
(NSC-24)

Hosted by
Institute for Plasma Research, Gandhinagar
January (22-24), 2013

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PREFACE

It gives us immense pleasure to release for publication the special issues of the Indian Journal of Cryogenics, Volume (39 and 40), for the peer reviewed manuscripts of contributory papers presented at the 24th National Symposium on Cryogenics (NSC-24) organized by Institute for Plasma Research, Bhat, Gandhinagar, held at Institute of Management, Nirma University, Ahmedabad, during January 22-24, 2013.

NSC-24 has brought together researchers from universities, institutes and industries, which stimulated the fruitful exchange of information and ideas in cryogenic engineering & superconductivity, outlined actual trends along with discussion on present and future developments.

The theme of NSC-24 as “Cryogenics for mankind” has been achieved by a number of theme talks, plenary talks by renowned experts from India as well as abroad. Several special talks have outlined the present status of various activities related to the Cryogenic and Superconductivity in India, globally along with a number of invited talks on specific topics. The key areas covered during the NSC-24 are large scale cryogenic refrigeration and liquefaction systems at 2K, 4 K and 80 K temperature levels for accelerator and fusion projects having applications in superconducting magnets, cryocoolers, space, medical with food & liquefied natural gas, low temperature physics as well as gas separation.

The symposium has been preceded by short courses on January 21, 2013 at Institute for Plasma Research, Gandhinagar. The courses were conducted by Dr. Christian Day, Dr. Maciej Chorowsky, & Prof. Parthasarathi Ghosh on Cryo Pumps, Cryo-biology and Cryogenic Process and heat exchangers, respectively and attended by about 40 participants.

The Symposium has attracted a very good response from the Cryogenics & Superconductivity community from Universities, Research Institutes and Industries. More than 180 contributed papers by more than 400 authors reflected the growing strength of the community. Eleven Industries showcased their products and the activities at NSC-24.

We would like to thank all of our professional well-wishers and colleagues who devoted their efforts for the successful event of the NSC-24. Our appreciation is also to the numerous reviewers for their excellent contributions. Finally, our special thanks to Dr. R. K. Bhandari, President, ICC and Prof. P. K. Kaw, Ex. Director, IPR for their unexplainable support towards organization of NSC-24.

Y.C. SAXENA
B. SARKAR
A.K. SAHU
R. BHATTACHRYA
(Guest Editors)

EDITORIAL

The 39th volume of "Indian Journal of Cryogenics" (2014) is again on time. It also happens to be the 39th year of the start of the publication of this journal by the founder of ICC in 1975. This is not merely a coincidence but also reflects our commitment to the continuity of publication of the journal. This volume consists of 38 peer reviewed papers, presented at 24th National symposium on cryogenics(NSC- 24) organized by the Institute for Plasma research during January 22- 24, 2013. Remaining 35 papers, presented in the same conference will be published shortly in Volume 40 (2015). We are thankful to our Guest Editors Prof. Y.C. Saxena and his colleagues for doing a wonderful job not only in organizing the conference but also completing the most toughest post conference job by coordinating the entire reviewing process. Without their sincere efforts in editing and reviewing more than 100 papers, the current volume would not have been on time.

we are making all possible efforts to improve the quality of the papers in the journal through our highly capable though honorary reviewer. The journal will continue to be published yearly. We are also pleased to announce that we have signed an agreement with Indianjournals.com for 'on-line publication' of our journal. The complimentary volume 37 is available for all ICC members and the public free of cost. Volume 38 onwards can be viewed by the subscriber and members of Indian Cryogenics Council by logging in.

We would like to thank once again our guest editors, Prof. Y.C. Saxena, Dr. B. Sarkar, Mr. A.K. Sahu and Mr. R. Bhattacharya for doing a stupendous work in getting about 73 papers ready for publication in Volume 39 and 40.

T.S. Datta
R.G. Sharma
(On Behalf of Editorial Board)

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CRYO COMPONENT DEVELOPMENT AND ANALYSIS

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CRYOCOOLER DEVELOPMENT AND STUDIES

MATERIAL AT LOW TEMPRATURE

Evaluation of a technique to mitigate effects of pulsed heat load of fusion devices on helium refrigerator

Rohan Dutta[1], Soumyarup Roy[2], Parthasarathi Ghosh[1] and Kanchan Chowdhury[1]

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Pulsed heat load in helium refrigerators used in fusion devices causes high fluctuation at return stream to cold-box. Therefore, inlet temperatures and volumetric flow rates to turbines and temperature profiles of heat exchangers varies unacceptably resulting tripping of the plant. Therefore, there is a need to reduce the fluctuation in return stream to an acceptable level. The simplest mitigation scheme is to bypass excess flow rate during high heat load. However, this technique leads to thermodynamic losses. The purpose of the paper is to present the losses associated with this technique and to demonstrate use of heating systems during low heat load together with this method for mitigation of fluctuating flow throughout the pulsed load. The competing parameters of thermodynamic losses vis-a-vis level of fluctuation of vital parameters have been presented in this paper to design and operate the plant at an optimum level.

Key words: *Fusion devices, Helium liquefier/refrigerator, Pulsed heat load, Heating systems*

Theoretical analysis and experimental validation of double wedge tuner performance at cryogenic temperature

Anupam Kumar Sinha[1], V.K.Mishra[1], Anindya Chakravarty[2], A.K.Sinha[1] and S.B. Jawale[1]

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A new type of tuner with double wedge mechanism for tuning of cryo-module cavity has been theoretically analyzed and tested at CDM, BARC. The tuner is a candidate for incorporation in International Linear collider (ILC) operations for tuning and micro-phonics stabilization of RF cavities by changing its length. Mathematical model of tuner performance has been developed for performance estimation at different temperatures. The system has been characterized for various temperatures and its performance has been tested at lower temperatures. In this paper, the performance characteristics of tuner and its dependence on various factors like tuner material, manufacturing and assembly parameters, external environment including external temperature and resistive forces has been discussed. It also describes the low temperature testing of the system.

