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FOREWORD

The National Symposium on Cryogenics (NSC) organized by the Indian Cryogenics Council is a biennial event. The Twenty Third National Symposium on Cryogenics, NSC-23 was hosted by National Institute of Technology, Rourkela during October 28 - 30, 2010. This Symposium, over the years, has grown steadily in terms of its character and diversity. Apart from traditional topics of cryogenic engineering, superconductivity, and low temperature physics, NSC-23 laid special emphasis on related subjects of cryomedicine and industrial gases. It was an attempt to bring together different streams of low temperature technology leading to fruitful discussions and promotion of inter-cultural knowledge.

We received a total of about 100 papers covering topics of Cryogenic processes, Cryogenic equipment, Cryogenic technology, Air separation and industrial gases, Low temperature physics & materials engineering, Cryogenics in biology and medicine. Apart from the contributed papers, there were two keynote lectures and eighteen plenary lectures. As per the convention of the Indian Cryogenics Council, selected full length papers of these abstracts are published in the Indian Journal of Cryogenics after a proper peer review process. The symposium was preceded by several short term courses conducted by the best known cryogenics teachers of the country.

It is our pleasure to present the full length papers to the Indian Journal of Cryogenics. The guest editors acknowledge the contributions made by the authors. We would like to thank all the reviewers for their excellent cooperation and services. We would also like to thank the Indian Cryogenic Council and all our friends and colleagues who contributed immensely to the successful completion of the symposium to the publication of the proceedings of the symposium in the IJC.

We sincerely hope that the articles published in the journal will serve as reference materials for researchers, professionals and the cryogenic community as a whole for a long time to come.

GUEST EDITORS

Prof. Ranjit Kr Sahoo	Convener, NSC-23
Prof. Sunil Kr Sarangi	Chairman, NSC-23

EDITORIAL

We have come a long way since the publication of the Indian Journal of Cryogenics (IJC) started some 36 years ago. This was soon after the Indian Cryogenic Council (ICC) was founded by a great visionary none other than Prof. A. Bose of the Indian Association for the Cultivation of Sciences (IACS) in the year 1975. The year 2011 also happens to be the centenary year of Prof. Bose and soon on Dec. 23, 2011 we will be celebrating it by holding a "Workshop on Hundred Years of Superconductivity and the Birth Centinary Celebration of Prof. A. Bose, Founder President of ICC" at VECC, Kolkata.

We have great pleasure in bringing out this 36th Volume of the Indian Journal of Cryogenics. Your journal is on-time since 2006 when the ICC was reorganized. We have no back-log. This issue is the proceedings (Part- A) of the "23rd National Symposium on Cryogenics" held at NIT, Rourkela during October 28-30, 2010. It has three invited talks and 29 contributed papers duly reviewed by the peers. Part- B of the NSC-23 proceedings will be in Volume 37 (2012) and is expected by April 2012. We are happy to note that the journal has become the mouthpiece of all the major institutions of India that are engaged in the area of cryogenics and applied superconductivity. Somehow we do not receive enough papers from several institutions engaged in high quality research in Low Temperature Physics. ICC is the body for the cryogenic engineers, scientists, cryogenic industry and low temperature physicist, all meeting under one umbrella. So is the IJC committed to publications from low temperature physicists, cryogenists and the industry. It will be our endeavour to attract papers from our institutions in the country engaged in high quality basic research. There is a good number of such institutions in India. Efforts will be made to raise the quality of publications to international standard so as to have listed it as a SERC journal. We are also planning to regularise annual publication rather than Quarterly combining all 4 issues together. We thank Prof. Sunil Kumar Sarangi, Chairman (NSC-23) and Prof. Ranjit Kumar Sahoo (Convener NSC- 23) for their sincere and hard work to get about 66 papers for publication in volume 36 and 37. We are pleased to attach the foreward from the guest editors.

