VOLUME 34 , NO. (1- 4) 2009 ISSN 0379-0479

INDIAN JOURNAL OF CRYOGENICS

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

Published by
Indian Cryogenics Council

Proceedings (Part-A) of Twenty Second National Symposium on Cryogenics (NSC-22)

held at
Indian Institute of Science. Bangalore
December (6- 8), 2008

December 2009

Indian Journal of Cryogenics

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

Guest editors for this volume

Subhash Jacob, R Karunanithi, D S Nadig

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

All the papers received for publication in Indian Journal of cryogenics are reviewed by a large no of distinguished scientists from all over india in an honorary capacity.

Communication regarding contribution of paper, subscription for the journal should be addressed to :

Amit Roy
President, Indian Cryogenics Council
Inter- University Accelerator Centre
Aruna Asaf Ali Marg. New Delhi- 110067

Tel : 0091-11-26893045, 26893955
Fax : 0091-11-26893666
Email : roy @iuac.res.in

For detail information, please visit our website :**http://www.iuac.ernet.in/iccwebsite/icc.html**

Indian Journal of Cryogenics

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

General informations :

A) Paper received for publication is being reviewed independently by referees and based on the feedback editorial board takes decision whether to be published with minor correction or to be returned to author with recommendation on additional work or analysis to consider publication in next volume.

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

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

D) The manuscript format is available in the ICC website : **(www.iuac.ernet.in/iccwebsite/icc.html).** Shorly format will be revised and a new format template will be iavailable in the website.

E) The subscription rate is revised and the present rate is

1) Institutes : Annualy Rs 4000/- (For four issues)
2) Individual : Annualy Rs 800/- Single Isuue : Rs 200/-
3) For Life Members of ICC : Only postage Charge

Payment in respect of subscription may be sent by Cheque/ DD in favour of **Indian Cryogenics Council- Delhi** and to be sent along with request letter to

President
Indian Cryogenics Council
Inter- University Accelerator Centre
Aruna Asaf Ali Marg
New Delhi – 110067

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)

CONTENTS

(Part -A of NSC-22 Proceedings)

CONTENTS

(Part -B of NSC-22 Proceedings)

Hundred years liquid helium

A.T.A.M. de Waele

Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands

This paper is a historical overview of the field of low-temperature physics since the liquefaction of helium by Kamerlingh Onnes in 1908. First the performance of the first helium liquefactor is analyzed using the Ts-diagram of ^{4}He. Next a bird's-eye overview will be given of the developments that followed: the discoveries of superconductivity, of superfluidity of ^{4}He and ^{3}He, Bose-Einstein condensation in dilute atomic gases, and of improved of cooling technology such as with cryocoolers, dilution refrigerators, and nuclear demagnetization. Alternative ways of cooling, such as the vortex cooler, thermoacoustic refrigeration, and the cooling of vibrating mechanical objects, are new techniques with high potential.

Key words: history, superconductivity, superfluidity, cryocooling

Cryogenics in launch vehicles and satellites

Dathan M.C[1], Murthy M.B.N[1] and Raghuram T.S[2]

[1]Satish Dhawan Space Centre SHAR and [2]LSSF/ SDSC SHAR

Indian Space Research Organisation is in the forefront of developing cost effective launch vehicles and satellites for the developing technological needs of India. The ever-increasing quest for high performance Launch Vehicles resulted in choosing higher specific impulse generating propellant combination of fuel and oxidizer. Towards meeting this objective, development and establishment of Cryogenic propulsion systems and launch facilities are under taken in the past decade. Also the future missions of ISRO like GSLV-MK3 as well as missions which are being planned for human in space targets the extensive use of Cryo propellants. This paper outlines the applications of cryogenics in brief and rocket technology in particular the historical evolution of Cryo propellant based rocket stages in the world, the criteria for selection of propellants and its associated problems, related developments in Indian Space Program, establishment of propellant filling facilities at Satish Dhawan Space Centre for current and future GSLV missions and the criticalities associated with filling activities at Launch Complex during chronological operations before Vehicle Lift-Off.

Key words: Launch Vehicle, propellant, thrust, specific impulse, hydrogen and oxygen

Nano-Kelvins in the laboratory

Unnikrishnan. C. S.

Gravitation Group, TIFR, Homi Bhabha Road, Mumbai 400005

The quest for getting closer to the absolute zero temperature is driven by the ever-rich physics treasures that are hidden in the fragile and thin layers of temperatures near absolute zero. The application potentials of these discoveries so far have been spectacular. Gaseous samples containing millions of atoms can be cooled to a few nano-Kelvin temperature by a combination of laser cooling techniques, magnetic or optical trapping, and evaporative cooling. Important quantum phase transitions that are sensitive to the spin of the fundamental particles, like Bose-Einstein Condensation, happen in the region between 1 micro-K and 100 nano-K. Applications of some of these developments are in high precision measurements, ultra-stable atomic clocks, inertial sensing, gravimetry etc. This paper discusses the various principles and techniques involved in cooling gaseous atomic samples down to 100 nano-Klevin or lower, starting from room temperature, maintaining their vapor state. Some recent advances in the use of the familiar adiabatic demagnetization at the atomic scale in vapor state in this context are mentioned. A selected assortment of important applications that became possible due to these developments is briefly introduced.