Key words: Double Wedge Tuner (DWT), Superconducting Radio Frequency (RF) cavities

Fabrication and testing of 2K cryostat for vertical test facility at RRCAT

S.Raghavendra, S.K.Suhane, N.K.Sharma, S.K.Chauhan and S.C.Joshi

Raja Ramanna Centre for Advanced Technology, Indore, India

Raja Ramanna Centre for Advanced Technology (RRCAT) has developed a 2K Cryostat for characterization of Superconducting RF (SRF) cavities, under Indian Institution Fermilab Collaboration (IIFC). A vertical Test Stand (VTS) is a facility for qualifying bare SRF cavities for their required performance by measuring quality factor and cavity accelerating gradient at a cryogenic temperature of 2K. The VTS cryostat has been designed for a large testing aperture for testing variety of SRF cavities including 325 MHz Spoke resonators, 650 MHz and 1.3 GHz multi-cell SRF cavities. The engineering design and analysis of VTS cryostat has been carried out using ASME B&PV Code and Finite Element Analysis . Fabrication of Cryostat was carried out in strict accordance with ASME B&PV code under joint supervision of engineers from RRCAT and Fermilab. The paper describes the fabrication & acceptance testing aspects of the VTS cryostat at the vendor location and at RRCAT.

Key words: *Vertical Test, SRF cavities, Cryostat*

Recent trials with the experimental helium liquefier developed by BARC

Anindya Chakravarty, Rajendran S. Menon, Mukesh Goyal, Naseem Ahmed, Mohananand Jadhav, Tejas Rane, Sandeep R. Nair, Jitendra Kumar, Satish K. Bharti and Sandip K. Ghos

Cryo-Technology Division, Bhabha Atomic Research Centre, Mumbai, India

An experimental helium liquefier has been designed and fabricated by Cryo-Technology Division and installed at Bhabha Atomic Research Centre, Mumbai. The helium liquefaction process is based on a modified Collin's cycle consisting of one pre-cooler turboexpander, a pair of by-pass turboexpanders (warm and cold) and a series of 7 compact brazed plate fin high effectiveness heat exchangers. Liquid nitrogen pre-cooling facility along with another heat exchanger to recover cold of gaseous nitrogenhas also been provided in the system. After the full installation of the process compressor and its integration with the helium liquefier cold box, trial runs were started.A lowest temperature of about 7.8 K was registered in a temperature sensor located downstream of the JT valve.

Key words: *Helium liquefier, Collin's cycle, Turboexpanders, Brazed plate fin heat exchangers*

Development of a tube-in-tube heat exchanger for a cryocooler based helium recondensation system

Jacob S.[1], Narasimham G.S.V.L.[2], KarunanithiR.[1],Kranthi Kumar J.[1], Damu C.[1], Samir M.[1] and Praveen T.[1]

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This paper reports design, fabrication and testing of one of the recuperative heat exchangers for a small capacity helium recondensation system. A tube in tube heat exchanger, with multiple tubes in a coiled outer tube, has been designed to operate in the 300 K-100 K range. The key parameters of the heat exchanger are optimized by numerical analysis to obtain highest heat transfer coefficients and lowest pressure drops to meet the design goals. The pressure drop performance of the heat exchanger was tested and it is found that the annular pressure drop increases due to spacer string beyond the design toleration. Pressure drop was also measured after removing the spacer string and the results agree with the correlations available in literature. Spacer pressure drop should be considered in heat exchanger design.

Key words: *Tube in tube heat exchanger, Pressure drop*

Design study of 4.5 MJ sector-toroidal SMES coil

U Bhunia, J Akhter, J Pradhan, B Mondal, C Nandi, V K Khare, U S Panda, A De, S Bandopadhayya, A Roy, T Bhattacharyya, S K Thakur, M Das, G Pal and S Saha

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In continuation of SMES technology development in our centre, design study of a 4. 5 MJ (1.25 kW h) sector-toroidal SMES coil using custom make Rutherford type NbTi cable is reported. The sector- toroid is optimized with six modular type solenoid coils connected in series. The basic module is considered to be solenoid type because of its easier winding technique though it is not the best choice from stress considerations. The coil operating current as well as maximum magnetic field at the inner layer has been determined in order to limit voltage across the coil during discharging mode of its operation and also to minimize the overall dynamic and static load in the cryostat. Due to asymmetric field distribution around the coil, each coil experiences a huge centered force that needs to be arrested with proper support structures. Therefore, extensive magneto-structural stress analysis has been carried out using commercial finite element code ANSYS. The paper describes the magnetic design, three dimensional stress analyses in coil and its support structure during cool-down and energisation, design scheme of sector- toroidal SMES cryostat, etc.

