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INDIAN JOURNAL OF CRYOGENICS

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

Published by
Indian Cryogenics Council

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

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

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EDITORIAL

The Indian Journal of Cryogenics (IJC) publishes the proceedings of the National Symposium on Cryogenics and papers received directly from the authors. It is a matter of great satisfaction that IJC has become a popular journal with our Cryogenics / Applied Superconductivity community. The quality of papers too has shown remarkable improvement. The journal has been on-time and there is no backlog either. We would like to take this opportunity to complement all our authors and the members of the Editorial Advisory Board. We would like to thank Dr. R.K. Bhandari who have been of great help in taking crucial decisions about the publication of the journal.

As already informed we have tied-up with “Indianjournals.com” who has taken up the responsibility for publicity and marketing of the journal. We hope that the circulation and the popularity of the IJC will go-up substantially. Some experts from abroad have expressed desire to become reviewers for our journal. We welcome it and will be utilizing their services now onwards. Our efforts will now be to bring the quality of papers at par with international level so as to attract papers from abroad. Starting with Vol. 41 we will be publishing one or two review papers written by peers in areas of cryogenics / low temperature physics or superconductivity in each issue.

Further IJC now is an “online journal“. You may go to “indianjournals.com” and then get registered. Once the registration is done you can access complementary copy of the Vol. 37 of the IJC online and the abstracts of all the volumes. This means that the journal will have much larger circulation far beyond the Indian borders. This is a matter of rejoice for all of us but it also brings certain responsibilities on our part while submitting the manuscript for publication. In this context we will like to draw your kind attention to the following:

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Dr. R. G. Sharma
Dr. T. S. Datta
(On behalf of the Editorial Board)

Indian Journal of Cryogenics

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All the papers received for publication in Indian Journal of cryogenics are reviewed by a large no of distinguished scientists and professors from all over India in an honorary capacity. The final authority in all the matters related to publication of papers lies with the editorial board.

Communication regarding contribution of paper for publication in the journal should be addressed to:

Dr. R. G. Sharma

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B) IJC is the only Indian journal which gives utmost importance to the publication of articles on cryogenic engineering. The Editorial Board encourages work on indigenous development of cryogenic systems as import substitutions and publish with IJC.

C) Editorial Board will be publishing at least one review article (by invitation) in each volume of the IJC beginning Vol.41. These articles will be invited from peers with long experience in the field of superconductivity, low temperature physics, cryogenic engineering or covering the status of major cryogenic related projects in India.

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PREFACE

It gives us immense pleasure to bring out part B of the proceedings of the 24th National Symposium on Cryogenics (NSC-24) as Vol. 40, a special issue of the Indian Journal of Cryogenics. NSC-24 was organized by the Institute for Plasma Research, Bhat, Gandhinagar and held at the Institute of Management, Nirma University, Ahmedabad, during January 22-24, 2013. This issue contains 38 papers presented at NSC-24 and duly reviewed by the referees. The symposium has successfully brought together researchers from universities, institutes and industries, which stimulated fruitful exchange of information and ideas in cryogenic engineering & superconductivity. Intensive discussion on present and future developments in cryogenics were carried out.

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

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

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

We would like to thank all our professional well-wishers and colleagues whose efforts made NSC-24 so successful. We also appreciate the excellent contributions made by our numerous reviewers. Finally, our special thanks go to Dr. R. K. Bhandari, President, ICC and Prof. P. K. Kaw, Ex. Director, IPR for their full support towards the organization of NSC-24.

(Guest Editors)

Y.C. SAXENA, B. SARKAR

A.K.SAHU, R. BHATTACHARYA

CONTENTS

CRYO COMPONENT DEVELOPMENT AND ANALYSIS

Thermal stress analysis of a large aperture dipole magnet

Sundeep Ghosh, Anjan Dutta Gupta, Pranab Bhattacharyya, Gautam Pal, and Alok Chakrabarti

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

Variable Energy Cyclotron Centre (VECC) is involved in the design of dipole and multi-pole magnets for a spectrometer having high acceptance for the Energy Buncher at the Low Energy Branch (LEB) of the Superconducting Fragment Separator (Super-FRS) to be built at Darmstadt, Germany under the umbrella of India and Facility for Antiproton and Ion Research (FAIR) collaboration. The cryostat of the dipole magnet, consisting of a bobbin structure and an epoxy impregnated superconducting coil, will be subjected to substantial amount of thermal stress when cooled to cryogenic temperature from room conditions. In this paper, a detailed thermal analysis of the coil and bobbin is carried out to have a clear idea about the displacements of the coil and the magnitude & direction of thermal stress developed. Finally structural integrity assessment of the structure is also done following ASME Pressure Vessel Code guidelines.

