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Guest editors for this volume

Subhash Jacob, R Karunanithi, D S Nadig

Centre for Cryogenic Technology, Indian Institute of Science
Bangalore- 560012

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EDITORIAL

It gives us great pleasure to bring out these special issues of the Indian Journal of Cryogenics, Vol. 34 and Vol. 35, which is compiled with manuscripts of invited talks and peer reviewed contributory papers presented at the 22nd National Symposium on Cryogenics (NSC-22) held at Indian Institute of Science, Bangalore during 4-6 December 2008. This symposium was jointly organized by the Indian Cryogenics Council (South Zone) and Centre for Cryogenic Technology, Indian Institute of Science and was held in the centenary year of helium liquefaction by Kammerlingh Onnes, coincidentally the centenary year of founding of Indian Institute of Science by the great visionary J.N. Tata. We were fortunate to have a galaxy of eminent cryogenic stalwarts from abroad and India to deliver invited talks at the symposium and many of them did agree to give manuscripts for publication in the Indian Journal of Cryogenics. The manuscript of Helium Liquefaction Centenary talk by Prof. A.T.A.M de Waele, published in this issue of Indian journal of Cryogenics is a rare collection of the fascinating history of helium liquefaction by Kammerlingh Onnes.

The NSC-22 witnessed unprecedented number of contributed papers reflecting the significant growth of cryogenic science and technology in the country. Key areas of space cryogenics, cryogenic heat transfer, cryocoolers, large scale cryogenic systems, materials technology, superconductivity and applications, gas liquefaction and storage systems, low temperature physics and cryo- instrumentation were adequately covered at the symposium.

Publication of the papers has been through a rigorous process of peer reviewing of the papers. For us it was a Herculean task to identify a large number of experts from the small cryogenic community in India for peer review of the 99 contributory papers. The referees rejected few papers and good number of papers was asked for revision.

The process of uploading, reviewing papers and incorporating corrections for this issue was done electronically, largely through the web portal of NSC-22, probably for the first time in the history of Indian Journal of Cryogenics. We are happy that for the first time a user-friendly electronic template giving exact format for publication in the Indian Journal of Cryogenics was evolved for this special issue. Naturally, complexity of all these developments coupled with large number papers to be dealt with has caused some delay in the publication. However we are glad that the processes we have generated for this issue will be aiding faster submission and publication of refereed manuscripts in the future. We are still awaiting corrected manuscripts from 25 authors, which will be published in regular Volume 36 of Indian Journal of Cryogenics, in the near future.

We are extremely thankful to the referees who spent substantial time in correcting the manuscripts in the most professional way. There are many who have worked behind the scenes to make this volume come through and we do not have adequate words to thank them. The Editorial Board of the Indian Journal of Cryogenics deserves special appreciation for their work to print out this volume. We bring out this volume with the hope that it sets new standards in publication for Indian Journal of Cryogenics.

Centre for Cryogenic Technology
Indian Institute of Science, Bangalore

Subhash Jacob, R. Karunanithi and D.S. Nadig
(Guest Editors)

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Development of the cryogenic systems for the superconducting cyclotron and operational experiences at CECC

R.K. Bhandari[1] (for the VECC team)

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A large superconducting cyclotron for research in the field of nuclear and allied sciences is under construction at this Centre. The iron core superconducting magnet, weighing about 100 tonnne, is now operational for the past over 3 years. The cryostat holds about 300 liters of liquid helium to maintain the superconducting coils at 4.5 K temperature to operate in the cryostable mode. The total mass to be cooled to liquid helium temperature is approximately 7.5 tonnes. The helium liquefier/refrigerator plant has a cooling capacity about 250 W at 4.5 K. An elaborate network of cryogenic transfer lines to cool the coils and cryopanels is also in operation. The magnet was kept energized for over one year to carry out magnetic field measurement in the year 2006. After a gap of about one and a half years to install the radiofrequency system, the coils were again cooled in March this year and since then they continued to operate at LHe temperature. A project to develop superconducting magnetic energy storage system (SMES) has also been started at the Centre. Designs of the cryogenic components of this device are being developed.

Key words: superconducting cyclotron, cryostat, cryopanel, helium liquefier, SMES

Cryogenic challenges in operating superconducting RF cavities in CW mode

Shrikant Pattalwar

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Superconducting RF (SRF) cavities have made impressive progress during the last few decades in terms of achieving higher Q values and higher accelerating gradients. As a result the SRF technology has been selected as a preferred technology for modern day particle accelerators like XFEL and ILC. Accelerators requiring high average currents or high intensity beams require these cavities to operate in continuous wave CW mode. Several issues arising due to extremely high/concentrated heat loads, lower operating temperatures, micro-phonic generations etc. must be resolved before these cavities are put into use on real systems. In this talk I will discuss some of the key issues which make the design of cryogenic systems extremely complex. STFC Daresbury laboratory UK (DL) has undertaken several projects, through international collaborations, to address some of these issues. I will highlight the Cryogenic aspects of some of these projects.