T S Datta & R G Sharma
(On behalf of Editorial Board)

CONTENTS

(PART - A OF NSC 23 PROCEEDINGS)

High Speed Miniature Cryogenic Turboexpander Impellers at BARC

Anindya Chakravarty and Trilok Singh

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Expansion turbine constitutes the most critical component of modified Claude and Collins cycle based modern helium liquefiers and refrigerators. BARC is engaged in the indigenous development of helium refrigerators and liquefiers with 3-D full emission expansion turbine and brake wheel impeller based rotor being a key focus area in the development efforts. The BARC program of turboexpander is directed towards the development of medium size helium liquefiers (100 l/hr) and refrigerators (1-2 kW at 20K). Accordingly, from a consideration of the process cycle of both the liquefier and refrigerator, turbine impellers of two different sizes (16mm and 26mm respectively) are designed and developed. The design speeds of 16mm and 26mm diameter turbine impellers are 264,000 RPM and 165,000 RPM respectively. The present paper describes the development efforts involved with these turbine impellers. Current state of research on these systems at BARC is also included.

Key words: *Cryogenic Turboexpander Impellers, Journal Bearing Clearance, Helium Liquefiers, Helium Refrigerators*

Thedarwinheliumfacility - Operationofa helium purification, lquefactionanddistribution plant

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In 2006, BOC Gases Australia, a member of The Linde Group, decided to install a helium facility in Darwin, Australia, to extract helium from a nitrogen rich off-gas from Darwin LNG Pty Ltd.'s facility. The plant with a nameplate capacity of 2.5 tpd of liquefied helium was engineered and fabricated by Linde Kryotechnik AG and subsequently installed and commissioned in the second half of 2009. Although rather small in size compared to other helium facilities, the plant depicts a complex process scheme to meet the needs of helium liquefaction. This includes partial condensation of nitrogen in two stages, cryogenic adsorption and finally catalytic oxidation of hydrogen followed by a dryer unit. The purified helium is eventually liquefied applying a modified Brayton cycle.

Key words: *NSC23, Helium, Purification, Liquefaction, Distribution*

Superconductingfaultcurrentlimiters - A review

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Superconducting fault current limiter (SFCL) based on high temperature superconductors (HTS) is an enabling technology for the extensive fault current limitation when compared to conventional circuit breakers (CBs). Recent advances in reliable production of long length high temperature superconductor (HTS) tapes have resulted in commercial application of superconducting fault current limiters (SFCLs) in electrical utility network. For past 10 years, there is a significant progress in the development and commercialization of SFCL. This paper reviews various SFCL concepts and technological R&D status of SFCL. At present SFCLs are not available for commercial applications in the power systems but successful field trials have recently been undertaken.

Keywords: *Superconducting fault current limiter, high temperature superconductor.*

Thermo-hydraulic analysis of a LTS current feeders system for SST-1

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The Low Temperature Superconductor (LTS) feeders for SST-1 use the same cable in conduit conductor (CICC), which has been adopted for its superconducting magnet system (SCMS). Steady State Superconducting Tokamak SST-1 consists of 16 numbers of modified D shaped Toroidal Field (TF) coils, 9 Poloidal Field (PF) coils along with a pair of resistive PF coils inside the vacuum vessel. Among these, the force flow cooled TF coils will be operating with a maximum conductor current of 10 kA. In order to supply such high currents from the power supplies to the SCMS, a superconducting (sc) current feeder system is required. The sc feeder system demands a safe and stable operation in normal conditions as well as in case of a failure or quench. This paper presents the one dimensional steady state analysis of the TF feeder.

Key words: *LTS, Current Feeder System, CICC, CLAC, Supercritical Helium*

Thermodynamic studies on mixed refrigerant J-T cryocooler heat exchanger

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The thermodynamic performance of Joule-Thomson cycle refrigerator can be greatly improved by using specific gas mixtures as refrigerants. The addition of an inert gas, neon to the working mixture causes reduction in the refrigeration temperature. In this paper, theoretical analysis of mixed refrigerant Joule-Thomson (MR J-T) cryocooler working on neon-nitrogen-hydrocarbon mixtures is reported. The recuperative heat exchange in the Joule-Thomson cryocooler operating with multicomponent non-azeotropic mixture is one of the most important processes. The present work theoretically investigates the behavior of heat exchanger when used with two specific mixtures designed for the temperature range of about 100-110 K. The effect of pinch point on heat transfer within the heat exchanger is also analyzed. It is observed that the variations in ratio of specific heat capacity rates and temperature distributions in the heat exchanger strongly depend on the mixture composition that affects the performance of real refrigeration system.