Key words: *SMES, Toroidal coil, Stress, Cryostat*

Indigenous development of a table top batch liquefaction for nitrogen using pulse tube crycooler

Srinivasan Kasthurirengan[1], Upendra Behera[1], Vivek.G.A[1], Krishnamoorthy. V[2], Ranjana Gangradey[2] and Gautam Pal[3]

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Cryogenic recondensation devices present considerable challenges towards condensing helium in systems such as MRI, NMR and SQUID cryostats etc. Normally refilling of cryogens is costly and also troublesome. To replace the standard refilling system, there is a need of small scale recondensing system. In a typical recondensation system, the evaporating gas is initially pre-cooled by the cooling power of the first stage cold head. Subsequently, it is passed on to the second stage cold head, where a special heat exchanger is mounted with large surface area for cooling. The gas when passing over this cold surface gets condensed into a liquid and returns back to the cryostat dewar. This paper presents the design and development of a simple experimental setup for batch liquefaction of nitrogen and is based on the two stage pulse tube Cryocooler already developed in our laboratory. The details of the system and the preliminary experimental results are presented here. This setup serves as a pre-runner for our subsequent development of re-condensation system for helium gas.

Key words: *Recondensation, Liquefaction, Pulse tube cryocooler, Heat exchanger*

A mixed refrigerant cycle for providing refrigeration below 70 k for superconducting applications

Vineed Narayanan and G Venkatarathnam

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There is worldwide interest in the development of mixed refrigerant cycle refrigerators and liquefiers. Most studies till date have been at temperatures greater than 70 K. However, there is a need for refrigerators working below 70 K for use in superconducting transformers, motors, generators and cables.In this paper we present a new process for a mixed refrigerant cycle refrigerator for use in superconducting applications.

Key words: *Mixed Refrigerant Cascade Cycles, Cryocoolers*

Performance analysis of cryogenic cold circulating pump

H. Vaghela[1], J. Banerjee[2], H. B. Naik[2] and B. Sarkar[1]

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[2]Sardar Vallabhbhai National Institute of Technology, Surat, India

Cryogenic Cold Circulating Pump (CCP) provides cryogenic cooling of superconducting magnets (SC) and cryopumps in fusion research reactors by forced flow circulation of supercritical helium (SHe) at desired pressure head during various operating modes. The existing operating CCPs for helium have comparatively very less capacity, of the order 1.2 kg/s, than the future requirements of the order of 3 kg/s. Actual performance of CCP deviates from the theoretical ideal performance due to various fluid-dynamic losses involved during the operation. Design of CCP may be improved by prediction of losses through performance analysis. The present work involves performance analysis of the cryogenic CCP with outline of its major geometric dimensions obtained through basic design. Various loss models and its contribution to the head versus flow (H-Q) characteristics curve at different operating speed of CCP, obtained from the MATLAB® program, shows the best operating point with respect to system characteristics.

Key words: *Cold circulating pump, Performance analysis, Performance curve*

Design and engineering validation of venturi flow meter for current feeder system of SST 1

R. Panchal, N. C. Gupta, A. Garg, R.Patel, P. Shah, V. L. Tanna and S. Pradhan

Institute for Plasma Research (IPR), Bhat, Gandhinagar 382 428, India

Current feeder system (CFS) of steady state superconducting tokamak 1 (SST-1) consists of ten pair of vapour cooled current leads (VCCL). Helium vapour consumption of a VCCL is an important parameter to be measured accurately during operation of current leads. To measure flow precisely and accurately, we use venturi type flow element. A venturi flow element was designed for required flow rate with accuracy of approximately +/- 1% and the same was machined, finally it was calibrated and validated to define its discharge co efficient and found to be in agreement with the designed value. These venturi flow elements with Differential pressure transmitter (DPT) have been installed in helium gas return network of current feeder system of SST-1. This paper describes design, validation and installation and commissioning of venturi flow element with its DPT.

Key words: *Current feeder system, Vapour cooled current leads, Venturi element*

Effects of axial heat conduction, property variation and parasitic heat in-leakon performance of compact plate-fin heat exchangers

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Modern helium liquefaction / refrigeration systems employ compact plate-fin heat exchangers having very high effectiveness (>0.95). Performance of such systems is a strong function of effectiveness of heat exchangers used. The calculation of heat exchanger effectiveness in such cases needs considerations of several secondary parameters apart from basic fluid film resistance. In the present paper, the combined effects of secondary parameters like axial heat conduction through heat exchanger matrix and parasitic heat in-leak from the surroundings has been studied numerically. Large temperature changes in cryogenic heat exchangers may result in correspondingly larger changes in fluid properties and metal matrix conductivity, which shall be taken care of during numerical calculations. Numerical model developed in the present work is based on the one given in the literature. Numerical technique to solve the system of equations is implemented in MATLAB®. Real properties of helium at each node are evaluated using HEPAK®, which is linked to the developed code. Using this model, performance of heat exchangers is studied at four different temperature levels of (300-77)K, (77-20)K, (20-8)K and (10-5.1)K. The results highlight the effects of each of the above secondary parameters.

Key words: *Plate-fin heat exchanger, Axial heat conduction, Variable properties, Heat in-leak*

Design of a triaxial bayonet for connecting a helium liquefier cold box and receiver Dewar vessel

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Cryo-Technology Division, Bhabha Atomic Research Centre, Mumbai, India

A transferline with a triaxial bayonet for connecting a helium liquefier cold box and Dewar has been conceived. Liquid helium (LHe) settles in the Dewar vessel and the remaining cold gaseous helium (GHe) returns to the cold-box as a part of the liquefier cycle. The two coaxial lines are enclosed in an outermost vacuum line. These three coaxial lines come out of the liquefier through a triaxial bayonet joint which facilitates assembly/disassembly of the system due to the absence of welded joints. The present paper discusses schematic, design, and working of such a triaxial bayonet. It is conceived such that reduction in overall length, ease of fabrication, reduction of thermal stresses due to flexibility of bellows and reduction in fabrication cost are achieved.