Key words: Superconducting RF, Accelerators, Cryogenics, CW mode.

Recent developments in cryocooler technology at IIT Bombay

Milind D. Atrey

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Cryocoolers have undergone various changes in the recent times, both from a technological as well as a size point of view. Over the last two decades, extensive work has been carried out in our laboratory on the design and the development of big and small Stirling coolers. The present talk gives the salient features of the work carried out during the recent years which mainly focus on Stirling type Pulse Tube Cryocoolers as well as Mixed Refrigerants Joule Thomson Cryocoolers. In addition, research in the area of dry compressors for such cryocoolers has been major focus of the work. Work is being carried out both on theoretical and developmental front on Moving Magnet and Coil type linear compressors, Sorption compressors and very recently on Thermoacoustic compressors.

Key words: Pulse Tube Refrigerator, Linear Compressor, J-T Cryocooler, Thermoacoustic Refrigerator

Development of tilting pad thrust bearings for cryogenic turboexpanders

Anindya Chakravarty, Rajendran Menon, and Trilok Singh

Cryo-Technology Division, Bhabha Atomic Research Centre, Mumbai – 400 085

A combination of damped tilting pad top thrust bearing and a bottom rigid spiral grooved thrust bearing with process gas as lubricant have been found to be a very good configuration for vertically oriented cryogenic turboexpander rotors. While the rigid spiral grooved thrust bearings have already been standardized in our laboratory, the present work describes the development of the new damped Tilting Pad Thrust Bearings. The work reported here describes the process of computation of steady state pad load capacity. Details of a prototype thrust bearing system are also provided. This bearing system was developed and successfully used to support a cryogenic turboexpander rotor up to a maximum speed of around 2,50,000 r/min. Hence, these bearings can be used to support cryogenic turboexpanders in Helium liquefier/refrigerator plants.

Key words: Tilting Pad Thrust Bearing, Gas Lubricated Bearings, Cryogenic Turboexpander, Helium liquefier/ refrigerator plant

Thermodynamic properties of helium: A comparative study on different equations of state

Rijo Jacob Thomas, Sanjay Basak, Parthasarathi Ghosh and Kanchan Chowdhury

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Large-scale helium liquefiers find applications in important disciplines of science and technology like accelerators, fusion devices, etc. Design of these plants for different load requirements with various objective functions is complex and hence necessitates using a simulator for its solution. One of the major factors that determine the accuracy of the results of process simulation is the availability of accurate thermo-physical property data of the process fluid i.e. helium in the case of helium liquefiers. In this work, the property data generated using the equations of state proposed by Peng-Robinson and Mann along with the ideal gas equation are compared with that of the 32-term modified BWR equation of state by McCarty and Arp. The properties like density, enthalpy and entropy that are repeatedly used during simulation calculations are compared. The outcome of this work would help to identify the suitability of employing an equation of state for helium in a given region in the thermodynamic plane in terms of accuracy, ease of computation and access speed.

Key words: Equation of state for helium, Thermo-physical property package

Experimental set up for the development of a room temperature bore cryogen free superconducting magnet system

S. Kar, A.Choudhury, P. Konduru, R. Kumar, R.G.Sharma, & T.S.Datta

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We have developed an experimental test rig to simulate the operation of 6 Tesla cryogen free magnet. A two- stage GM cryocooler of refrigeration capacity of 35 W @ 50 K and 1.5 W @ 4.2 K has been used in the test rig. For simulating the cool down of the magnet to 4.2 K, we have used a dummy copper mass weighing about 14.5 Kg (equal to the mass of the magnet). Performance of the hybrid current leads (copper and HTS) has been studied in detail. The lowest temperature achieved is 27.4 K at the 1st stage and 2.75 K at the 2nd stage. The cold mass takes 7.5 hours to cool down to 2.75 K. The pair of hybrid current leads gives approximately 13.8 W dynamic load to the 1st stage and 135 mW to the 2nd stage at a current level of 70A. This paper will briefly describe some of the major experimental observations and the analysis.