Key words: Laser Cooling, Absolute Zero, Evaporative Cooling, Ultra-cold atoms, Bose-Einstein Condensation, Fermions, Demagnetization cooling.

Development of plate and fin heat exchangers

Mukesh Goyal, Rajendran Menon, Trilok Singh

Cryo Technology Division, Bhabha Atomic Research Centre, Mumbai

This paper presents development of compact plate and fin heat exchangers with offset-strip fins carried out for use in helium liquefaction/ refrigeration systems. Various empirical correlations [1, 2, 3] available in the literature for dimensionless heat transfer and pressure drop characteristics have been reviewed. Design optimization and sizing calculations based on these empirical correlations taking into account axial heat conduction [4], temperature dependant fluid and material properties have been presented. Based on our design heat exchangers were fabricated. Testing for mechanical strength and leak- tightness was done. Destructive examination was done to see the quality of core brazing and distribution of fins inside the core. Thermal performance evaluation tests were carried out. Test results have been analysed and presented in this paper.

Key words: Offset strip fins, compact plate and fin heat exchangers, heat exchanger design, cryogenic system.

Helium liquefaction/refrigeration system based on claude cycle: A parametric study

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

Cryogenic Engg. Centre, Indian Institute of Technology, Kharagpur, 721302, India.

Large-scale helium liquefaction/refrigeration systems are based on modified Claude cycle and its variations. These systems are constituted of various components including compressors, purification systems, an array of heat exchangers, turbo-expanders, etc. The performance of these systems is dependent on the geometric and operating parameters of each of these components. These parameters are intricately connected with each other, and decide the final output of the system. The combined and intertwined action of these process parameters makes the study of system behavior difficult. This necessitates the use of process simulators for understanding the steady state and dynamic behaviours of such large-scale systems. As the ground work for designing a large-scale helium liquefier, a parametric study of a liquefaction system based on two-turboexpander Claude cycle has been undertaken. Such a simple cycle, however, has all the basic characteristics of a large-scale helium liquefier and the results of the study can always be extrapolated to large-scale systems effectively.

Key words: Helium liquefaction, Parametric study, Cycle design, Multi-expander Claude cycle.

Computation of liquid helium two phase flow in horizontal and vertical transfer lines

Tejas Rane, Anindya Chakravarty, R K Singh and Trilok Singh

Bhabha Atomic Research Centre, Mumbai, India.

In a liquid helium transfer line, heat transfer and pressure drop occurs along the length of the pipe resulting in boiling. The present work describes theoretical modeling and computation of two phase liquid helium flow in a pipe with pressure drop and heat transfer. Empirical correlations have been used for heat transfer coefficient and pressure drop. The transfer line has been modeled as a two dimensional, axisymmetric heat conduction problem, with a constant external heat flux (as a boundary condition) flowing into the pipe, through superinsulation. The heat transfer coefficient forms the other boundary condition. The pipe length is divided into small segments within which the fluid properties are assumed constant, however property variation along the length from segment to segment is considered. This model has been used to predict flow variables and their behavior for two-phase liquid helium flow.

Key words: two phase liquid helium flow, transfer line, empirical correlation.

Experience in design and operation of a cryogenics system for argon cover gas purification in LMFBRs

B.Muralidharan[1], M.G.Hemanath[1], K.Swaminathan[2], C.R.Venkatasubramani[2], A.Ashok kumar[1], Vivek Nema[1] and K.K.Rajan[1]

[1]Fast Reactor Technology Group, [2]Chemistry Group
Indira Gandhi Centre for Atomic Research, Kalpakkam-603102 (bmurali@igcar.gov.in)

The 500 MWe Prototype Fast Breeder Reactor (PFBR), is at an advanced stage of construction at Kalpakkam in India. In case of a breach of clad, the gaseous fission products – isotopes of krypton and xenon - are released to the argon cover gas. The simplest technique to remove these radioactive gases is by adsorption on activated charcoal. The process taking place is called Dynamic Adsorption and results in a time delay for the passage of the noble gases through the bed allowing the short lived radionuclides to decay. The Dynamic Adsorption Coefficient (DAC) increases substantially with decrease in temperature and at cryogenic temperatures, the residence time increases significantly for a given quantity of activated charcoal. To validate the design parameters used for the cover gas purification system in PFBR and to gain experience in operating a cryogenic system, it was decided to set up a pilot plant. This paper describes the design and operation of the pilot plant and the feedback from the same.