Key words: *Triaxial bayonet, Transfer lines, Helium liquefier, Cryogenic coupling*

Experimental studies on cu-ss diffusion bonded Perforated plate heat exchangers

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[2] Asst. Prof, Cryogenic Engineering Centre, IIT, Kharagpur -721302, India

In this paper experimental studies on Cu-SS diffusion bonded perforated plate heat exchangers (PPHEs) are reported. A test set up has been developed for testing the heat exchangers at cryogenic temperatures. The paper presents the details of the test setup, instrumentation and the test results. Due attention is given to the accuracy of the experiment. Data on frictional pressure drop have been obtained under isothermal conditions. These data are useful for observing the behavior of the heat exchangers. Besides, these will also be useful for validation of numerical models of PPHEs.

Key words: *Perforated plate heat exchanger, Thermal performance, Frictional pressure drop*

Design and analysis of concentric helical heat exchanger for dilution fridge

Naser Md. Zamal Abdul, Das Nisith Kumar, Pradhan Jedidiah, Roy Anindya, Mondal Bidhan, Mallik Chaturanan and Bhandari Rakesh Kumar

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The lowest temperature which can be reached in a continuously operating dilution fridge is determined by the performance of heat exchanger. Operation of dilution system requires a continuous tubular heat exchanger (Hex) for heat exchange primarily between the concentrated ^{3}He and dilute ^{3}He solution. The helical Hex is made of two thin walled cupro-nickel capillary tubing with stainless steel ends. The inner tube is spirally wound and inserted inside the outer tube. Based on the proposed flow rate of 15 µmoles/s, lengths and diameters have been optimized as to minimize the viscous and axial conduction heating. Flow impedances of the concentrated and diluted phase flow channels are maintained 10^{-7} cm^{-3}and 10^{-6} cm^{-3} respectively. Analytical results show that a base temperature of around 100mK can be achieved with this Hex. Effectiveness of condenser for condensation of helium isotopic gas mixture and temperature dependent quality factor has also been determined. This paper presents the detailed analytical results based on enthalpy and energy balance consideration relevant to the Hex.

Performance of mixed refrigerant cascade refrigerator for cooling a space simulation chamber

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A mixed refrigerant cascade (MRC) refrigeration system has been developed to replace a conventional two-stage cascade refrigeration system for the cooling of space simulation chambers. A fast cool down of the refrigerator to 193K within a time of 16 min is achieved. The details of the system developed and its performance characteristics such as cool down, heat load and exergy efficiency with different mixtures will be presented in this paper.

Key words : *MRC refrigerators, Refrigerant mixtures, Low temperature cooling*

Cryogenic rocket engine thrust chamber test facility

Narayanan. A

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A unique facility viz Thrust Chamber Test facility has been established at Liquid Propulsion Systems Centre, Mahendragiri for performing static firing test for development of cryogenic rocket engine's thrust chamber in pressure-fed mode. This facility has capability to feed cryogenic propellants viz liquid Oxygen and liquid Hydrogen at pressure as high as 20 MPa at the required temperature and flow rate. Due to complex requirements, several technical challenges were encountered such as regulated chill-down for controlling thermal stress of heavy-walled vessels, pipe bends for thermal compensation with floating suspension, chill-down of transfer piping system at variable flow rates to compromise between thermal stress and bowing effect and pilot plug design for isolation and control valves. The facility has been realized and successfully commissioned in three phases viz first phase with inert fluids at atmospheric temperature, second phase with inert cryogenic fluids and final phase with actual cryogenic fluids.

Key words: *High-pressure, Cryogenics, Thrust chamber, Test facility, Propellants*

Recent operational experience of cryogenic system for sst-1

V.L. Tanna, P. Panchal, R. Panchal, D. Sonara, R. Patel, G. Mahesuriya, N.C. Gupta, LN Srikanth G, J.C. Patel, K. Patel, A. Garg, D. Christian, N. Bairagi, P. Shah, H. Nimavat, R. Sharma and S. Pradhan

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Prior to the SST-1 device integration, all the TF as well as some of the PF superconducting coils were tested in a dedicated cryostat in respective rated parameters. Many of new auxiliary cryo sub-systems were made functional as per the design parameters prior to SST-1 cool-down activities. Recently the cool-down attempts of SST-1 machine has been carried out for the engineering commissioning. SST-1 cryogenics system comprises of cryogenic helium and liquid nitrogen systems. IPR has an operational 1.3 kW at 4.5 K custom designed cryogenic helium refrigerator-liquefier (HRL). In order to minimize the static heat loads from ambient (300 K), double embossed type thermal shields system has been provided. The major new auxiliary cryo-systems include the current feeders system (CFS) and 80 K thermal shields system. These auxiliary cryo-systems have demonstrated their rated performance during the recent cool-down of SST-1. This paper will elaborate the recent experience of SST-1 cool-down results.

Liquid nitrogen distribution for pelletronlinacfacility, Mumbai

K.V. Srinivasan,[1] V. A. Arolkar,[1] R.D. Deshpande,[2] A.G. Hedukar,[1] K.A. Jaison[1] and A.A. Shinde[2]

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Low temperature facility of Tata Institute of Fundamental Research Mumbai provides liquid helium and liquid nitrogen along with the various other cryogenic support services to many facilities and laboratories of the institute. On the total annual liquid nitrogen consumptionover 3,00,000 liters, majority supply is utilized by the Pelletron LINAC Facility, for cooling the thermal shields of the quarter wave resonating cavities, distribution line of the cryostats, precooling of helium refrigerator and for the beam hall experiments. Liquid nitrogen is produced by STIRLIN-8 plant with a liquefaction rate of 110 liter per hour at an elevated pressure of 2barg. The vacuum jacketed and super-insulated liquid nitrogen transfer line of about 310 meters long interconnects plant and SC LINAC accelerator. The paper present the in depth details about the cryogen distribution, VJ piping and also the technical modifications and various automation carried out by us on the liquid nitrogen plant.