Key words: GM Cryocooler, HTS current leads, Thermal contact conductance

Coil design and development for 0.6 MJ SMES

U. Bhunia, J. Pradhan, S. Bandyopadhyay, A. De, T. Bhattacharyya, U. S. Panda, A. Roy, A. DuttaGupta, S. K. Thakur, M. Das, S. Saha, and R.K. Bhandari

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A SMES (Superconducting Magnetic Energy Storage), featuring a high speed and efficient large energy output has the ability to mitigate short time voltage fluctuation and sag, which causes downtime of a machine or critical load. Variable Energy Cyclotron Centre has taken up the project of design and development of SMES system in the XIth five-year plan period. Initially a smaller unit (~0.6 MJ) is being aimed at with the existing facility available at the centre followed by two more units of 5 MJ and 30 MJ respectively.
The detail design of 0.6 MJ SMES system is finalized. The solenoid type cryostable magnet is under fabrication and the magnet coil is to be bath-cooled inside the Superconducting Magnet Dewar (SMD-20). The various parameters of the magnet coil have been optimized to maximize the stored energy, taking into consideration the various constraints like geometry, maximum current limit, etc. The power conditioning system is responsible for charging the SMES and also for transforming the dc stored energy from the coil to the required three phase AC energy. The paper will describe the design aspect of the coil and its protection system, the proposed scheme for the power conditioning system, etc.

Key words: SMES, Quench, PCS

Performance analysis and experimental results of cryogenic reciprocating expansion engine with helium gas

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PO RRCAT Indore - 452013

Reciprocating expansion engines are used as work extraction device in low and medium capacity Claude cycle based helium refrigerators and liquefiers. Claude cycle based cryogenic refrigerator with reciprocating expansion engines has been developed indigenously at RRCAT. Expansion engine is a key component that affects the performance of this type of refrigerators. Therefore, it's important to improve its efficiency and performance. Work has been carried out to understand the behaviour of an actual engine. Analytical study, considering real gas properties, has been made about the role of various engine parameters which influence the efficiency and performance of expansion engine. Experiments have been conducted to investigate various problems affecting the performance and compare some analytical results. Various losses impairing the efficiency of the expansion engine were estimated from experimental data

Key words: Expansion engine, Efficiency, Cooling power, Cutoff angle, Dead volume

Design of vortex tube module for high purity LOX separation

Upendra Behera[1], S. Jacob[1], P. J. Paul[2], S. Kasthurirengan[1], R. Karunanithi[1], K. Dinesh[1]

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Vortex tubes are finding increased use for separation and purification of gas mixtures and separation of liquid oxygen (LOX) from two-phase air stream. Based on our studies on LOX separation by vortex tubes, a vortex tube module has been designed which can produce approx. 1 kg/s of LOX with ~98% purity and can be very useful for on-board collection of LOX for futuristic launch vehicles. The module has been divided into two stages. The enriched air stream from the first stage of vortex tubes is fed to the inlet of the second stage of vortex tubes. The first stage is designed to achieve high separation efficiency with moderate LOX purity while the second stage is designed to improve the LOX purity to ~98% with separation efficiency of 73.5%. The overall separation efficiency of the system is estimated to be 63.5%.

Key words: Vortex tube, LOX purity, Separation efficiency

Study on the performance of coiled heat exchanger for cryogenic application

R.Satya Meher, S.Srinivasa Murthy and G.Venkatarathnam

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Joule-Thomson (J-T) refrigerators are used in a number of applications such as cooling of infrared detectors, in missiles, cryosurgery etc. Nitrogen at a pressure of 200 to 400 bar is expanded to ambient pressure to produce the required cooling. The working pressure can be reduced to less than 20 bar if nitrogen is replaced with a mixture of nitrogen-methane-ethane and propane. Such systems are called as mixed refrigerant cascade (MRC) refrigerators. The performance of these systems is dependent on (a) the choice of refrigerant mixture (composition) and (b) the effectiveness of heat exchangers used. A number of heat exchangers with effectiveness of 97-99 % have been built and tested in our laboratory. Mathematical models have been developed for the design of high effectiveness heat exchangers for J-T refrigerators. The results obtained, and comparison between experimental results and analytical models for the prediction of performance of high effectiveness heat exchangers are presented in this paper.

Keywords: Cryogenics, Heat exchanger, Simulation

Performance analysis of a moving coil, opposed piston linear compressor

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Limitations of disciplined compressors led to the development of linear, electromagnetically driven compressors which utilize either moving coil or moving magnet type linear motor drive. Linear compressors are more reliable than the conventional compressors because of fewer moving parts, flexure bearings and lubrication free operation. The power drawn by the compressor is least when the impressed frequency of current is equal to the natural frequency of the system. The natural frequency depends on the gas impedance, stiffness of flexure bearings and total moving mass in the system. The gas impedance is determined by the gas charge pressure and connected volume to the compressor. The present work aims to predict the natural frequency of the system for various charge pressures and connected volumes. The predictions are compared with the experimental results carried out on the moving coil compressor developed in our laboratory.