Key words: *Joule-Thomson cryocooler, mixed refrigerant, heat exchanger.*

Performance Characterization by Optimized Design of Thermoacoustic Prime Mover

B.V.Kamble[1], B.T.Kuzhiveli[1], S. Kasthurirengan[2], Upendra Behera[2], K.V.Dinesh[2], Geeta Sen[3], M.V.N.Prasad[3]

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Thermoacoustic prime mover is a new alternative system particularly for cryogenic refrigeration. The objective of this paper is to design thermoacoustic prime mover which can be used to drive pulse tube cryocooler. Also experiments have been performed on thermoacoustic prime mover which is built based on this design. The design and optimization of standing wave thermoacoustic prime mover have been done based on procedures outlined by Swift [1] and Tijani [2] with simplified linear thermoacoustic model of short stack and boundary layer approximations. The theoretical design shows dependence of performance of system on geometry and relative locations of various parts of thermoacoustic prime mover along with properties of working fluid. For best performance of thermoacoustic prime mover, the optimization of design parameters is essential and these are discussed. This design procedure has been used for the development of thermoacoustic prime movers in our laboratory. Experiments have been carried out to validate the design and these experimental results are presented.

Key words: *Thermoacoustics, Cryocooler, Prime mover, Stacks, Working fluid.*

Finite element analysis of a spiral flexure bearing

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Sangli, Maharashtra.

Spiral flexure bearings are used in miniature cryocoolers to support the compressor motor and displacer assembly. Research has been carried out to present the methodology for the analysis of spiral flexure bearing. The methodology is extended for parametric analysis of spiral flexure bearing. The parametric analysis is also presented to study the influence of spiral swept angle, spiral inner radius and spiral slot width on strain, stress, fatigue, axial and radial stiffness. Finite Element Analysis (FEA) has been used to understand the von mises strain, axial and radial stiffness characteristics for different spiral geometries. To validate the FEA model results dead weight method was used to measure the axial stiffness of flexure bearing. The close match of experimental results and those predicted by FEM based analysis supports the use of FEA modeling for design of flexure bearing springs.

Key words: *spiral flexure bearing, finite element method, different spiral geometries, strain, axial and radial stiffness measurement.*

A vertical test cryostat for testing of elliptical Niobium cavities

Tejas Rane, Naseem Ahmed, and Trilok Singh

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A vertical test cryostat has been designed for testing of superconducting cavities at liquid helium temperature. The neck of the cryostat determines the maximum diameter of the elliptical cavities that can be inserted. The present cryostat is designed for maximum 400mm diameter cavities with 60W of working heat load, to operate for approximately 4 hours without liquid helium input. The designed cryostat is a double walled vessel with a single vapour cooled thermal shield. The material of construction is SS304L, Aluminium and copper. During working the heat inleak has been limited to about 4W. Hence the total heat flow to liquid helium is around 64W. Both, the inner and outer vessels with flanges, are designed using ASME Sec VIII, Div 1.

Key words: *Vertical test cryostat, cryostat modeling, large neck cryostat.*

Design Optimization of 1K-Helium Evaporator

N.K. Das, J. Pradhan, Md. Z.A. Naser, C. Mallik and R.K. Bhandari

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In order to achieve ultralow temperature (mK) by evaporative cooling, we have optimally designed the pre-cooling stage for helium isotopic mixture to bring down the temperature from 4.2K to 1.0K by way of reducing the pressure from 1000 mbar to 1 mbar. This is done by controlling the helium flow from the helium bath in to the He-evaporator (~228cc) through high impedance capillary and proper pumping system. Several important considerations have been made to design the evaporator pot and the pumping line as to minimize the thermal load, to prevent super fluid film creep across the tube as also optimizing the pumping impedance at the He-evaporator. This paper presents the results obtained from CFD analysis along with relevant analytical calculation and details of mechanical design.

Key Words: *1K Pot, Vacuum, Low temperature, Capillary.*

Analysis of Temperature Distribution in a Sorption Compressor during Desorption

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The requirement of a cryocooler, with practically zero vibrations in space borne surveillance system and highly sophisticated electronic devices for ground applications, have led to the development of non mechanically driven Sorption compressor type J-T cryocooler. The sorption capacity of any adsorbent is a function of temperature and adsorption pressure. In a Sorption type compressor, adsorbed gases are discharged in a confined volume by raising the temperature of the adsorption bed. Owing to poor thermal conductivity of adsorbents, there exists a temperature gradient between the heating source, an electrical heater and the adsorbent material at the farthest point. A uniform temperature across the sorption bed ensures a higher maximum discharge from the compressor.