Key words: *VJ-piping, Spool, LINAC, Nitrogen, Accelerator*

Up-graded Control System of Liquid Nitrogen Management System of SST-1

Pradip Panchal[1], Dileep Shukla[2], Rakesh Patel[1], Vipul Tanna[1] and Subrata Pradhan[1]

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Liquid Nitrogen (LN_2) is used for 80 K thermal shield of Steady-state Super-conducting Tokamak (SST-1), Integrated Fluid Distribution and Control System, Current Feeder System and 80 K refrigerant in Helium Liquefier / Refrigerator. A dedicated storage and distribution system for $LN_2$was installed at IPR. The present system includes 3-nos of storage tanks, sub-cooler dewar, vacuum jacketed cryo-lines and instrumentation. This system employs PLC based supervisory control system with smart process instrumentation. Considering non-upgradability and lack of reliability due to obsolesce of components of automation system and future plan of 80 K single phase distribution system for thermal shield of SST-1, new control system is required. Various control schemes are employed for sub-cooler dewar, evaporators and storage tanks. The up-graded control system will offer ease of operation with improved automation, better maintainability and reliability. This paper describes design and development of up-graded control system of LN_2 system.

Key words: Liquid nitrogen, PID, PLC, SCADA

Experimental studies for semi-cryo engine development

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Development of Cryogenic engine is essential requirement in order to improve the pay load capability of rocket launching systems. Cryogenic stage is more suitable for the upper stage of the launch vehicle mainly due to the high specific impulse and relatively low structural weight. As the pay load increases a high thrust booster engine is also required for the launch vehicle. Semi cryogenic propulsion is ideally suitable for booster engine, in terms of higher density impulse and low cost and easy handling. LPSC has undertaken the development of Semi Cryo Engine to power the booster stages of India's future launch vehicles. The Engine works on Oxidizer rich staged combustion cycle, using LOX and Isrosene propellant combination. Preburner (PB) and Thrust Chamber (TC) are the major subsystems of the engine. PB produces the hot gases at lower temperature for driving the turbo pump which raises the propellant pressure and TC produces hot gas in the chamber at high temperature which expands through the nozzle for generating thrust. Design of injector and arrangement of injector are critical in the design of pre burner and Thrust chamber so as to admit and meter the propellants into the chamber with proper mixture to ensure complete and stable combustion. The propellants require ignition source for initiating ignition. A mixture of Tri-ethyl Aluminium and Tri-ethyl Boron (TEA/TEB) is used as a source of ignition which is hypergolic with oxygen. In order to understand the behavior of the different systems and technology involved, it is planned to design and realize injector and evaluate the characteristics of its performance during cold flow as well as hot test. The development programme is planned in two phases. Initially Single element pre burner and thrust chamber hardware are realized, cold flow test are carried out and hot test are being done. It is also planned to realize subscale thrust chamber and pre burner as a phase-2 activity to study the behavior of multi element interaction and its performance. A lot of critical technologies are to be developed and demonstrated prior to the development of full scale engine. The characterization of injector elements, performance validation at near operating conditions, Ignition characteristics of hypergolic liquid, validation of material, evaluation of different coating are set for the objectives of the initial phase of tests. This paper discuss the different experimental studies carried out, experimental results and features of hardware, design aspects, cold flow characteristics, hot test result for the initial phase of development and also future plan of action.

Key words: *Semi cryogenic engine, Preburner, injector, Thrust chamber, Staged combustion cycle.*

Experience of superconducting current feeders system of SST-1

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The superconducting current feeder system for SST-1 which has been installed and commissioned recently along with SST-1, felicitates to energize the SST-1. The CFS consists of ten pairs of 10,000 Ampere (A) rating helium vapor cooled conventional current leads, interconnecting Cu-SC joints, three numbers of cryo-compatible SC feeders ducts, current leads assembly chamber, hydraulic network and three numbers of joint boxes operated at different current rating to charge Toroidal Field and Poloidal Field coils separately. During the last three campaigns, it was possible to achieve a controlled cool down up to 4 K and showed its rated operational performance. Actively cooled liquid nitrogen shield showed temperature profile in the temperature range of 80-85K and the whole system was evacuated up to $6x10^{-6}$ mbar. The measured LHe consumption rates from TF VCCL were 0.3 g/s and 0.35 g/s at zero current and 1kA respectively.

Key words: *Current leads, SC magnets, SC joints*

Realization and thermal performance analysis of liquid nitrogen based 80 K Cryo-Target system for space simulation of meteorological payloads

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Liquid nitrogen based Cryo-target system need to be used in thermo-vacuum chamber to simulate on-orbit environments of meteorological payloads. For a number of reasons it is essentially important to quantify the thermal performance of CT system prior to the actual tests of meteorological payloads. In this paper we present thermal performance of an efficient closed loop liquid nitrogen circulated blistered type embossed CT system inside thermo-vacuum chamber. We discuss important experiments, tests and their results that were carried out for the performance optimization of CT system. The optimized CT systems with space qualified conductive black painted aluminum honeycomb mounted on it were successfully used for Met payloads of INSAT 3D during TVP tests. The heat load handling capacity of closed loop flat plate CT system in thermo-vacuum chamber is analytically investigated. It is concluded that a closed loop CT system is better for low temperature and high external heat load requirements.