Key words: Moving coil, gas stiffness, natural frequency, cryocooler volume, resonance.

Evaluation of key parameters involved in the design of a superconducting cable in conduit conductor (CICC)

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Since last few decades the design of CICC based prototype coils for high energy magnets (Fusion grade magnets and SMES) are being reviewed with special attention. The conductor designs are affected by some special requirements such as large stored energy, high magnetic field and heat removal rate. The other issues which limit the designers are mechanical stresses, operating voltages, ac losses and stability criteria [3]. On the other hand, the evolution of the available technologies for cryogenics and superconducting materials opens new frontiers for performance, reliability and cost of CICC [3, 4]. The present work is an attempt to design a Cable in Conduit Conductor (CICC) for the large scale superconducting magnets from analytical and computational points of view for currents as high as 80kA.

Key words: CICC, Fusion grade magnets, Stability.

Development of cryogen delivery system for VECC K500 superconducting cyclotron cryopanels

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VEC Centre, Kolkata is at an advanced stage of commissioning a K500 superconducting cyclotron. The cyclotron requires high vacuum in the accelerating chamber in order to reduce loss of charged particles during acceleration. The chamber is pumped using liquid helium cooled cryopanels placed inside the Dees of the radio-frequency system. The chevron baffles and radiation shield of the cryopanel are cooled using liquid nitrogen. The copper cold head for liquid helium and liquid nitrogen are interconnected and connected to the vacuum pipe using stainless steel thermal short. The dissimilar material joint, which had to be leak tight at 4.5K posed a difficult problem during fabrication of the lines. A theoretical model was developed to estimate the temperatures of the cryopanel. The paper discusses the construction experience of the cryogen delivery system for cryopanels, the commissioning results and the results of the theoretical analysis for estimating the temperature of cryopanel and radiation shield.

Keywords: cryogen distribution, cryopanel, superconducting cyclotron

Integrated stress analysis for section of ITER torus & cryostat cryoline

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Integrated stress analysis for a long trains of cryoline is a state of the art techinique, being an important aspect to introduce flexibility due to thermal contraction. Flexibility analysis of the torus and cryostat (T&C) cryoline, which supplies cryogens to the cryopumps of the ITER machine, has been carried out to support the design of the T&C cryoline. The integrated stress analysis includes all the six process pipes and outer vacuum jacket. Loading conditions have been considered for design and failure scenarios. A section of the T&C cryoline has been modelled in CAESAR II software to find out the values of stresses, deformation, moments and loads on anchor points. The results have been compared with the design code of the T&C cryoline, ASME B31.3. The paper presents the approach for integrated stress analysis of the cryoline and discuss the results of the analysis.

Key words: T&C Cryoline, CAESAR II, ASME B31.3, Restraints

Design of HYRA superconducting quadrupole magnet cryostat

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A superconducting quadrupole doublet for HYbrid Recoil Mass Analyser (HYRA) beam line is under development at IUAC . The estimated cold mass at 4.2K is 1.5 Ton and is mainly contributed by iron core and pole. Considering the space restriction on the existing cryo-line and operational problems on refilling of LHe, it is planned to have a cryostat fitted with a two stage cryo cooler. Cryo cooler 2nd stage will reliquefy liquid helium evaporated from the helium vessel and the first stage will provide the cooling necessary to maintain the intermediate shield to ~50K. HTS current leads will be used to reduce the head load. Design optimisation of the cryostat is done based on the available refrigeration capacity of the cryo cooler, heat load input map of the cryostat and design of helium vessel. This paper will discuss important features of the cryostat.

Key words: HTS, Superconductor magnet, Cryostat, UHV Vacuum vessel

The effect of stabilisation of sensing element on the performance of pressure transducer in space applications

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Pressure transducers with mechanical sensing elements are in use for space application for over 50 years. In these transducers, the transducing element is a metallic diaphragm with bonded foil strain gauge. When the measurand pressure is applied to the diaphragm, the strain experienced by it is sensed by the strain gauge. This is converted into a measurable electrical output through a Wheatstone bridge network. The material used for the sensing element is a high modulus material with low compliance, typically, Precipitation Hardened Martensitic steel. The reasons for instability in the sensing elements and their impact on reliability as a sensor must be understood in relation with the material behaviour. This paper details the various errors in measurement related to material properties and their variations. It further tracks the various stabilization processes in common practice, their evolution, merits and demerits. Special attention is drawn to the novel Cryo treatment process that improves long term dimensional stability.

Key words: Martensite, Retained Austenite, Cryo tretement, Tempering, Sensing element.