Key words : DAC, purification, adsorption, charcoal, cryogenic, CGPS, liquid nitrogen, cold box

Design and implementation of an adiabatic demagnetization set up on a dilution refrigerator to reach temperatures below 100mK

L. S. Sharath Chandra, Deepti Jain, Swati Pandya, P. N. Vishwakarma and V. Ganesan

UGC-DAE Consortium for Scientific Research, University Campus, Khandwa Road, Indore – 452 001

The design and implementation of an adiabatic demagnetization cell using Cerium-Magnesium-Nitrate salt to work with an existing 100mK dilution refrigerator are presented. The salt crystals were grown by slow evaporation technique. Salt and Glycerin are mixed to make slurry and filled inside a copper can. Copper wires are used as thermal link between the salt and the can. Graphite rod was the thermal isolator below 1K. The measurement leads are the weak links between mixing chamber and the cell. The salt was magnetized and allowed to reach thermal equilibrium at ~150mK and then stepwise demagnetization trials were carried out to reach temperatures as low as 69mK.

Thermal design of recuperator heat exchangers for helium recondensation systems using hybrid cryocoolers

G.Jagadish[1], G.S.V.L.Narasimham[2], Subhash Jacob[1]

[1]Centre for Cryogenic Technology, [2]Department of Mechanical Engineering
Indian Institute of Science, Bangalore-560012, India

This paper reports the thermal design of heat exchangers for a pulse-tube refrigerator based helium recondensation system consisting of recuperators and regenerators of a two-stage pulse tube cooler. The constraints on the thermal design of the heat exchangers are the need for high effectiveness and lower pressure drop. A detailed study is carried out to choose the best recuperator heat exchangers out of Giauque-Hampson, Perforated plate and the Collins heat exchanger configurations, based on the design considerations in terms of temperature and pressure. The pressure drop should be commensurate with the optimal pressure ratio of the linear motor compressor. During the calculations, due consideration is given to the geometrical parameters and practical constraints for manufacturing, apart from performance and pressure drop. To this end, suitable computer programs have been developed. Results are presented in the form of graphs for pressure drop on the hot and cold sides and the effectiveness for varying physical dimensions of the recuperator heat exchangers.

Keywords: Heat exchangers, Collins heat exchanger, Giauque heat exchanger, Perforated plate heat exchanger

Experimental investigation on performance of aluminum tape and multilayer insulation between 80 K and 4.2 K

Anup Choudhury[1] , R S Meena[1], M Kumar[1], J Polinski[2], , Maciej Chorowski[2] and T S Datta[1]

[1]Inter University Accelerator Centre (IUAC), Aruna Asaf Ali Road, New Delhi-110067
[2]Wroclaw University of Technology, Wroclaw, Poland
tsdatta@iuac.res.in

Complexity of fabrication, limited available space for insulation, requirement of clean environment around cavity for the development of cryomodules and cryo lines related to Superconducting linear accelerator at IUAC, necessitated to explore alternate cryogenic insulation between 80 K and 4.2 K. Thermal performance study of single layer adhesive aluminum tape between 80 and 4.2 K is carried out by an indigenously developed SS calorimeter. Comparison of performance with multi layer insulation at various level of vacuum is also reported here. This paper will present the experimental procedure and results on heat transfer rate for combination of different parameters.

Keywords : MLI, Aluminum tape, Calorimeter, Heat transfer

Finite element analysis of a spiral flexure bearing for miniature linear compressor

Gawali B. S and Khot M. M.

Department of Mechanical Engineering,
Walchand College of Engineering,
Sangli, Maharashtra.

Spiral flexure bearings are used in miniature cryocoolers to support the compressor motor assembly and displacer. Research has been carried out to present the methodology for the analysis of spiral flexure bearing. The parametric analysis is performed to study the influence of spiral swept angle on strain, stress and axial stiffness. Finite Element Analysis (FEA) has been used to determine the von mises strain characteristics and axial stiffness characteristics for different spiral swept angles using commercial code ANSYS 10. Some of the FEA model results are validated with experimental results.

Key words: spiral flexure bearing, finite element method, flexure thickness and spiral swept angles, strain and axial stiffness measurement.

Assessment of thermal radiation load on cryopanel of refrigerator based cryopump

S G Gilankar and P K Kush

Cryogenic Section, Raja Rammana Centre for Advanced Technology, Indore-452013

The cool-down time for a refrigerator cryopump is one of the important performance parameter as it determines total operation cycle, pumping speed, maximum pumping throughput and other parameters. A closed cycle refrigerator based cryopump for 1000 lit/s pumping speed for nitrogen was developed earlier using small indigenous two stage GM-cryocooler. Performance of this cryopump was evaluated over a long period by carrying out exhaustive tests in order to establish its cool-down time, ultimate pressure, pumping speed, cross-over rating, maximum throughput, and gas capacity. Thermal radiation load is a major heat load on cryopanel affecting the cool down time of cryopump, particularly in case of first stage radiation shield. In this paper, cool down time of cryopump with blank–off flange is approximately estimated and compared with experimental cool down performance. Thermal radiation load on cryopanels was assessed from experimental data of ideal cool down performance of cryopump with blank-off flange and the same is compared with theoretically estimated values. Variation of specific heat with temperature for copper was considered for cool down estimation.