Comparative design evaluation of plate fin heat exchanger and coiled finned tube heat exchanger for helium liquefier in the temperature range of 300-80 K

Prabhat Kumar Gupta, Vivek Nema and P.K.Kush

Cryo-engineering and Cryo-module Development Section Raja Ramanna Centre for Advanced Technology, Indore (MP)

Present Indigenous Helium Liquefaction system at RRCAT uses the cross-counter flow coiled-finned tube heat exchangers developed completely from Indian resources. These coiled-finned tube heat exchangers are mainly suitable up to medium capacity helium liquefiers. For large capacity helium liquefier, plate fin heat exchangers are more suitable options. This paper presents the comparative evaluation of the design of both types of heat exchangers in the temperature range of 300-80 K for helium liquefier.

Study and analysis of various factors affecting evaporation loss of liquid nitrogen storage vessels and detailing of standard procedure for measurement of such loss rate

S. Tino, S. L. Upadhyay, M.C.A. Naidu, K. M. Kavani and D. R. Patel

TTSD / EnTSG / ESSA Space Applications Centre (ISRO), Ahmedabad

Loss rate of Cryogenic fluid storage vessels depends on many factors like type of insulation, vacuum level of annular space, ambient temperature, degradation of MLI / absorbers / getters used in the annular space etc. It also depends on volume and pressure of the cryogenic fluid inside the container. This paper describes in detail the possible heat leak paths in a typical cryogenic fluid storage vessels, contribution of pressure, volume of the cryogenic fluid and ambient temperature in these losses, practical methods to find evaporation loss and its accuracy, causes for the deterioration of performance of these vessels, identification and detection of leak to the annular space between inner vessel and outer vessel and

remedial actions to trim down the loss rate of cryogenic fluid storage vessel. It also details a model test procedure to establish standard evaporation loss rate considering all the factors.

Design of helium thermo-siphon circuit for injector cryomodule of superconducting electron linac

S. Ghosh[1], M. Ahammed[1], A. Duttagupta[1], M.K.Dey[1], S. Singh[1], B. Hembram[1], S. Biswas[1], V. Naik[1], G. Pal[1], A. Chakrabarti[1] and K. Ghosh[2]

[1]VECC, 1/AF, Bidhan Nagar, Kolkata, 700064.
[2]Jadavpur University, Kolkata, 700032

Design of a ICM for VECC's superconducting electron linac project based on the technology developed for niobium made elliptical TESLA type SRF cavities is underway in collaboration with TRIUMF. There are five connections to a single cavity, operating at 2K temperature, from atmosphere in the form of two beam tubes, two couplers and a tuner. Penetrations were intercepted at 77K temperature and 4K temperature to reduce the heat leak to the cavity.

Thermo-siphon loops are designed to minimize the heat load to the 2K cavities. Analytical analysis is carried out to estimate the effect of heat load on the helium flow rate through the loops using diameter of the tube as parameter. Effect of the inclination of the thermo-siphon's hot arm were studied and accordingly thermo-siphon loops were optimized within the physical constrain of the ICM. Temperature rise at the cavity beam tube flanges were estimated to facilitated the desired heat removal.

Development and performance evaluation of external helium purifier

Sandeep Nair R., Mukesh Goyal, Naseem Ahmed, Rajendran S. Menon and Tejas Rane

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

Helium purification system is vital for removing gaseous and oil aerosol/oil vapour impurities in helium which can freeze and damage ultra high-speed turbo-expanders and choke fine passages of cryogenic heat exchangers or fine filters of helium refrigerators/ liquefiers. An external helium purifier is designed and fabricated for purification of 10 Nm^3/hr flow of impure helium with maximum N_2 impurity of 1%. It consists of an evacuated super-insulated cold box, a helical coil heat exchanger with tube in tube type configuration, an LN_2 bath and a charcoal adsorber maintained at LN_2 temperatures. The main features of the purifier are its compactness, low LN_2 consumption, ease and simplicity of charcoal regeneration. Performance evaluation of the purifier is carried out by observing the impurities (N_2, moisture and hydrocarbons) in the purified helium gas at its exit. Total LN_2 consumption and effectiveness of heat exchanger used for recovery of cold of outgoing helium are also evaluated.