Comparative study of two concepts for 80 K helium generation system

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The prototype cryoline of International Thermonuclear Experimental Reactor (ITER) will be tested in an operating condition of 4 bar Supercritical Helium (SHe) at 4.5 K for the process and 18 bar Gaseous Helium (GHe) at 80 K for the thermal shield. The thermal shields of prototype cryoline, supply valve box (SVB) and return valve box (RVB) will require 110 g/s GHe at 80 K. Two concepts have been studied to generate 80 K GHe with the required operating condition. The first concept is based on warm compressor with primary and secondary heat exchangers where secondary heat exchanger will be cooled with liquid nitrogen. The second concept is based on a cold circulator and heat exchanger, all in cold condition. In the first concept, the component requirement at cold condition is less but electrical power requirement is comparatively high. However, in the second concept, apart from an advantage on electrical power, the thermodynamic efficiency is higher than the first concept. The 80 K system is a closed loop system with steady state heat load estimated as 300 Watt at 80 K. This paper presents the design and comparative study of the two concepts as a function of value engineering, efficiency and reliability.

Key words: 80 K system, warm compressor, cold circulator

Thermal performance of 20 K helium cryotarget simulator for space environment simulation of imager radiant cooler thermal balance testing

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Thermal Balance Test on IMAGER Cooler Assembly was conducted in space simulation chamber simulating space condition of vacuum and space sink by achieving vacuum better than 10-6 mbar and shroud of 100K. To simulate deep cold space and to achieve low temperature on cooler cold stage, a cryotarget simulator of 1400 mm diameter is utilized achieving a temperature of 20K. It consists of cryotarget plate, GM cycle helium cryo-refrigerator and temperature indicator. The cryo-refrigerator system consists of six compressors, six cold heads and interconnecting hoses. The solar heat input and incident IR heat input to cooler is simulated by supplying the precalculated power through onboard heaters mounted on cooler assembly. Thermal Balance Tests were conducted for equinox condition and sensitivity analysis. The thermal performance of 20K cryotarget simulator was evaluated for different test cases. The performance of 20K cryotarget simulator was found satisfactory and met all the specifications and requirement of IMAGER radiant cooler thermal balance testing.

Key words: Cryotarget, Radiant Cooler, Cryogenic Cooling, Thermal Balance Test

Large-scale helium liquefier/refrigerator for fusion devices: A global review and Indian perspective planning

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Cryogenic system is considered as one of the key subsystems of fusion devices. As a part of the Indian program on fusion research, a project has been initiated under the national fusion program for developing the concept of process for a 10 kW refrigerator at 4.2 K. The process developed will be simulated for all the operating conditions of a fusion device. The major features to be studied will be the behavior of the process under transient load condition apart from the steady state operation as well as the cool down process. A review study has been made on the existing cryogenic plants operating in different fusion devices around the world, namely, TORE SUPRA, LHD, EAST, KSTAR, etc. The paper discusses the plan of adaptation of such dynamic heat load in the process of a 10 kW helium liquefier/refrigerator, for which indigenous effort has been implemented.

Key Words: Large scale helium liquefier/ refrigerator, Fusion devices, Pulsed heat load

Experimental investigations on 80 K stirling type coaxial pulse tube refrigerator

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Pulse Tube Refrigerator (PTR) is a special class of regenerative cryocooler where there is no moving part at the cold end. Due to this, it has inherent advantages of higher reliability, reduced vibrations and light weight. Based on the arrangement of regenerator and pulse tube in a PTR, there are various configurations possible like inline, U-shaped, coaxial and annular. Coaxial and annular have the most compact geometry out of all the other configurations, but they suffer from losses due to pressure drop during flow reversal and heat transfer between gas in pulse tube and regenerator having different temperature profiles.

The present work aims towards development of a single stage, split, Stirling type coaxial PTR for a minimum temperature of 80 K with a maximum available electrical input of 100 W from a linear compressor. Isothermal model has been used for preliminary design. Till date, a minimum temperature of 96 K has been successfully achieved from the developed PTR configuration. Experimental investigations are carried out for different design parameters viz. Inertance tube lengths, cold end cap geometry and L/D ratio of regenerator at different operating parameters like frequency of operation and charging pressure.

Key words: Pulse Tube, Coaxial, Linear Compressor, Regenerator, Refrigeration Effect.

CFD Modeling of double inlet pulse tube refrigerator

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CFD analysis of Double Inlet Pulse Tube Refrigerator (DIPTR) was carried out using the commercially available package FLUENT. The integrated model consists of a valveless compressor, transfer line, compressor cooler, regenerator, cold heat exchanger pulse tube, hot heat exchanger, orifice vale , buffer and a bypass tube. The modeling is done with the assumption of axisymmetry to reduce calculation time. This can be achieved by taking the bypass tube axially with the regenerator and releasing at the hot heat exchanger. Two configurations of DIPTR with an inertance tube connecting to buffer and an orifice connecting to the buffer are tested. The given configuration is capable of producing 100K under no load condition. The results show that DIPTR with inertance tube configuration is slightly better than the same geometry with orifice configuration.