Key words: Cool down time, Thermal radiation, Refrigeration capacity, Cryopump

On-orbit performance of Kalpana-1 VHRR radiant cooler

B.S. Akkimaradi, Madhu Prasad, Santa Ram, Subramanya, A. K. Shrivastava, D. W. Tijare, S.C. Rastogi and D. R. Bhandari

Thermal Systems Group, ISRO Satellite Centre, Bangalore 560 017

Three-stage passive radiant cooler has been designed and successfully realized in the KALPANA-1 spacecraft that was put into orbit on September 12, 2002 using the Polar Satellite Launch Vehicle (PSLV-C4). The radiant cooler maintains the detectors of the VHRR at cryogenic temperature (100–110 K) for optimum performance. The flight performance of the radiant cooler has been very much up to satisfaction. Now it has successfully completed six years in orbit. Initially cooler was maintained at nearly 300 K for one week to avoid contamination of thermo-optical surfaces. On-obit data for seasons like equinox (September, March), winter (December) and summer (June) of all the years in orbit are presented. Performance of the cooler over the years is depicted and prediction is done for end of life condition.

Key words: radiant cooling, cryogenic cooling, on-orbit performance

Commissioning of superconducting linear accelerator at IUAC

R.Mehta, S.Ghosh, G.K.Chowdhury, A.Rai, P.Patra, B.K.Sahu, A.Pandey, D.S.Mathuria, J.Chacko, A.Chowdhury, S.Kar, S.Babu, M.Kumar, R.S.Meena, S.S.K.Sonti, K.K.Mistry, J. Zacharias, P.N.Prakash, T.S.Datta, A. Mandal, D.Kanjilal and A.Roy

Inter-University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi – 110067

First module of niobium (Nb) based Superconducting Linear Accelerator (LINAC) has been commissioned to augment the energy of the ion beam from the Pelletron of Inter University Accelerator Centre (IUAC). Full accelerator will consist of three LINAC modules, one superbuncher cryostat and one rebuncher cryostat. At present one LINAC module along with superbuncher and rebuncher cryostat is operational. This paper deals with basics of rf superconductivity, various surface preparation techniques to improve the cavity performance and acceleration of beam through the first LINAC module.

Key words: Superconductivity, RF, Cavity, Surface Treatment, LINAC

Evolution of thermal shield for ITER torus & cryostat cryoline

Badgujar S., Vaghela H., Shah N., Bhattacharya R. and Sarkar B.

ITER-India, Institute for Plasma Research, Bhat, Gandhinagar – 382428, India

The design, engineering and analysis of the torus and cryostat (T & C) cryoline of International Thermonuclear Experimental Reactor (ITER) cryogenic system, have been done to satisfy the functional requirements. It has been understood from the design that the performance of the cryoline greatly depends on the performance of thermal shield and it has a great influence in achieving the target of minimizing overall heat load for the cryoline. During the design evolution of T & C cryoline, various options of thermal shield have been considered. The design options considered are of varied thickness and configuration with fixed and demountable assembly. The thermal analysis has been carried out using ANSYS© Simulation 10.0 for the thermal equilibrium. Aluminum as material of construction (MOC) with 3 mm thickness has been considered for the design of cryoline. The paper presents the design, configuration, analysis, optimization and prototype test concept of the thermal shield for the T & C cryoline.

Key words: ITER, T & C cryoline, Thermal shield, Finite element analysis

Operating experience of cryogen distribution system for VECC K500 superconducting syclotron

Chinmay Nandi, Tamal Bhattacharyya, Tanmoy Das, Sanjay Bajirao, Santosh Mishra, Gautam Pal and Rakesh Kumar Bhandari

Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata.

The VECC superconducting cyclotron is now undergoing commissioning test for beam trial. The 6.5 ton cold mass cyclotron magnet was first cooled down from room temperature to liquid helium temperature in a controlled manner during the year 2004. Detailed magnetic field mapping at different current was then carried out for almost 15 months. The magnet was cooled for the second time in March 2008. A dedicated control logic was developed to operate various controls, generate interlocks and communicate with the supervisory control of the cryogen distribution system for superconducting cyclotron magnet. The control parameters are operated through control loops operating independently on the dedicated PLC. Based on the earlier operating experience, some modifications in the hardware and control logic have been incorporated. During the operation and commissioning periods, many relevant parameters have been measured. The paper presents the improvements made, the operating experience and some observations related to cryogen distribution system.

Key words: Superconducting Cyclotron, Cryogenic system

Cryo-Box for testing small components

H.Anantha Krishna[a], N.K.Misra[a], M.S.Suresh[b]

[a]ISRO Satellite Centre Bangalore; [b]BNM Institute of Technology, Bangalore.