Dynamic loss analysis for 4.5 MJ SMES

Bidhan Chandra Mandal, Uttam Bhunia, Javed Akhter, Jedidiah Pradhan, Chinmay Nandi, Sajjan Kumar Thakur, Manoranjan Das, Gautam Pal and Subimal Saha

Variable Energy Cyclotron Centre, 1/AF, Bidhannagar, Kolkata-700064.

Dynamic or transient loss inside the proposed sector toroidal coil cryostat has been evaluated for the indigenous development of 4.5 MJ/1 MW superconducting magnetic energy storage (SMES) at VEC Centre, Kolkata. The frequent charging/discharging mode of operation in SMES coil results in dynamic loss that needs to be addressed for safe and reliable operation of the coil. The dynamic losses are derived considering local bi-directional magnetic field variation on the conductor for constant voltage output across the SMES coil through DC link. This loss will eventually determine the stability of Rutherford type cable inside the bath cooled cryostat. The result of dynamic loss analysis and subsequent additional cryogen load on plant is presented here.

Seismic and random vibration analysis of internal cryogenic lines of cold valve box

Himanshu Kapoor, Jotirmoy Das, Uday Kumar, Hitensinh Vaghela, Ritendra Bhattacharya and Biswanath Sarkar

ITER-India, Institute for Plasma Research, Gandhinagar

To ensure proper forced flow cooling of superconducting magnetsin nuclear fusion reactor, sufficient mass flow rate with proper pressure head of cryogen is one of the critical parameters with respect to the operation scenarios involved. Under this condition, the role of cold circulating pump (CCP) is vital as it operates across the operation spectrum often without any redundancy. Consequently, a test is proposed in cryogenic test facility at Japan to simulate the thermo-hydraulic conditions with CCP, before actual operational deployment. Essential components for test are housed in a Cold Valve Box (CVB). Internal piping system of CVB is prone to experience random vibration during transport and installation in addition to ground acceleration during seismic event. The paper presents conceptual design as well as the associated seismic and random vibration analysis of CVB to ensure design safety within the relevant response spectrum likely to occur during its operational life.

Hydraulic and thermal analysis for cryodistribution lines of cryopumps for NBI system of SST-1

B. Pandya, A. Sahu, B. Choksi, N. Contractor and S. Parmar

Institute for Plasma Research, Bhat, Gandhinagar, Gujarat-382428

Cryo-pumps had been developed for the long duration continuous pumping (~4000sec) with pumping speed of $2x10^5$l/sec of hydrogen for the Steady state Superconducting Tokamak-1 (SST-1) Neutral Beam Injection (NBI) system[1][2]. Two pumps have been placed in the vacuum chamber along with the

components required for the test and operation of NBI system. A liquid helium plant is used to produce and circulate liquid helium in the cryo-condensing panels at temperature ~4K. Chevron-baffles, around this panel are cooled by liquid nitrogen (LN2) to reduce the external heat loads on the panels. It is necessary that, both pumps should get equal and required flow rates of helium and nitrogen as both pumps are identical. Detailed analysis is required as flow regimes will be different for different segments of the distribution system. In nominal operations, for certain segments, it may be single-phase flow and for certain others it may be two-phase flow. This two-phase flow can be affected due to the heat loads on these cryo-lines. In this report, we discuss the hydraulic as well as thermal analysis including the routing of the cryodistribution lines.

Dynamic simulation of modified claude cycle

Balaji Kr Choudhury, R. K. Sahoo and Sunil Kr Sarangi

Mechanical Engineering Department, National institute of technology, Rourkela-769008, India

The dynamic simulation of a modified Claude cycle has been carried out to liquefy Nitrogen. The cycle consists of two heat exchangers, one turboexpander and one J-T Valve. A phase separator is present to separate the liquid and vapor. The simulation model has been built using commercially available software Aspen Hysys® of AspenTech company. The paper aims to study the dynamic behavior to estimate the cool down time to get the liquid. To get the accurate results the sizing data of the heat exchangers and phase separator are given as input to the model. A level controller also used to maintain the liquid level of the phase separator. The transient behavior of streams inside the heat exchangers, the J-T valve, turboexpander and liquid volume percentage in the phase separator are discussed. This knowledge of simulation can be utilized for optimized operation of the plant.