The present work reports both theoretical and experimental temperature distribution across the sorption bed depending on the heater position and number. The effect of gas distribution on temperature is also studied.

Key words: *Adsorption chamber, Temperature gradient*

Finite element analysis and testing of C-Type flexure bearing element

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The flexure bearing is a key technology used in cryocoolers. The use of wear less, friction free clearance seals in linearly driven miniature cryocoolers and linear compressors has tremendously increased the reliability and life of such unitsas compared with those using contact type seals. This has been achieved by employing a non-conventional suspension system, called flexural suspension or flexure bearing. As far as cryocoolers are concerned, this concept was first used in the Oxford University Cryocooler reported in the mid-1980. Since then, it has irrefutably proved to be the best option for small-capacity cryocoolers (nominally 1 W at 80 K) developed for satellite-based cooling applications which calls for very high reliability in performance and a high operation life. In the present work, C Shaped Flexure is used; initially single arm is considered and later extended to two arms. The flexures are optimized such that the Von Misses stress values are about 50% of the fatigue limit for the spring steel. This is done through the modeldeveloped using ANSYS®11.0 FEM.

Key words: *C shape flexure, Cryocoolers, Flexure bearings.*

Design, Fabrication and Testing of HTS based Current Lead

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A current lead is designed, developed and fabricated for 500A of current. It consists of vapor cooled resistive part at the top and HTS at the bottom. The HTS part of the current lead is detachable and can be used for cryocooler-cooled magnet system, where the temperature of the warm-end can be as high as 60-70K. The current lead is designed considering the dimension of port in the existing dewar (SMD20), and it has a lug to connect to the power supply and sockets for the helium gas cooling the resistive part. Optimum helium gas flow rate is obtained with reasonable pressure drop in the resistive part of the current lead. Additional design consideration is done to take care of quench in case of increase in warm-end temperature due to interruption of helium gas flow and current overloading. Fabrication of both the resistive and HTS part is now over and is presently installed with 0.6 MJ SMES magnet system in SMD20 dewar for testing. This paper describes the details of the design features and thermal performance of the lead.

Computation of AC Losses during fast field transients of SMES coil

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This paper addresses the AC loss of solenoid type superconducting magnetic energy storage (SMES) coil under magnetic field ramping up/ down during charging and discharging. FEM package ANSYS is used to find the correction factor required to adopt conventional analytic approach. Time constant for magnetic diffusion is estimated using FEM to find out rise up/ decay period of eddy current. Eddy current dissipation contributed by various parts of the coil is calculated summing up the contribution from unit cells of coil cross-section. The computation is performed for 0.6 MJ SMES coil with linear temporal variation of both radial and axial magnetic field.

Key words: *SMES, Superconducting Magnet, AC Loss*

Performance test of indigenously developed 6T Cryo-Free NbTi Magnet With Warm Bore

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IUAC, New Delhi. Is engaged in the development of a 6T superconducting magnet with a 50 mm roomtemperature bore. The magnet has been wound on a specially designedcopper former using MF NbTi wire. A total of 32layers havebeen wound without an inter layer. Each layer consists of 370 turns. A total of4.1Km wire has been used. Before the magnetis installed in the designatedcryostat(tested already), theperformance tests have been carried outina liquid helium cryostat normallyused forcharacterizing RFsuperconducting cavities.Specially developed vapor cooled current leads were used to energize the magnet. The magnet has been rigorously trained at 4.2K. A field of 6.2T has been achieved at 105.3 A current. An axial fielduniformityof 0.06 % in a10mmDSV(Diametric spherical Volume)has been observed. The quench system worked very satisfactorily.During the training,the magnet quenched atcurrents of80A, 87A and 99A before reaching 6.2T central axial field. Animpressive ramp rate of currentof 32A / minute has been attained. This paper describes the winding procedure;test setup employed and stored energy estimations. Epoxy seems to be cracking at large Lorentz forcereleasing strain energy which leads to quench. These cracks probablydo not open up further and get stabilized during successiveruns making high ramp rates possible for theenergization ofthe magnet.