Spacecrafts in Geostationary earth orbit and Low earth polar orbit experience temperatures in the range of -180^{0}C to +80^{0}C[1][2] depending on the orbit. Environmental chambers and thermo vacuum chambers are used for tests (from small packages to a complete satellite) in temperature range -150^{0}C to +100^{0}C. The operation and maintenance of these chambers are very expensive and consume a lot of resources. As these chambers / facilities are huge, test setup needs to be relocated depending upon the availability of the chambers. A simple Cryo-box that use easily available components and materials is designed, built, tested and calibrated for operation in the temperature range of -180^{0}C to +80^{0}C. The Cryo-box was specifically designed and developed for measuring the characteristics of a solar cell but it may be used for any other small component. A linear temperature sweep of 1.4^{0}C/min is achieved using this facility.

Key words: Cryo-box, Cryo-box component testing, Expanded Polystyrene (EPS).

Superconducting electron cyclotron resonanceion source using gifford mcmahon cryo coolers

G.Rodrigues, P.S.Lakshmy, P.Kumar, A.Mandal, D.Kanjilal, A.Roy

Inter University Accelerator Centre, New Delhi–110067
gerosro@gmail.com

As a part of the accelerator augmentation program at the Inter University Accelerator Centre, New Delhi, a high temperature superconducting (HTS) electron cyclotron resonance (ECR) ion source using single stage Gifford McMahon cryo-cooler has been developed and installed. It will be used as a high current injector device for injection of ion beams having a A/q (max) up to 7 for further acceleration into the superconducting linear accelerator. The novel feature of this ion source is the use of high temperature superconducting BSCCO wires instead of normal copper to minimize the power requirements from ~ 200 kW to ~ 20 kW for operating the source on a 400 kV high voltage platform. The high temperature superconducting coils are cooled using single stage Gifford McMahon cryo-cooler to ~ 20 K for optimum operation. The ion source is presently in continuous operation at ground potential and being utilized for various kinds of experiments. The source will be placed on a high voltage platform in order to prepare for injection into the superconducting linear accelerator. Some of the operational experiences of the Gifford McMahon cryo-coolers and its impact on the performance of the ion source will be presented and highlighted.

Key words: ECR ion source, cryo-coolers, high voltage platform

Performance prediction and test results of LOX tank pressurisation system of cryogenic propulsion stage tested in ISRO facility

M. Xavier, P.P. Kailasanathan and Ashish K. Kartikeya

Cryogenic Propulsion Stages Group, LPSC /ISRO, Thiruvananthapuram, India

Indian space research organisation has successfully completed the ground testing of a cryogenic propulsion stage using LOX and LH_2 as propellant. This stage has propellant loading of 15,700 kg and engine thrust of 75 kN. Out of 15,700 kg of propellant, about 13,300 kg of LOX is stored in a foam insulated tank at sub-cooled condition and is pressurised by a cold gas pressurisation system during engine operation. Two gas bottles made of titanium alloy are kept inside LOX tank for storing helium gas at 22 MPa and 80 K and is regulated to 0.17 MPa by tank pressurisation module. This is to meet the net positive suction head required for the booster pump mounted inside the LOX tank. Helium bubbler circuit provided as part of tank pressurisation system stirs up the LOX and keeps the liquid uniformly mixed in the tank during engine operation. The pressurisation process is mathematically modeled incorporating heat transfer effect of pressurant gas inside the ullage volume, thermodynamic change of helium in gas bottle, helium mass consumption from gas bottle to maintain the required tank pressure, pressure fall trend in gas bottle during engine operation etc. This paper presents the test scheme, system configuration and comparison of pre-test predictions and test results.

Key words: LOX tank, Cryogenic propulsion stage, Helium gas, Pressurisation system

Performance investigation of pulse tube refrigerator using straight and stepped pulse tubes

Lokanath Mohanta, M.D. Atrey

Refrigeration and Cryogenics Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Bombay, Powai, Mumbai – 400 076

The flow in the pulse tube is complex because of its oscillatory nature. The flow pattern plays an important role in the performance of the pulse tube Refrigerator (PTR). Various design parameters like dimensions of pulse tube, regenerator and operating parameters like pressure and frequency affect the PTR performance. The paper compares the performance of the PTR in terms of refrigerating effect and lowest temperature achieved for two different designs, namely, using straight pulse tube and stepped pulse tube keeping the same volume of the pulse tube. The paper also brings out the effect due to change in the dimension of the straight pulse tube and regenerator on the performance of the PTR.

Key words: Stepped Pulse Tube, Dimensional Change

Analysis of irradiation problems in optical cryocooler

Biju T. Kuzhiveli[1], Subhash Jacob[2]

[1]Department of Mechanical Engineering
National Institute of Technology Calicut, India-673601,
[2]Indian Institute of Science, Bangalore-560 012
Email: btkuzhiveli@nitc.ac.in

A network matrix method has been envisaged and developed to encompass complicated combined heat transfer mechanism associated with all solid state optical cryocooler. A numerical solution and computer program package has been made to asses the radiation penalties caused by external and different internal surfaces of an optical cryocooler. The network matrix method so developed is unique in its nature and been able to incorporate all the heat transfer modes. The study takes in to account of the following factors which can affect performance of the cryocooler: Radiation coupling between the optical material and the sink, effect of shape factors and emmisivities, influence of heat generation and absorption on the elements of the cryocooler, effect of conductivities of different materials used in the construction, Influence of connecting wires to cryotip, sensors and optical material, contribution of laser heat etc.