Thermal and hydraulic analysis of 3-stream multi fluid (He/He/N_2) plate fin heat exchanger for helium plant

V. R. Chavda[1], A. K. Sahu[2] and J. M. Patel[1]

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[2]Institute for Plasma Research (IPR), Bhat Village, Gandhinagar. Gujarat, India

One of the key components of helium refrigerator/liquefier (HRL) plant is heat exchangers working at cryogenic temperature. For some cases, heat exchangers with effectiveness less than 90% can be a reason for failure of helium plant to produce liquid helium. To achieve such high effectiveness, it is necessary to use plate fin heat exchangers, which provides very high heat transfer surface area per unit volume. For the heat exchangers of HRL, High effectiveness, compact volume and low pressure drop are main optimizing parameters. The first heat exchanger whose temperature range is ~310 K to ~90 K is analysed with plate-fin type heat exchanger. This heat exchanger is a part of indigenous development work of HRL of ~2 kW cooling capacity at 4.5 K at IPR. Liquid nitrogen (LN_2) is used to cool incoming hot He gas around ~80 K. The detailed thermal and hydraulic analysis is discussed in this paper.

Cryogenically economical frame bridge structure for horizontal test stand

Rajeev Chaube, Prashant Khare and Pradeep Kumar Kush

Raja Ramanna Center for Advanced Technology, RRCAT, Indore-452013

The paper presents a thermo mechanical design study on frame bridge structure for dual cavity Horizontal Test Stand (HTS). HTS is being developed at RRCAT under SCRF technology development program. The conventionally employed frame bridge structure with stainless steel 304 components is numerically compared with frame bridge structure made up of aluminum alloy 6061-T6 components using FEM code. A significant reduction in cool down time for the frame bridge structure to arrive at 4 K is estimated when using aluminum frame bridge structure in place of stainless steel structure without impairing the structural strength of the structure. The comparative study aims at material and shape selection for the frame bridge structure to be light weight with less cool down time yet yielding comparative strength.

Mitigation of effects of pulsed heat load to helium refrigerator in fusion devices: use of cold-compressor

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

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An immediate effect of pulsed heat load in helium refrigerators used in fusion devices is high fluctuation in return stream, which often leads to instability in plant operation. In this paper, a technique for mitigation of this fluctuation has been proposed using cold-compressor at the coldest part of the helium refrigerator. The cold-compressor is characterized and performance curves scaled according to the requirement. Mitigation of 75% fluctuation in mass flow rate during low heat load condition is demonstrated using dynamic simulation of the coldest part of the helium refrigerator based on modified Claude cycle. Influence of various cycle parameters on refrigeration capacity and the extent of mitigation of mass flow rate fluctuation have been analyzed and results presented. An optimum discharge pressure of cold-compressor is found to exist at 4.5 bar(a). Limitations of the proposed mitigation scheme are also discussed.

Design consideration for piping and equipment layout within the cold box of helium refrigerator/liquefier

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[2] Institute for Plasma Research, Bhat Village, Gandhinagar, Gujarat, India.

The indigenous Helium Refrigeration/Liquefier (HRL), being developed at IPR, is planned to have cooling capacity and different component layout/configuration, nearly same as that of the existing HRL of the

magnet system of Steady state Superconducting Tokamak (SST-1) of IPR. The existing HRL has equivalent refrigeration capacity of about 1.3kW at 4.5 K. The indigenous HRL will have option of upgrading the cooling capacity in modular way up to approximately 2kW. The vacuum chamber of the cold box will contain all the cold equipments/elements necessary to produce liquid helium at 4.5 K. Similar to the existing one, it is planned to have horizontal long cylindrical vacuum chamber with two removable cover plates at both ends for maintenance access to the components inside the chamber. There will be provisions for penetration of process pipes, instrumentation tubes, cable feedthroughs and valve penetrations. Turbo expanders will be placed such that without opening the end plates of the chamber these can be removed and replaced. At the low temperature end of the cold box, heat load to the cold components could reduce cooling capacity of the HRL. Appropriate thermal shield, cooled by LN2 (liquid nitrogen) at about 80 K, need to be designed to reduce this external heat load. This will need planned layout of different cold components/elements inside the vacuum chamber of the cold box considering thermal, hydraulic, mechanical, maintenance and repair requirements. During operation, at low temperature, these components will shrink and can lead to severe thermal stress. To avoid this it will need a proper piping layout and flexibility analysis to check whether stresses are within limit.