Key words: *Cryofree superconducting magnet, Vapor cooled current leads, Quenching*

Steady state thermo-hydraulic design of supercritical helium to liquid helium heat exchanger for cooling loop of cryopumps in fusion grade tokamak machine

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The fusion grade Tokamak machines require high vacuum inside torus and cryostat vacuum vessels, which can be efficiently achieved using cryo-pumps as they can provide high pumping speed along with clean and reliable operation. The forced flow cooling of the cryo-pumps using supercritical helium (SHe) at 5.0 K temperature level is considered as one of the best choice. A cold circulator with a heat exchanger in closed loop is normally used for this purpose. The heat transferred to SHe from cryopump is dumped in the heat exchanger where cooling fluid normally used is liquid helium bath. The architecture of this heat exchanger, being one of the most critical components of cryo-pump cooling circuit, requires compact design with minimum weight due to limited space inside distribution box where it is placed. The present paper discusses design approach, methodology, configuration, thermo-hydraulic analysis and preliminary optimization of heat exchanger within specified design constraints.

Key words: *Pool boiling, liquid helium I, supercritical helium, heat exchanger*

Conceptual Design of Large Cryoline for Fusion Reactor

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High performance cryolines are one of the key components of cryogenic systems for fusion reactors or accelerators. The cold powers are produced in cryoplant and distributed via complex network of cryolines and distribution boxes. The conceptual design has been carried out for 'MAG CL', largest and most complicated multi process pipe cryoline which supports various operating modes of magnet system. Hydraulic analysis has been performed to finalize process pipe sizes. Different internal arrangements of process pipes for cross-section have been evolved. Line segmentation has been done to follow modular design of the cryoline. Conceptual design of typical sections has been carried out to satisfy the design constraints. The concept for fixed and sliding support has been developed along with three concepts for thermal shield. The paper discusses the conceptual design details of 'MAG CL' along with design challenges, constraints as well as analysis results of fixed support, sliding support and thermal shield.

Key words: *Fusion Reactor, Cryoline, Fixed support, Sliding support, Thermal shield*

Modification of Liquid Nitrogen Dewar Pressure Control for Superconducting Cyclotron at VECC

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The superconducting cyclotron at VECC Kolkata requires continuous supply of liquid nitrogen to cool the radiation shield of the cryostat and cryopanels. The flow of liquid nitrogen is maintained by pressurising the liquid nitrogen dewar. Electric heaters immersed in liquid nitrogen pressurize the dewar by boiling liquid nitrogen. The system is operated without human intervention using a PLC. A SCADA based HMI is used for monitoring process parameters. The heaters, installed initially, had high response time and were not reliable. A new pressuriser has been designed and fabricated at VECC Kolkata. Custom made power supplies were used to energize them. PLC logic and subsequent modifications in SCADA were also made. The system was under continuous test for last six months. This paper presents details of the pressuriser, the instrumentation and control for the liquid nitrogen dewar and its integration with the existing cryogenic control system.

Key words: *Pressuriser, Pressure control, PLC, SCADA.*

Modification of Cryogenic System of VECC at Kolkata with introduction of New Helium Liquefier

R. Dey, Sandip Pal, A. Mukherjee, U. Panda, T. Maiti, and N. Dutta

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There was a requirement from the cryogenic processes to enhance the capacity of the helium liquefier/refrigerator. Cryogenic system of VECC passes through a major modification by introducing a new liquefier/refrigerator, Helial 2000. This process will help to cater additional refrigeration loads from different projects under XI five year plans in VECC. This will also add redundancy to the cryogenic system as liquid helium supply is mandatory requirement for uninterrupted operation of the cyclotron. The liquefaction capacity of the new liquefier is 85 lph and the refrigeration capacity is 415W at 4.5K. It contains a subcooler to avoid splashing in the cryostat and a valve box to switch from one liquefier to the other easily. There is also a challenge to control the pressure in the ORS as the LP and HP lines from the two liquefiers are common. To meet more helium gas requirement for two liquefiers, another buffer tank of 60 m3 at 25 bar operating pressure will be added in the system. Impure gas is also difficult to handle because of its enormous quantity during any trip. One gas bag of 20 m3 capacity is being installed and two more of 25 m3 capacity is planned. Three quads made of 48 cylinders placed horizontally are being fabricated. The new liquefier is under commissioning, the cool down with the cryostat is already over.