Key words: *Cryo-target, INSAT 3D, Thermo-vacuum Chamber, Thermal vacuum Performance test*

Development of excel based static simulator for various test phases of iter prototype cryoline

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The prototype of multi process pipe ITER cryoline will be tested at ITER-India laboratory to measure heat load at 5 K and 80 K level, thermal shield temperature profile, stresses at critical locations and temperature of outer vacuum jacket during Loss of Insulation Vacuum scenario.

The cold test of PTCL will be performed using helium gas to measure the heat load. Considering the complex thermo-hydraulics involved, Microsoft Excel, Hepak© and NIST material data has been integratedtodevelop the static simulator which performs detailed thermo-hydraulic calculations for various input data to estimate pressure and temperature profile of fluid along the process pipes of PTCL as well as to estimate the cooldown / warm-up duration and total inventory of helium during the test.

The present paper describes the test set up, major phases of PTCL test, background calculations performed, various in-built options in the simulator and results for specific cases.

Key words: *Cryoline, ITER, Simulator*

Speech alarm and cycle helium gas monitoring of helium refrigerator

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*Two helium liquefiers are running round-the-clock in parallel. One of them is always connected to the Superconducting Cyclotron in refrigeration mode. EPICS based alarm system **is** running with alert sound in computer speaker. But the fault **can**not be located without opening the fault screen. An audible English speech alarm system was envisaged and implemented in EPICS platform. Voice message are now being played in relation to faults or alarms. In continuously operating refrigeration system pure helium gas inventory is an important parameter to log. We need to calculate total pure equivalent helium cycle inventory. Now, we have put these calculations together in EPICS controller. This continuously calculates displays and archives the pure equivalent cycle helium gas. If any leak develops in the process, this trend gives a quick indication.*

Key words: *Helium Liquefier, Supervision control system*

Upgradation of liquid nitrogen distribution lines of large thermal vacuum chamber at SAC, Ahmedabad

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A 5.5m Dia. Thermal vacuum chamber was commissioned in 2002 to cater to the test requirements of electro – optical payloads developed at SAC, Ahmedabad. About 550 meter LN_2 transfer lines were installed for supply and distribution of LN_2 to various system elements. Out of this about 320 meter lines run in the clean room which were Superinsulated one and rest 230 meter located within the plant room and LN_2 yard area were PUF insulated one. Over a period, PUF insulation efficiency got deteriorated and vapor barriers no longer effective. This paper describes the upgrade task accomplished to improve overall loss rate of LN_2 lines and overall LN_2 consumption. It also describes the technical efforts and experiences gained during up-gradation of PUF insulated lines with S.I. lines ensuring minimum system down time and quality tests performed at segment level and assembly level for these lines.

Key words: *S.I. lines, PUF insulation, Thermal shroud, LN_2*

Control system design of test auxiliary cold box for qualification testing of ITER cold circulating pumps

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Cold circulating pumps (CCP) in ITER-Cryodistribution system has been evaluated as the most technology critical component. Test Auxiliary Cold Box (TACB) is a valve box to perform the pre-series test of CCPs of ITER. The operating conditions of the CCPs installed in TACB during the test demands for detailed design of instrumentation and control system including physical and functional interfaces with subsystems of the test facility. Control system of TACB consists of a programmable logic controller (PLC) at the system level and two dedicated controllers for CCPs at component level, integrated together using various control and handshaking signals. Local Controllers at component level are capable of standalone local operation of respective CCPs. This paper describes the control system design using system level PLC, local controllers, associated network system, interface definition controller programming and data acquisition considering all the operating scenarios of the TACB during the pre-series test.

Key words: *Cold circulator, Instrumentation & control, System level PLC, CCP controller*

Supervisory control and data acquisition system development for superconducting current feeder system of SST-1

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The Current Feeders System (CFS) is essentially an optimized bridge between the power supply at room temperature and Super Conducting Magnet System (SCMS) of the SST-1 machine at 4.5 K.CFS is a complex electrical and cryogenic network which consists of ten pairs of 10 KA rating helium Vapor cooled Conventional Current Leads (VCCLs), superconducting (SC) current feeder and associated components. For the safe and reliable operation of CFS, it is equipped with different physical process parameters measuring instruments like flow, pressure, temperature, level, vacuum, voltage taps and final control element like control valves, heaters, vacuum pumps etc. PLC program is developed in ladder language for acquiring and controlling the process parameters. Independent SCADA applications developed in WonderwareIntouch software for data communication from PLC, front-end Graphical User Interface (GUI), auto-manual interface, real time trends, history trends, events and alarm pages. Time synchronized communication established between CFS control system and Industrial SQL server (InSQL) Historian for centralized storage of CFS process parameters which intern provides the CFS process data to SST-1 central control room. SCADA based data acquisition and data retrieval system is found to be satisfactory during the recent SST-1 cool down experiment. This paper describes the SCADA and PLC application development and their communication to InSQL server.

Key words: *CFS, SCADA, PLC, GUI, InSQL*

Experimental investigation of pressure drop in pulse tube cryocooler

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Highly efficient Pulse Tube Cryocooler (PTC) is subject of recent research and development activities. High efficiency can be obtained by increasing the available refrigeration effect at desired temperature. Various geometrical and operating parameters affect the performance of PTC. Pressure drop is one of the significant parameters. A major pressure drop occurs in regenerator compared to other components of PTC. Experimental investigation is carried out on two different single stage U-type Pulse tube cryocoolers. Regenerator and pulse tube volumes are kept same in both the cases. SS meshes with mesh number 400 are used. Length to Diameter (L/D) ratio of regenerator is changed from 1.93 to 9. A noticeable pressure drop of 2.07 bar is measured for higher L/D ratio as compared to 0.29 bar in the lower one. The effect of pressure drop is studied on no load temperature as well as refrigeration effect. The study is further extended to understand the effect of pressure drop using coarse meshes in the regenerator. The pressure drop for oscillating flow prevailing in the pulse tube cryocooler is measured using the high frequency miniature pressure transducers.