Analysis of various liquid nitrogen pre-cooling schemes for large-scale helium liquefiers/ refrigerators

Rahul Verma[1], Rohan Dutta[1], Parthasarathi Ghosh[1], Ananta Kumar Sahu[2] and Kanchan Chowdhury[1]

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Liquid nitrogen precooling is widely used in helium liquefier/refrigerator for increased liquefaction as well as providing initial cool-down up to 80 K. The advantages are reduction in plant size and in number of equipment. There are several configurations of liquid nitrogen precooling for helium plants have been proposed in literature and are being used in practice. The configurations mainly differ in number of equipment like heat exchangers, valves, dewars and the arrangement of helium and nitrogen streams. In this paper, through parametric analysis of some reported configurations using Aspen HYSYS® V7.3, design decisions for adopting a precooling scheme for given helium plant has been presented. Results have been analyzed for the adopted plant configuration to arrive at conclusion regarding optimum configuration for precooling in the helium plant.

Assembly of magnets using flux diversion techniques

Abhay S. Gour, R. Karunanithi, S. Jacob and M. Das

Centre for Cryogenic Technology, Indian Institute of Science, Bangalore-12, India

Rare earth magnets like Nd-Fe-B (Neodeuim-Iron-Boron) have gained popularity in various rotational and linear actuators, because of higher flux density, compact, easy availability in various shapes, sizes and magnetization directions. This paper discusses the assembly procedure for making magnet rings using radially magnetized segmented arc magnet of N45 and N33H grades, and the mover assembly of a linear motor. The above assemblies have been successfully carried out by diversifying the flux through the least reluctance path using external magnetic materials like iron. A magnetostatic analysis has been carried out

for better understanding and verification of the adapted procedure. In this paper, the simulation results for N45 grade Nd-Fe-B magnets have been highlighted.

Design optimization of perforated plate heat exchangers using taguchi method

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Performance of a Perforated plate heat exchanger (PPHE) depends on many design variables such as plate thickness, spacer thickness, pore diameter, porosity etc. For a given heat duty, these parameters can be optimized for maximizing effectiveness, minimizing volume and minimizing or limiting pressure drop. In this paper an attempt has been made for optimization of the design variables of a PPHE so that effectiveness of the heat exchanger per unit volume is maximized under the constraints of fluid pressure drop and length of the heat exchanger. Unlike the conventional approach, importance is given to the length of the heat exchanger which is limited to the available space inside the vacuum chamber of the diffusion bounding machine or the space available in a specific application. Using the given length of the heat exchanger and allowable pressure drop, the problem has been defined in unconstrained form and solved by Taguchi method.

Design and analysis of cryogenic storage equipment and multi process pipes transfer lines

Rajkumar Panjwani[1], Hardik Vyas[2] and Paras Choksi[3]

[1]Vice President, Cryo Scientific Division, Inox India Ltd.
[2]Executive, Cryo Scientific Division, Inox India Ltd.
[3]Executive, Cryo Scientific Division, Inox India Ltd.

This paper covers the Mechanical Design and finite element analysis of Cryogenic Storage Tank and Transfer Lines for Helium Services. This paper emphasizes the challenges as well as the solutions that can be used for shortening the process of Design without losing the accuracy of the solution. This paper also covers the simulation of various components used in cryogenic design.