Keywords: *Helium Liquefier, Refrigerator, valve box, sub-cooler Code Number: 202*

Experiences during fabrication, assembly and preliminary cool down of prototype thermal shield for ITER cryoline

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The prototype thermal shield of ITER cryoline has been designed and developed to intercept heat flux from 300K to 4.5K temperature regime. The basic cover of the thermal shield is anchored with 80 K process pipe by means of upper and lower thermal clamps. The validation of the effectiveness of conduction cooling and to address the issues of engineering, manufacturing as well as assembly, a prototype thermal shield has been fabricated. The thermal performance of the shield is measured in terms of the temperature distribution over the surface of thermal shield. Temperature sensors are mounted with special arrangement on the surface of the shield. Specially developed "I" piece assembly with strain gauges has been used for stress measurement on the clamping locations. In order to assess the mechanical integrity of the prototype thermal shield assembly, a preliminary cool down has been performed using liquid nitrogen as a cryogen. This paper will describe experience gained during the fabrication & assembly of the prototype thermal shield, test setup, scheme of preliminary cool down and the cool down results.

Key words: *ITER, Thermal shield, Temperature Sensor mounting, Strain Gauge mounting*

Safety study of wide aperture superconducting quadrupole magnet and cryostat

C. Nandi, S.Roy, A.Datta, S. Bajirao, T.K. Bhattacharyya, P.R.Sharma, G.Pal, C.Mallik and R.K. Bhandari

Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700064 *Variable Energy Cyclotron Centre, Kolkata is designing wide aperture superconducting quadrupole and sextupole magnets having high field quality for the Facility for Antiproton and Ion Research (FAIR), an international collaboration to build an accelerator facility at GSI, Darmstadt, Germany. The usable aperture of these magnets is +/- 300 mm. A large amount of heat shall be dumped into liquid helium within a very short time period, if magnet quenches or annulus vacuum is lost. The worst scenario will occur, if both the process occurs at the same time. The helium relief system of the cryostat must be sized to handle the large quantity of helium gas generated due to heat dumped in liquid helium by quenching and loss of vacuum. This paper presents the study of quench for the magnets, loss of vacuum and sizing of safety relief system for the cryostat.*

Key words: *superconducting magnet, quench, loss of vacuum, cryostat safety*

Performance Studies of Single and Two Stage Pulse Tube Cryocooler Under Different Vacuum Levels With and Without Thermal Radiation Shields

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Single and two stage Pulse Tube cryocoolers (PTC) have been designed, fabricated and studied. While the single stage PTC reaches a no-load temperature of ~ 29 K, the two stage PTC reaches ~ 2.9 K in the second stage with ~60k in the first stage, when insulated with thermal radiation shields and high vacuum, in the inter space. The single stage system uses stainless steel meshes along with Pb granules as its regenerator materials and two stage PTC uses combinations of Pb along with Er3 Ni / HoCu2 as the second stage regenerator materials. To evaluate the performance of these system in the possible conditions of loss of vacuum and without radiation shields, experimental studies have been performed. The heat in leak under such severe conditions have been estimated from the heat load characteristics and results are analysed to obtain surface emissivities and effective thermal conductivities as a function of interspace pressure.

Key words: *Pulse tube, Cryocooler, Regenerator, Heat transfer, Gas conduction, Radiation, Emissivity*

Experimental Investigations on Stirling type Two stage Pulse tube Cryocooler with U type Configuration

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Multistage high frequency Pulse Tube Refrigerators (PTR) are subject of recent research and development activities. In multistage PTR the stages are cascaded to provide cooling for the next stage. This paper reports on design and experimental investigations on the Stirling type two stage split PTR with U type configuration for both the stages. The investigations are carried out for different operating conditions. The minimum temperature of 28.8 K is achieved at second stage cold end of the pulse tube for operating parameter of 22 bar charge pressure and operating frequency of 72 Hz with 320 W input power. The phase shifting mechanism used for the first stage is an inertance tube while the second stage consists of an inertance tube with double inlet valve. The better performance is expected using finer mesh in the second stage regenerator.