Key words: Pulse Tube, Regenerator, Porous Media, Oscillating flow.

Performance investigations on single stage stirling type pulse tube refrigerator with inline configuration

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Pulse Tube Refrigerator (PTR) has become highly popular due to its inherent advantages like absence of moving parts at the cold end, reduced vibrations and high reliability. Different configurations possible in PTR are inline, U–type, co-axial and annular. Also, different phase shifting mechanisms like orifice valve, double inlet valve, Inertance tube, etc. are in practice. The present work aims to study the performance of a single – stage Stirling type pulse tube refrigerator with inline configuration, developed in Cryogenic laboratory at IIT Bombay. The focus of experimentation is on the investigation with regards to the no load temperature and refrigeration load at higher temperatures. Orientation of the cold tip plays a vital role from cryocooler performance point of view. This phenomenon is experimentally verified in the present work. The effect of change in configuration from integral to split is also studied. The experimental investigations are carried out with different charging pressures. The operating frequency and the compressor input power are maintained constant for comparison purpose.

Key words: Pulse Tube, Regenerator, Orientation, Integral, Split

Development of stirling miniature cryocooler

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Stirling cryocooler is valve less machine. It consists of reciprocating compressor, displacer, regenerator and Dewar assembly. A compact and light weight design is necessary for applications like IR sensor cooling which requires less than watt refrigeration. Stirling cryocooler has large dead volumes reducing the compression ratio. It is shown through cyclic simulations and backed up by experiments that this problem with compression ratio becomes further critical while miniaturizing the cryocooler. This is because leakages through clearance seals are no more negligible for smaller active volumes in miniature coolers. It is shown that performance of miniature cryocooler can be drastically degraded due to large piston cylinder clearance making it an important component of miniature cryocooler technology. Other components of miniature cryocooler are also discussed along with results of experiments and trials with prototype cryocooller developed at BARC.

Key words: Miniature Stirling cryocooler, Compression ratio, Clearance seal.

Performance of an auto refrigerant cascade refrigerator with a phase separator and operating with nitrogen-hydrocarbon and argon-hydrocarbon mixtures

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Experiments have been carried out on an auto refrigerant cascade (ARC) refrigerator with a phase separator with different N_2-HC and Ar-HC mixtures. The performance could be improved substantially by modifying the hardware to reduce flow maldistribution in the heat exchangers. A maximum external exergy efficiency of 7.2% was obtained at 113.3 K with the new hardware configuration.

Keywords: Phase Separator, Mixed Refrigerant Cascade, Hydrocarbon Mixtures

Phasor analysis of pulse tube refrigerator using cfd analysis and isothermal model

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Phasor Analysis proposed by R. Radebaugh [1] is a simple analysis to visualize the physical phenomena taking place inside the pulse tube. The phasor analysis introduces the concept of the phase difference between pressure in the pulse tube and mass flow rate at the cold end of the pulse tube. Similarly, Isothermal model presented by Zhu et al.[2] predicts the refrigerating effect in addition to various parameters like pressure ratio, phase difference etc. The present work highlights pressure and mass flow rate variations at different locations in the pulse tube refrigerator using Computational Fluid Dynamics analysis (CFD). Phasor diagrams are drawn using the CFD analysis and the isothermal model. Comparison of phase angle obtained by these analyses is carried out. Also, refrigerating effect predictions are compared with experimental results.

Key words: CFD Analysis, Phasor Analysis, Isothermal model

Design guidelines for a thermoacoustic refrigerator

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Development of refrigerators based on Thermoacoustic technology is a novel solution to the present day need of cooling without causing environmental hazards. With added advantages of absence of moving parts and circulating refrigerants, these devices can attain very low temperatures maintaining a compact size. The present theoretical work is based on theory of linear thermoacoustics[1]. Under the short stack and invicid assumptions, an algorithm for design of a standing wave thermoacoustic refrigerator, with main focus on the stack, is described. A stack is designed for a given cooling requirement of the refrigerator and certain chosen operation parameters.

Key Words: design, thermoacoustic, refrigeration

Development of mixed refrigerant cascade refrigerator operating with non-flammable and flammable refrigerant mixtures

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Mixed Refrigerant Cascade (MRC) refrigerators are under development worldwide, including our laboratory. A number of studies are carried out with flammable refrigerant mixtures such as Nitrogen-hydrocarbon, Argon-hydrocarbon mixtures etc. There is, however, very little information in open literature on the performance of MRC refrigerators operating with non-flammable refrigerants. This paper presents the performance of a MRC refrigerator operating with non-flammable refrigerant mixtures and flammable refrigerant mixtures. Performance of the system is compared with two different compressors.