Key words: *Pulse Tube cryocooler, Pressure drop, Regenerator mesh*

Comparison of c-type flexures with different bending radius

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The flexure bearing is one of the key components of linear motor. Due to its frictionless, wearless, high radial and low axial stiffness; it is a very critical part of any linear actuator. The flexure bearing has increased the reliability and life of operation of linear actuators used in cryocoolers. This paper discusses the failure aspects of C-Type flexure with 3 mm bending radius in comparison with flexure bearing of different bending radii. Experimental results of 3 mm and 8 mm bending radii flexures are also discussed.

Key words: *Flexures, FEM, Bending radius, Axial stiffness, Radial stiffness*

Optimization of regenerator of a stirling cryocooler

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The applications like IR detector cooling in satellites, imaging cameras in battle tanks and HTS devices require cryogenic cooling in the range of 60-80 K with cooling power varying from mW to a few Watts. A miniature StirlingCryocooler can be used for these applications. The regenerator is an important design component of Stirling cooler because the performance of the cooler largely depends on the effectiveness of the regeneratorused in the system. A parametric study has been carried out using REGEN 3.3 to optimize a regenerator operating with a warm end temperature of 300 K and cold end temperature of 80 K.The investigation was carried out for a frequency range of 40-70 Hz with mean pressure of 12 bar and pressure ratio of 2. The results obtained are useful for the complete design of Stirling Cryocooler.

Key words: *Stirling Cooler, Regenerator, COP*

Prediction of temperature distribution in heat exchanger for mixed refrigerant Joule–Thomson cryocooler

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The overall performance of a mixed refrigerant Joule-Thomson (MR J–T) cryocooler depends on the efficiency of the heat exchanger used to cool the refrigerant prior to J-T expansion.The multi-component refrigerant mixture gets condensed and evaporated simultaneously at different pressures in the recuperative heat exchanger which is responsible to increase its performance. However, at present, the design of such heat exchanger is difficult due to lack of experimental heat transfer data.

In the present paper, the temperature profile of the hot fluid condensing inside the inner tube of the tube-in-tube helical coil heat exchanger is predicted. The temperatures of both, the condensing and the evaporating stream are measured along the length of the heat exchanger. The energy balance equation is used to predict the temperatures of the hot fluid at the corresponding locations of the cold fluid temperature measurement. The calculated temperature profiles are compared against the experimentally obtained data for different mixtures. It is found that the predicted temperature profile matches well within ± 6 % limit for all the mixtures.

Key words: *J-T cryocooler, Temperature profile, Helical heat exchanger, Refrigerant mixture.*

Development of inline high frequency miniature pulse tube crycryocooler for 80 K applications

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In today's world, miniaturization is the buzz word. It is not only the production of low temperatures that is important, but also the size of the equipment. It is imperative that a Pulse Tube Cryocooler must be operated close to its resonance frequency to deliver an optimum performance. Increasing the resonance frequency of a system not only decreases the cool down time but also the overall size of the system. However, the viscous dissipation losses become more and more predominant at higher frequencies. The present paper reports the development of High Frequency Pulse Tube Cryocooler operating at 148 Hz. The total pulse tube – regenerator volume of this system is as low as 1.72cc. A low temperature of 90 K is obtained in less than 5 minutes while the no load temperature of the system is 86 K. The experimental investigations aimed to study the performance dependence on the operating and dimensional parameter changes. The operating parameters include variation in charging pressure, frequency. The dimensional changes include variations in the lengths of inertance tube, pulse tube and regenerator.

Key words: *Pulse tube cryocooler, High frequency, Miniaturization, Cool down time, Resonance frequency.*

Synthesis and physical properties of pure and f-doped REFeAsO (Re=Pr, Nd & Sm)

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We report a comparative study of crystal structure, electrical, and magnetic properties of the pure and F-doped superconducting REFeAsO (Re = Pr, Nd, and Sm) samples. The presence of superconductivity in these iso-structural compounds provided an opportunity to understand the doping mechanism in oxy-pnictide superconductor. Bulk polycrystalline samples are synthesized by solid state reaction route in an evacuated sealed quartz tube. The Rietveld analysis of room temperature X-ray diffraction (XRD) data show that all the studied samples crystallize in single phase in a tetragonal structure with space group P4/nmm. The lattice parameters of the studied samples follow the well-known rare earth contraction. The decrease in c-parameter and the volume is indicative of successful substitution of F^{-1}(R_F = 1.33 Å) at O^{2-} (R_O = 1.40 Å) site. The ground state REFeAsO compounds shows a metallic step in resistivity measurements below say 150-130 K. This metallic step is attributed to structural and SDW transition. The superconductivity in the F-doped sample is confirmed by resistivity measurements as well as magnetic measurements. Superconducting transition temperature (T_c) is found to be at 51K, 48K and 38 K respectively for RE = Sm, Nd and Pr. The superconducting transition temperature of the F-doped samples increase with deceasing the ionic radii of the rare earth. The temperature dependent upper critical field $H_{c2}(0)$ is calculated from detailed up to 14 Tesla R(T)H measurements using the extrapolation method employing Ginzburg-Landau (GL) theory. Thus calculated $H_{c2}(0)$ is found to be above 200 Tesla, which is second best to the High T_c cuprates.