Key words: *Multistage, Pulse Tube Refrigerator, Split Stirling, U type.*

Design of Pulse Tube Cryocooler and Initial Performance Studies

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The work reported here is the design of low mass pulse tube cryocooler (LMC-P), comprising of a low mass compressor and a U-type inertance cold head. The compressor flexure spring and linear motor design were carried out using FE analysis tools. The design of the flow passages in compressor and cold head has been carried out using SAGE 1-D pulse tube cooler analysis software. Based on the above design, the fabrication and assembly of the LMC-P compressor and cold head having a total mass of around 4kg is completed. During the initial performance studies, the LMC-P has provided a cooling of 1W at 105K with 50W of input power.

Key words: *Design, pulse tube, cryocooler*

Analytical Performance Study of a Pulse Tube Refrigerator

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Pulse tube refrigerator has the advantages of long life and low vibration over the conventional cryocoolers, such as Gifford–McMahon (GM) and Stirling coolers because of the absence of moving parts in low temperature. This paper performs a two-dimensional computational fluid dynamic (CFD) simulation of a Gifford–McMahon type double inlet pulse tube refrigerator (DIPTR), operating under a variety of thermal boundary conditions. A commercial Computational Fluid Dynamics (CFD) software package is used to model the oscillating flow inside a pulse tube refrigerator. Helium is used as working fluid for the entire simulation. The simulated double inlet type pulse tube refrigerator consists of a transfer line, an after cooler, a regenerator, a pulse tube, a pair of heat exchangers for cold and hot end, an orifice valve with connecting pipe, a double inlet valve with connecting pipe and a reservoir. The general results, such as the cool down behaviours of the system, the density contours, velocity vectors and the temperature profile along the wall of the cooler are presented.

Keywords: *Pulse Tube Refrigerator, CFD, Helium*

Performance of double inlet pulse tube with and without buffer volumes

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Pulse Tube Cryocoolers have emerged as fast growing cryogenic technology in last two decades. They are highly reliable and offer maintenance-free operation with reduced vibrations. The Pulse Tube Cryocooler consists mainly of compressor, distribution valve, pulse tube and regenerator. In Pulse Tube Cryocooler, Compressor is connected to a distribution valve through buffer tanks at high pressure and low pressure end. Though this tank acts as a buffer volume in the system and helps to maintain the pressure ratio during the run, they increase the system volume. In the present work, the effect of removal of buffer volume on the performance of pulse tube cryocooler in orifice and double inlet mode has been investigated. Some preliminary results of effect of variation on No Load Temperature for orifice and double inlet openings, pressure wave form and cool down trends for both cases are presented.

Key words: *Double Inlet Pulse Tube, Buffer volume*

Development of a Stirling type in-line single stage Dual Pulse Tube Cryocooler driven by a single Compressor

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The work presented in this paper aims to develop a Stirling type In-line single stage Dual Pulse Tube Cryocooler (Dual PTC) driven by a single compressor. Experiments are carried out to investigate the effect of the operating parameters viz. charging pressure and operating frequency on the performance. The developed Dual PTC gives minimum temperature of 56 K at no load and 12.5 W of refrigeration power at 80 K with 300 W input power. The results are compared with the In-line single stage Single Pulse Tube Cryocooler (Single PTC) already developed in our laboratory [1]. The comparisons have been made with respect to cooldown time and cooling power. There is a significant increase in the cooling rate and the cooling capacity for the Dual PTC developed.

Key words: *In-line, Pulse Tube Cryocooler, Dual Pulse Tube Cryocooler*

Design and development of standing wave thermoacoustic prime mover for 300 Hz operating frequency

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A Thermoacoustically driven pulse tube cryocooler is gaining significant interest in the recent time due to its key advantage of complete absence of moving components. The system performance, mainly in terms of acoustic power and pressure ratio is significantly influenced by the operating parameters like heat input, hot end temperature, frequency, filling pressure and geometrical parameters like stack length, stack position, resonator length and dimension of acoustic amplifier etc. The present work reports design and development of different components of standing wave type thermoacoustic prime mover. Components are designed and fabricated based on theoretical analysis carried out. Preliminary experiment is performed at low pressure and relatively low hot end temperature. Results of experiment are presented.