Key words: MRC Refrigerator, Hydrocarbon Mixtures, Non-Flammable Mixtures.

Theoretical analysis of pulse tube cryocooler using gas mixture as working fluid

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The performance of the pulse tube Cryocooler depends on the type of working fluid used in the Cryocooler. The thermodynamic and thermophysical properties of the working fluid govern the performance of the Cryocooler. Generally Helium or Hydrogen is used as single component working fluid in such cryocoolers. The use of two component working fluid, ($He+N_2$), in which one condenses at the required refrigeration temperature, can improve the Cryocooler performance. In the present work, a theoretical model is developed to investigate the effect of gas mixture ($He+N_2$), as working fluid, on the performance of the pulse tube Cryocooler. The study is carried out to understand the effect of change in mixture concentration on the Cryocooler performance. The results are compared with those obtained using single gas (He) as a working fluid.

Key words: Pulse Tube Cryocooler, Gas Mixture, Isothermal Model, Helium, Nitrogen

Effect of regenerator material compositions on the performances of a two-stage pulse tube cryocooler

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A two-stage Pulse Tube Cryocooler (PTC) has been designed and fabricated which produces a no-load temperature of ~2.5 K in its second stage cold head and ~60 K in its first stage cold head respectively at the operating frequency of 1.6 Hz. A cooling power of ~250mW is available in the second stage. A water-cooled 6kW helium compressor and an indigenous rotary valve serve to generate the pressure oscillations. Stainless steel meshes (of size 200) and lead (Pb) granules (average grain size ~ 250 μm) towards the cold end in the volume percentage ratio 70:30 are used as first stage regenerator materials. The second stage uses regenerator materials such as Pb, Er_3Ni and $HoCu_2$ (average grain size ~250 μm) arranged in layered structures. The studies show that the second stage cold end temperature and its cooling power are dependent both on the dimensions of Pulse Tubes and regenerators as well as on the regenerator composition. Hence detailed experimental studies are conducted by varying the regenerator material compositions and their volume percentage ratios to understand their effect on the performance of the PTC. These experimental results provide useful technical information towards the design of Pulse Tube Cryocoolers.

Key words: Pulse Tube Cryocooler, Regenerator, Refrigeration power, helium

Miniature hybrid regenerator for cryocoolers

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A study has been conducted to find out the optimum configuration of regenerators to be used for miniature cryocoolers. Mesh sizes starting with 150 up to 300 with an interval of 50 have been sampled and performance estimation has been made. The study has been extended to determine the performance of a hybrid regenerator and its suitability to use in a cryocooler which can produce 80 K. Since the moving mass in the free displacer plays a major role as regards the dynamics is concerned, a compromise between mass and the geometrical parameters are necessary. A methodology has been developed to arrive at the appropriate mesh size and number of mesh to be used in the hybrid regenerator to go hand in hand with the available moving mass. Results are presented which could be helpful in the design of miniature regenerators. The mathematical model presented is solved by finite difference techniques for different mesh size of the regenerator with appropriate length and diameter. The analysis is further extended to study the performance behavior of the regenerators under different operating conditions.

Key words: cryocooler, regenerator, matrix, hybrid

Design of a cryogenic amplifier using GaAs MESFET

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In this paper, we present a design procedure for a cryogenic amplifier which uses commercial Gallium Arsenide based Metal Semiconductor Field Effect Transistor (MESFET). The amplifier consists of two stages namely a common source amplifier followed by a source follower which is impedance matched to a 50 ohms load, that allows operation over a wide bandwidth of 5 MHz with a gain of $2*10^6$ V/A.

Key words: Cryogenic amplifier, Gain, Bandwidth

Temperature sensor bonding and thermalization for measurement of temperature during proto-type cryoline test of ITER

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Reliable, accurate and precise temperature measurement is always a challenging task. Temperature measurements are required to get the performance validation of the proto-type cryoline test of ITER. This experiment imposes limitation on the bonding and thermalization procedure, which is otherwise factory recommended because of its non-standard surface geometry with varying curvatures. This need calls for an optimized characterization of the factory recommended process. Thermal modeling of the sensor mounting with lead-wire anchoring is performed. Lead-wire with different material, cross-sections and lengths are considered. Model is then analyzed and optimized for the 4.5 K and 77.3 K temperature ranges, which are of interest in this test. Further validation to the thermal modeling has been done by experiments for the optimization at 77.3 K temperature range. This paper describes the experimental set-up, results for bonding validation, evaluation of the thermalization of lead-wire of temperature sensors.