Design and development of injector cryomodule for superconducting electron linac

M. Ahammed[1*], S. Ghosh[1], S. Saha[1], A. Duttagupta[1], M. Mondal[1], S. De Choudhury[1], R.E. Laxdal[2], A. Koveshnikov[2], V. Zvyagintsev[2],T.Rise[2], Y.C. Chao[2], V. Naik[1], G. Pal[1] and A. Chakraborty[1]

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As an alternative and to complement the production of the rare isotope beam(RIB) using beam from K130 Cyclotron, a project is being underway for the development of superconducting electron linac (e-Linac) to produce RIB following photo fission rout. In the first phase, development of the injector cryomodule (ICM) has been taken up in collaboration with TRIUMF. ICM is consist of the 2K and 4K helium chamber, joule thomson(JT) valve, heat exchanger, LN2 cooled radiation shield, warm and cold magnetic shield, strong back, supports, power coupler, tuner and vacuum chamber.

Mechanical design of the ICM has been carried out along with evaluation of safe cool down rate of the cold mass. Cryogen distribution layout has also been designed considering conversion of the 4K liquid helium to 2K super fluid helium inside the ICM. Relief mechanism has also been formulated after carrying out the safety analysis considering the extreme eventualities. *manir@vecc.gov.in

Design optimization of heat exchanger used in cryopump cooling circuit for a typical fusion machine: A parametric study

Nitin Shah[A], Biswanath Sarkar[A] and Hemant Naik[B]

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The supercritical helium (SHe) is typically used for cooling the cryopanels of cryopumps employed in large applications like fusion machine. The heat absorbed by SHe is dumped to liquid helium (LHe) in the heat exchanger. The typical SHe to LHe heat exchanger for such an application of 5.18 KW has been designed. The optimization of heat exchanger design has been carried out by performing the parametric study to investigate the effect of various design specific parameters on the size and weight of the heat exchanger. The objective of design optimization was to minimize the weight of heat exchanger respecting all design requirements. The design has been also optimized by selecting standard components and materials. The results have been analyzed considering the economics of heat exchanger. The paper discusses about the thermo-hydraulic and mechanical design of heat exchanger as well as parametric study performed for design optimization.

Commissioning of the new 1kw class refrigerator for superconducting LINAC at IUAC

Anup Choudhury, Joby Antony, Jacob Chacko, M Kumar, S Babu, S Kar and T S Datta

Inter University Accelerator Centre (IUAC), Aruna Asaf Ali Road, PO Box – 10502
New Delhi 110067

For the LINAC booster project 5 cryostats with 27 resonators have been commissioned in phases. The total measured heat load on cryostats and distribution system together is 350 W at 4.4 K. At present total heat load is managed by the 15 year old LHe refrigerator from CCI, USA which has a capacity of approx. 300 W @ 4.4 K. A new LHe refrigerator of higher capacity (750 W at 4.4K) with automation features from LINDE Kryotechnik, has been recently commissioned. Also new LHe distribution system connecting the new refrigerator with the existing distribution system has been commissioned. This paper will highlight the efforts and results in commissioning both these systems and also report a set of pressure drop data

received from 1st set of experiments over the entire LHe distribution system with preliminary analysis of the data obtained.

Thermal stability analysis of the niobium made elliptical cavity for superconducting electron linac project

M. Ahammed*,S. Ghosh, A. Duttagupta, M.K.Dey, M. Mondal, V. Naik, G. Pal and A. Chakrabarti.

VECC, 1/AF, Bidhan Nagar, Kolkata, 700064, INDIA

Design and development of injector cryomodule(ICM) for the superconducting electron linac (elinac) is going on at VECC. Injector cryomodule is meant to house one nine-cell niobium elliptical SRF cavity operating at 2K. Thermal stability analysis has been carried out to evaluate the effect of the cavity thickness, the residual resistivity ratio(RRR) of the cavity material and the dimension of the impurities present in the cavity surface, on the performance of the cavity. Based on this analysis we have been able to formulate the inspection procedure for the niobium sheet material and the cleaning techniques. The surface impurities size must be kept below the prescribed value to prevent thermal break down of the cavity.