Key words: cryocooler, phonon, photon, emissivity

Theoretical analysis of sorption compressor for J–T cryocooler

Rohit Mehta[1,2] , S.L.Bapat[1] , M.D.Atrey[1]

[1]Department of Mechanical Engineering, IIT Bombay Mumbai - 400076
[2]Government Engineering College Bharuch Gujarat - 392002

The requirement of a cryocooler with practically zero vibrations in space borne surveillance system and highly sophisticated electronic devices for the ground-based applications have led to the development of Non Mechanically driven Sorption compressor type J-T Cryocooler. These cryocoolers satisfy the above requirements and at the same time utilize thermodynamically low grade heat energy. Sorption coolers are not only compact in size but maintain the same COP irrespective of the size in terms of refrigeration power. The present work aims to develop a theoretical design procedure of such a Sorption compressor. Design parameters like refrigerant flow rate, Adsorption and Desorption temperatures, mass of Adsorbent, heating and cooling cycles need to be optimized for a particular application depending on the cooling effect required at a particular temperature. The specific requirements of the adsorbent for a particular adsorbate are also discussed.

Key words: Equilibrium Adsorption capacity, Refrigerant mixture composition

Theoretical model for thermoacoustic devices

S. Mehta[1], H. B. Naik[1], K. P. Desai[1], M.D.Atrey[2]

[1]Mechanical Engineering Department, S.V. National Institute of Technology, Surat
[2] Mechanical Engineering Department, IIT Bombay, Mumbai

The Pulse Tube Cryocooler has the chief advantage of not having any moving component in the cold region. However it does require a mechanical compressor. If this mechanical compressor is replaced by a thermoacoustic prime mover then the system will be without any moving component. Design and development of a thermoacoustic prime mover is a challenging work. This requires thorough understanding of thermoacoustic phenomenon. The performance of a thermoacoustic prime mover depends upon various parameters viz. heat input, hot and cold end temperatures, stack type, geometrical dimensions of different components, mean pressure etc. These parameters are correlated by Rott's wave equation [1]. The present work aims to solve Rott's wave equation in various components of a thermo acoustic device. The results obtained will be compared with those available in the literature [8].

Key words: Pulse tube, Thermoacoustic Prime mover, Wave Equation

Modeling of inertance tube based on RLC circuit analogy

Sarkar M. and Atrey M. D.

Indian Institute of Technology Bombay, Powai, Mumbai - 400076, India.

Inertance tube pulse tube refrigerator (ITPTR) has thin capillary tube which acts as phase shifter and provides additional phase shift between pressure and mass flow rate at the warm end, compared to that with simple orifice. Thus, with proper sizing and dimensioning of inertance tube, optimum cooling effect can be achieved. In the present work a simple model to analyze the phase shift characteristics of an Inertance tube has been presented. The basic principle is to establish a simple behavioral character of fluid flow through an Inertance tube, analogous to a RLC circuit. Every component of a PTR system has been associated with electrical elements. Pressure difference and mass flow rates are viewed as potential difference and current. This model is then clubbed with Isothermal model. The pressure variations are compared with practical results and are found to be closer than what obtained from Isothermal model.

Key words: Inertance tube, PTR, RLC Circuit, Isothermal Model

Relationship between the composition of a four component nitrogen-hydrocarbon mixture charged into the system and that in circulation during steady state operation of a J-T refrigerator

N. Lakshmi Narasimhan, S. Srinivasamurthy and G.Venkatarathnam

Refrigeration and Airconditioning Laboratory, Dept. Mech Engg., IIT Madras, Chennai-36, India.

Joule Thomson (JT) cryocoolers are small refrigerators that can provide refrigeration at temperatures in the range 30-200 K. JT cryocoolers operating with mixed refrigerants are being studied worldwide including our laboratory. Previous studies have shown that the performance of JT cryocoolers is markedly influenced by the composition of mixtures in circulation. The mixture composition in circulation is quite different from that charged into the system due to the solubility of some of the components in the compressor lubricating oil as well as the liquid hold up in the heat exchanger. In the present work, the variation of composition during circulation of four component nitrogen-hydrocarbon mixed refrigerants operating in a single stage Joule-Thomson cryocooler has been investigated experimentally. A method has been developed to predict the composition of the refrigerant to be charged for obtaining a desired mixture in circulation based on the experimental data. The efficacy of the method has been tested experimentally. The details of the experiments performed, results obtained and the basis of the method are presented in this paper.