Breakthrough studies of activated carbon and oxysieve for helium purification at 77K

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Selection of a suitable adsorbent for a specific application constitutes the first step towards development of an adsorption based separation system. In this context, we have done the breakthrough measurement at 77K using the facility assembled in our laboratory. It was observed that for activated carbon, breakthrough time for nitrogen was 20 minutes, 23 minutes and 27 minutes at pressures of 1.0 bar, 1.5 bar, and 2.0 bar respectively. No oxygen emerged at the outlet during this measurement period. However, for oxysieve the breakthrough time for nitrogen was 19 minutes, 20 minutes and 27 minutes while breakthrough time for oxygen was 16 minutes, 20 minutes and 27 minutes at pressures of 1.0 bar, 1.5 bar and 2.0 bar respectively. The study reveals that the breakthrough characteristics of both activated carbon and oxysieve are reasonably favorable for helium purification under the given operating conditions.

Key words: Helium purification, adsorption, breakthrough, dynamic activity.

Palladium doped tin oxide based hydrogen gas sensors for safety applications

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Hydrogen is considered to be a hazardous gas since it forms a flammable mixture between 4 to 75% by volume in air. Hence, the safety aspects of handling hydrogen are quite important. For this, ideally, highly selective, fast response, small size, hydrogen sensors are needed. Although sensors based on different technologies may be used, thin- film sensors based on palladium (Pd) are preferred due to their compactness and fast response. They detect hydrogen by monitoring the changes to the electrical, mechanical or optical properties of the films. We report the development of Pd-doped (<5%) tin-oxide based gas sensors prepared on thin ceramic substrates with screen printed platinum (Pt) contacts and integrated nicrome wire heaters. The sensors are tested for their performances using hydrogen – nitrogen gas mixtures to a maximum of 4 % H2 in N2. The sensors detect hydrogen and their response times are less than a few seconds. Also, the sensor performance is not altered by the presence of helium in the test gas mixtures. By the above desired performance characteristics, field trials of these sensors have been undertaken. The paper presents the details of the sensor fabrication, performance evaluation and the test results along with the developed electronic circuits.

Key words: Hydrogen sensors, Tin Oxide, Palladium, Platinum, Ceramic substrates

Temperature measurement using fiber bragg grating sensors for superconducting magnets

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Knowledge of temperature distribution (TD) in a superconductor (SC) coil helps for an optimized SC magnet design. Finding a suitable sensor for measuring TD is a critical issue. Fiber Bragg grating (FBG) sensors with specific coating can be one of the solutions to this problem [1]. This sensor have many significant advantages like being passive to electric fields, multiplexing capabilities, independent of fluctuating light levels and magnetic field In the present work, thermal sensitivity of the polymer coated and specially designed dual metal coated FBG (DMCFBG) sensors is studied. The temperature changes the grating periods which can be read out with the tunable laser in a wavelength division multiplexing (WDM) scheme. The spectral position of the reflections may be correlated with the spatial position of the gratings. The shift of the gratings maximum reflection indicates the changes of the grating period. This in turn measures the temperature.The study is carried out for the temperature interval of 300 K-4.2 K.

Keywords: Fiber Bragg Gratings, Low temperature measurements, Superconducting magnets

Analysis of heat transfer modes through multilayer insulation (MLI) in the ranges 300 – 77 K and 77 – 4.2 K

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This paper presents analysis of heat transfer modes through MLI based on the experimental heat flux values and temperature profiles. The heat flux and the temperature profiles through different types MLI were measured in the ranges 300 – 77 K and 77 – 4.2 K using a double guarded boil-off calorimeter. The analysis shows that the heat transfer by conduction is 3.5 – 5 times higher than that of radiation for the 300 – 77 K range. In the 77 – 4.2 K range, radiative heat flux is negligible compared to conduction.

Key words: Multilayer insulation, Heat transfer modes

Design of LOX/LH_2 cooled hydrostatic journal bearings for cryogenic rocket engine turbopumps

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Cryogenically cooled hydrostatic journal bearings (HJBs) offer several advantages over conventional ball and roller bearing systems of a cryogenic rocket engine turbopump. These include increased rotational speed, reduced pump impeller and turbine wheel size, and improved efficiency of the pumps and turbine. Several attempts have been made world wide for developing this type of bearing system. For applications in India's future cryogenic turbopumps, a computer program has been developed for performance prediction of cryogenic hydrostatic bearings. The program has been validated with literature reported experimental data.

Key words: Hydrostatic journal bearing, Cryogenic turbopumps