Key words: *FeAs, Iron superconductor*

Significant magneto-resistance in $Pr_{2/3}Sr_{1/3}MnO_3$ near room temperature

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Polycrystalline $Pr_{2/3}Sr_{1/3}MnO_3$ sample has been synthesized by solid state reaction method with final sintering temperature 1400^0C. Thus synthesized sample is crystallized in single phase orthorhombic Pbnm space group confirmed from the XRD pattern. The insulator-metal transition temperature (T^{IM}) is observed at ~297K. Magneto-resistance (MR) of the sample is as high as 36% at 300K in applied field of 3T. Temperature coefficient of resistance (TCR) is found to be maximum 7% at ~280K. Thus the synthesized $Pr_{2/3}Sr_{1/3}MnO_3$ sample having good MR (36% 3T) can serve as a potential magnetic sensor near room temperature.

Key words: *Manganite, Magneto-resistance, Temperature coefficient of resistance*

Numerical simulation for prediction of thermal history in cryoprobe assisted biological tissue freezing

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Cryosurgery is fast gaining popularity as a minimally invasive surgery for treatment of various types of cancers. It involves destruction of cancer cells within a limited spatial domain by exposing them to very low temperatures while minimizing injury to the surrounding healthy tissues. The volumetric extent of the critical isotherm in the ice ball decides the efficacy of the cryosurgical process. The thermal history within the ice ball during the freezing process remains an unknown and possesses a major challenge in any cryosurgical process. Numerical simulations prove to be very useful in this regard.

This paper presents an Enthalpy based numerical solution for phase change heat transfer in biological tissue cryo-freezing process using the Bio-heat transfer equation. The tissues are treated as non-ideal materials which freeze over a finite temperature range. The effects of blood perfusion and metabolic heat generation in the unfrozen tissues are also taken into account in the heat transfer model. This paper also discusses in brief the cell destruction mechanisms. Analytical solution for one dimensional water freezing was used for benchmarking the numerical model. Primary findings of these numerical investigations would prove to be useful in deciding the cryosurgical protocol and in the design and development of cryoprobes for future medical applications.

Key words: *Cryosurgery, Bio-heat model, Phase change heat transfer, Enthalpy method, Cryoprobes*

Mechanical performance degradation of glass fiber insulation material after neutron irradiation

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Epoxy based glass fiber reinforced plastic composites G-10 CR grade are suitable material for electrical insulation breaks of the superconducting fusion device. At IPR, under the national fusion program, characterization of G-10 CR material with the neutron irradiation dose is studied. This study will help us towards the indigenous development project of electrical insulation breaks for future superconducting fusion magnets under the radiation environment. The insulation material has been irradiated by 14 MeV neutrons D-T generator in the Fusion Neutronics Laboratory, I.P.R. The mechanical and electrical performance was investigated after irradiation (with a fluence of 8.63×10^{14} n/m^2) at room and cryogenic temperature condition. The results show that the mechanical degradations (by ~ 9 to 30%) after neutron irradiation in tensile strength and impact strength at 300 K and 77 K. In this paper, we present the experimental details of the neutron irradiation and the data have been compared using MCNP code for flux calculation on glass fiber insulation composite along with Stycast 2850 GT epoxy. Investigation of mechanical, electrical, SEM analysis for internal surface morphology, glass transition temperature measurement of insulation material and its test results at 300 K and 77 K before and after neutron irradiation will be presented.

Key words: *Irradiation, Neutron flux, Neutron influence, GFRP*

Low temperature TEP measurement setup for thin plates and films

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A setup to measure thermoelectric power (TEP) of thin plates and films is designed, developed and tested to work in 77K–300K range. Sample is pressure mounted flat on two Cu blocks having independent resistive heaters of appropriate power and platinum resistance thermometers (PRTs), which results in several advantages. For instance, the arrangement allows for very large range of PID controlled stable temperature gradients 0.5 to 100 K between the blocks, and the distance between the blocks can be adjusted according to the sample size. The measurements can be performed in both vacuum and inert gas atmosphere. The dimensions of the sample-holder-unit have been optimized to fit commercial Liquid Nitrogen/Helium dewars with neck sizes >56 mm. The setup also allows resistivity $\rho(T)$ measurements and with suitable temperature sensors can be easily adapted to lower temperatures down to 4.2K. To check the performance, variety of measurements were carried out on different samples of Al, Cu, Mo, MgB2, $YBa_2Cu_3O_7$ superconductor and Bi_2Te_3 in thin plate and film forms.

Key words: *TEP Setup, Thin film*

Prediction of thermo-physical properties of argon at cryogenic conditions using modified Benedict-Webb-Rubin equation of state

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The present work aims to determine thermo-physical properties such as mass density, specific heat capacity, viscosity, enthalpy and thermal conductivity of argon at cryogenic temperatures and high pressures up to 20 MPa. The deviations from the ideal gas law led to development of many empirical models based on equation of state (EOS) such as van der Waals EOS, Benedict-Webb-Rubin (BWR) EOS, Peng-Robinson EOS, Soave-Redlich-Kwong, etc. to predict the properties of pure substances. The present paper describes the development of a simple computer program in MATLAB for prediction of the properties using Modified Benedict-Webb-Rubin (MBWR) equation of state.

The details of the thermodynamic calculations and the algorithm of the program are given so as to easily extend the program for any other cryogens. The calculated properties are compared with those obtained from standard software such as ASPEN, REFPROP and with the experimental values from the literature. The average deviation for all the calculated properties is less than ±2 %.

Key words : *Properties, Cryogen, MBWR equation of state, Argon.*

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