Key words: JT cryocoolers, mixed refrigerants, composition variation

High frequency pulse tube refrigerator for 100 K

C.V.Thaokar and M.D. Atrey

Refrigeration and Cryogenics Laboratory
Department of Mechanical Engineering
Indian Institute of Technology Bombay, Powai, Mumbai – 400 076

In recent advances, research on High frequency Pulse tube refrigerator (PTR) working near 100 Hz has gained substantial momentum. This is due to the fact that high frequency PTR is miniaturized in size for a given refrigerating power. This is very important considering the recent work towards the development of Micro-Cryocoolers. A high frequency PTR with a volume of 1 cc regenerator and a 0.5 cc pulse tube working at 93 Hz has been developed in our laboratory. Based on the preliminary results obtained till now, the PTR could reach below 100 K temperature at 16 bar charge pressure with 60 W electrical power input to the compressor. Work is in progress to optimize PTR performance to reach near 80 K temperature.

Key words: Miniature Pulse Tube Cryocooler, High Frequency, Isothermal Model

Comparison of stirling type pulse tube refrigerators by CFD simulations

Y. P. Banjare[1], R. K. Sahoo[2], S.K. Sarangi[2]

[1]Deptt. of Mech. Engg. GEC Bilaspur
[2]Deptt. of Mech. Engg. NIT Rourkela

Pulse tube refrigerators have no moving parts in the cold region. It brings longlife operation, high reliability, and low vibration at the cold section. In this paper, the commercial computational fluid dynamic (CFD) package Fluent is utilized for twodimensional axis-symmetric modeling of entire inertance tube pulse tube refrigerator (ITPTR) and orifice pulse tube refrigerator (OPTR). In order to compare the performance of ITPTR and OPTR by CFD simulation, a same compression and expansion process and a same piston movement was applied for both the systems that were geometrically similar except the inertance tube in ITPTR is replaced by an orifice valve in OPTR. The general results such as phase relations between mass flow rate and pressure, mass flow rate at cold end section, temperature contour along the axial direction, velocity vectors in pulse tube are presented for both the models to compare their performance. Results showed that the use of the ITPTR configuration offers a better potential for higher performance and efficiency.

Keywords: Orifice pulse tube, Inertance pulse tube, dual opposed piston compressor, Fluent.

Numerical analysis of performance and loss mechanisms of a two-stage pulse tube cryocooler

S.Kasthurirengan[1], Upendra Behra[1], Rahul N. Sagar[1], K.V.Dinesh[1], N.K. Mohammed Sajid[2], K.A. Shafi[2]

[1]Centre for Cryogenic Technology, Indian Institute of Science, Bangalore, 560012, India.
[2]TKM College of Engineering,Kollam,Kerala,691005,India.

The importance of Pulse Tube Cryocoolers (PTC) has grown rapidly in the last two decades due to the absence of moving parts at cryogenic temperatures, high mechanical stability and reliability for long-term performance. Although commercial PTCs are available, the basic mechanisms of cooling are still a subject of detailed studies and hence many numerical models have been used. The theoretical analysis of PTC has been carried out using an one dimensional adiabatic model, assuming real gas properties of the working fluid. The refrigeration power is determined taking into account of various loss mechanisms such as axial heat conduction through the walls of pulse tube and regenerator matrix, regenerator ineffectiveness, pressure drop and radiation from the ambient. A heat balance analysis is carried out for the second stage to understand the relative magnitudes of various losses. The predicted refrigeration power and temperature profiles have been compared with the available experimental results. The reasonably good agreement between them indicates the validity of the model developed here.

Keywords: Pulse tube, Cryocooler, Regenerator, Cooling power, Numerical model

Characterisation of adsorption compressor used in a charcoal – nitrogen adsorption cryocooler

Leena. R[1] and M. Jose Prakash[2]

[1]Department of Mechanical Engineering, Younus College of Engineering and Technology, Kollam,691010
[2]Department of Mechanical Engineering, TKM College of Engineering, Kollam, 691005, Kerala

Adsorption refrigeration is a relatively new breakthrough in the field of cryogenic cooling. A knowledge of the adsorption compressor characteristics is necessary to calculate the cooling load the cryocooler can cater to. A procedure for simulating the compressor characteristics is described. Although the procedure is tested for a charcoal - nitrogen system, this scheme can be used for any adsorbent adsorbate pair. The temperature distribution in the adsorbent bed, which is necessary for the simulation is obtained using finite difference method. It is observed that by increasing the packing density of the adsorbent, higher operating pressure in the compressor cycle can be achieved and the throughput of the gas can be increased. It is also observed that for a given packing density there is a limit to the higher operating pressure that can be attained. With this simulation extensive experimentation to characterise the compressor can be avoided.

Key words: Cryocooler, Charcoal, Adsorption, Simulation

Developmental studies on low mass cryocooler

Ramasamy, A., Padmanabhan and Gurudath, C.S.

Thermal Systems Group, ISRO Satellite Centre, Bangalore-560 017, India

ISRO Satellite Centre (ISAC) has developed and completed the technology demonstration phase of a single stage split Stirling cryocooler for cooling of onboard IR Detectors. The development model has capability to provide 80K temperatures with 1W load for an input power of 25W. The mass of the present development model is around 11 kg, which is high compared to the present development trends that are reported in literature. To realize the low mass cryocooler (<4kg) for space applications, developmental studies were done, from which it is concluded that it is possible to realize a cryocooler whose mass can be less than 4 kg for cooling capacity of 1W at 80K.