Key words: *Thermoacoustic, Stack, Heat exchangers, Operating parameters.*

Initial phase developmental studies to realize pulse tube cryocooler for spacecraft applications

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The work reported here is the initial phase developmental study carried out on a proof-of-concept Lab-Model PTC, whose cold head design was based on information available in the literature. These studies have helped in understanding and resolving fabrication related issues and arriving at the proper sequence of processes involved in the assembly of the pulse tube cold head. Performance studies carried out by connecting the Lab-Model pulse tube cold head to the existing Stirling compressor (higher mass compressor) have been reported. Test case taken from the above study has been used to validate the SAGE pulse tube cooler analysis software. For meeting the onboard requirements, design and fabrication of a low mass PTC is initiated.

Key words: *Cryocooler, pulse tube, regenerator, onboard Topic code: 205*

Cooldown Measurements in a Standing Wave Thermoacoustic Refrigerator

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Thermoacoustic Refrigerators (TARs) use acoustic power to generate cold temperatures. Apart from the operating frequency and the mean temperature of the working medium, the charging pressure and the dynamic pressure in the TAR govern its attainable cold temperature. The effect of charging pressure on the dynamic pressure in a loudspeaker driven gas filled standing wave column has been well understood. The present work aims to investigate the effect of charging pressure on the cold end temperature of a standing wave TAR. The cold end temperature lift and the cooldown for several changing pressures are reported. The effect of vacuum around the cold end on the TAR performance is also presented.

Key words: *Thermoacoustic, standing, acoustic, refrigerator Paper Code: 200*

Eleven point calibration of capacitance type cryo level sensors of LOX and LH_2 systems of cryogenic stage using four wire type discrete array level sensor setup

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The continuous monitoring of liquid level in a cryogenic stage tank is essential feature from control and safety point of view. Therefore the demand of precision measurement of level is addressed using two coaxial and separated tubes forming a capacitance type sensor. The linearity measurement of coaxial capacitance sensor ensures the cylindricity of the internal and external tubes. By using discrete diode array level senor, the linearity of the capacitance sensor is being verified. The array composes of eleven diode sets spaced at 40mm and 70mm for 400mm (LOX) and 700mm (LH2) level sensors respectively. Liquid Nitrogen (LN2) is used for the calibration of both the level sensors. Each diode set consists of three diodes placed 1mm above and below the center diode which provides level measurement accuracy of ±1mm. The variation in voltage across the diode is measured using four wire method. The automatic detection and data logging through multiplexers is done using a program created with LabVIEW 8.5.

Key words: *Capacitance level sensor, Linearity, Discrete diode array, Calibration.*

Establishment of 13 channel SQUID based MEG system for Studies in biomagnetism

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We report the establishment of a thirteen channel SQUID based Magnetoencephalography and Magnetocardiography system for the measurement of biomagnetic fields originating from the human heart and brain. These fields are extremely weak, typically of the order of 2 pT in case of MEG and about 50 pT in case of MCG and are accessible for measurement only by SQUID sensors. A magnetically shielded room has been established to attenuate the ambient magnetic noise, which is often a million times larger than the signals of interest. The SQUID sensors based on Nb-AlOx-Nb Josephson junctions were used for these measurements. The system can simultaneously record biomagnetic signals at thirteen different locations covering an area inside a circle with a diameter of 130mm. The measured typical white noise of the system is ~ 36 µVrms /√Hz at a gain setting of 5V/Φ0 which translates to an estimated field noise of ~7 fT/√Hz; this is adequate for the measurement of biomagnetic fields. The measurement of the α-rhythm of the brain and the Magnetocardiogram have been successfully carried out using this system.

Key words: *Magnetoencephalography, Magnetocardiography, 13 channel SQUID system:*

Data logging, Graphical Process Visualization of Cryogenic Plant Parameters through PLC

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The objective is to monitor the operation of cryogenic plants effectively, as the available skilled manpower is much limited and also the operation being at very low temperatures and also from safety point of view (due to involvement of high pressure). Even though, the current helium liquefiers are fully automated, still there are large numbers of plant operative parameters, arising from auxiliary equipments which needs to be monitored and controlled for the smooth & trouble free plant operation. Further, the important task in the cryogenic facility is to keep a watch on the plant healthiness, advance indication about the possibility of problem development by means of pre-warning or alarms, so that the remedial action can be taken well before the actual failure affects the plant operation, so that the plant down time is kept almost negligible. Our paper will describe our work carried out at TIFR, Mumbai.