Keywords: cryocooler, development, space application

Magnetocardiogram and magnetoencephalogram using a SQUID based system

K.Gireesan, C.Parasakthi[1], S.Sengottuvel[1], L.S.Vaidhyanathan, R.Baskaran, M.P.Janawadkar and T.S.Radhakrishnan[1]

Materials Science Division, Indira Gandhi Centre for Atomic Research, Kalpakkam-603102, India
[1]MEG Project Scientists of the Department of Science & Technology, Government of India at IGCAR

The first recordings of Magnetocardiogram(MCG) and Magnetoencephalogram (MEG) of a human subject using a SQUID based single channel MEG system established at Kalpakkam are reported. The probe is inserted into a FRP cryostat with the pick up loop inside a step in the bottom plate. The distance of the pick up loop to the subject outside is 12 mm. The system operates inside a magnetically shielded room (MSR) with the latter installed in a low magnetic noise building, constructed with SS 316 as reinforcement in concrete. The SQUID electronics is inside a RF shielded room connected with waveguides to the MSR for cable entry. The MCG is distinct and rhythmic, morphologically similar to the ECG. The R-wave amplitude was estimated to be 47 picoTesla (pp) and the noise is 33 femtoTesla (RMS)/√Hz. The MEG signal recorded from the occipital lobe shows the alpha rhythm at 9 Hz in the 'eyes closed' condition and is suppressed in the 'eyes open' condition.

Key Words: SQUID, Magnetically shielded room, Magnetocardiogram, Magnetoencephalogram

Effect of tempering on the cryotreated intergral diaphragm pressure transducers

Nadig D.S.[+], Jacob S. [+], Karunanithi R.[+], Manjunatha. R[+], Patil. S[+] & Subramanian D.[*], Prasad M.V.N.[*], Geetha Sen[*]

[+]*Centre for Cryogenic Technology, Indian Institute of Science, Bangalore – 560 012, India*
[*]*Liquid Propulsion System Centre, ISRO, Bangalore, India*

Any machined component develops residual stresses during machining and heat treatment. In many cases, the presence of these induced residual stresses are seriously detrimental for the functional reliability of the system. In this study, a cryotreatment system is designed and developed to reduce the residual stresses induced within the integral diaphragm of the pressure transducers during machining. These pressure transducers machined out of precipitation-hardened stainless steel were cryotreated for 24 hours at 98K. The residual stress results of cryotreated transducers indicated significant reduction. These reductions have reduced the problems of zero shift of the outputs of transducers

Key words: Residual stress, Martensite, Austenite, Tempering

Cryogenically multiplexed discrete array type liquid level sensor for calibration of capacitance type cryo level sensor of LOX and LH_2 systems of cryogenic upper stage

R. Karunanithi[1], Subhash Jacob[1], D. S. Nadig[1], D. Subramanian[2] and M.V. Narasimha Prasad[2]

[1]Centre for cryogenic technology, Indian Institute of Science, Bangalore
[2]Liquid propulsion systems centre, ISRO, Bangalore

In large cryogenic storage systems, usually continuous monitoring of liquid level is accomplished using capacitance type level indicators. To check the accuracy and linearity of such level indicators and associated electronics, it is necessary to calibrate them against a standard. Also, the cryogen has to be maintained with very less heat transfer from ambient in order to have minimum bubble formation. The linearity and the accuracy of indigenously developed capacitance type cryo liquid level sensors for LOX and LH_2 systems are evaluated by calibrating them with liquid nitrogen at different pressures up to 2.5 bar. For this purpose, a cryogenically operated multiplexer based discrete array type level sensor system has been used as an electronic scale. The design of a cryostat for this purpose with very less bubble formation which is capable of withstanding up to 5 bar pressure and the multiplexer based level sensor system used as a standard are described in the paper.

Keywords: Multiplexer, Cold electronics, Capacitance type cryogenic level sensor, Calibration

A numerical model for prediction of effective thermal conductivity of perforated plates in matrix heat exchangers

S. Sunil Kumar and T. K. Nandi

Cryogenic Engineering Centre, IIT, Kharagpur, WB-721 302

Effective thermal conductivity (k_{eff}) of the perforated plates is essential for design and optimization of matrix heat exchangers (MHEs). The cylindrical holes in the plates may be arranged in square or hexagonal array. Published data show that for porosity up to 0.6, which mostly covers the MHE applications, the k_{eff} values for square and hexagonal arrays are very close. Thus, the k_{eff} values for square array can also be used for hexagonal array (up to porosity 0.6). This paper presents a numerical model using finite difference method for predicting k_{eff} of plates having holes in square array. The results obtained are compared with the available experimental data and with the data obtained from analytical expressions. An appropriate correlation suitable for the design of MHEs is also identified.

Key words: Perforated plates, effective thermal conductivity, matrix heat exchanger