Design, fabrication and experimental investigation of liquid nitrogen based thermal chamber to achieve desired thermal gradients for aerospace/ missile testing applications

JB Singh and Prateek Kishore

Terminal Ballistics Research Laboratory, Chandigarh – 160030, India

In the present work, an environmental chamber is chosen to study the feasibility for its conversion to a better high thermal gradient system keeping in view the present and future demands of climatic tests of the advanced missile systems/sub-systems. Mathematical calculations have also been made to achieve desirable steep thermal gradients by controlling the liquid nitrogen flow rates even without using any other cooling system like vapour compression based system which involves regular maintenance, bulky and noisy mechanisms. With this, a liquid nitrogen based test setup has been designed, fabricated and integrated with existing thermal chamber to achieve variable temperature gradients of the order of 15^0C per minute. The mathematical calculations have been duly validated by experimental work. This newly designed system can be directly used for climatic testing of aerospace components, missile systems and warheads/explosives at desired thermal gradients.

Development in design of test infrastructure for ITER prototype cryoline test

Choukekar Ketan, Bhattacharya Ritendra, Shah Nitin, Srinivasa Muralidhara, Kapoor Himanshu, Patel Pratik, Kumar Uday and Sarkar Biswanath

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The prototype cryoline (PTCL) for ITER is a representative cryoline from the complex network of all cryolines for the project. PTCL consist of six process pipes (of which four are operating at 4 K temperature level while two are operating at 80 K temperature level), thermal shield and outer vacuum jacket. PTCL will be tested for its thermal performance, mechanical integrity, leak tightness and functioning of components at cryogenic temperatures. The test infrastructure requirements for testing of PTCL have been identified based on the optimized test methodology. The best suited infrastructure option to test PTCL involves 80 K system with helium compressor, test boxes, liquid helium Dewar, liquid nitrogen Dewar and interconnecting cryolines. Process study and various analyses have been performed to finalize the specifications of test infrastructure. The present work describes study on global thermo-hydraulic analysis of PTCL test infrastructure. Preliminary process simulation using the ASPEN HYSYS® has been performed to study the dynamic behavior of 80K system.

Analytical model of cryo-target in thermo-vacuum chamber

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Nitrogen and Helium based Cryo-Target (CT) systems are used for various experimental, industrial and testing applications in high vacuum chambers. Thermal performance of such systems depends upon a number of factors such as thermal exchange coefficient of coolant, various forms of heat losses, coolant properties, CT plate characteristics, externally applied heat loads etc. Therefore an analytical formulation is necessary in order to quantify the effect of such factors over thermal performance of CT system. In this paper analytical model is developed for flat plate CT system based on the positive root of heat balance quartic equation. Important analytical formulas related to characterization of thermal performance of CT systems are presented. This paper doesn't consider mixed phase flow in CT.

Instrumentation and DAQ aspects of SST-1 current feeder and 80 K thermal shield systems

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The operational requirement of Steady State Superconducting Tokamak (SST-1) Current Feeder System (CFS) and 80 K thermal shield demands large number of parameters to be measured and monitored. The parameter includes the temperature, pressure, liquid level, fluid flow and voltage across different current carrying components of SST-1. In refurbished SST-1 CFS which is equipped with (+/-) 10 pairs of conventional vapor cooled current leads (VCCL), superconducting (SC) feeders, actively cooled LN2 shield etc. All these components are installed with suitable and sufficient instrumentation and diagnostics. Similarly, 80 K thermal shield of SST-1, also need a large number of temperature sensors to monitor the temperature profile of the shield. We have carried out the online measurement and monitoring of these parameters to smoothen the operation of both the above systems during the recent commissioning of SST-1.This paper describes the details of instrumentation and data acquisition systems of the current feeder and 80 K thermal shield.

Design and realization of pure LN_2 supply system for cooling of black body targets to qualify meteorology payloads

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Radiometric calibration of meteorological payloads like IMAGER and SOUNDER of INSAT-3D is mandatory to evaluate the instrument for its onboard performance at different temperatures. For such calibration, black body targets (BBTs) are required to be maintained at different constant temperatures within the calibration temperature range. During operation of BBTs, supply of pure LN_2 at a constant pressure controlled within 20-25 PSI is essential to control temperature stability and reduce cooling time for each BBTs. simultaneously other subsystems of thermo vacuum chamber needed supply of pure LN_2 in the range of 60 – 80 PSI. To handle this situation, various options were studied and based on the merits of each option, it was concluded to incorporate a phase separator system with its own pressure control system which will serve these competing requirements and provide required immunity to the BBT system from other system fluctuations.

Design, development and testing of coaxial pulse tube cryocooler and linear compressor

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Cryocoolers, particularly pulse tube cryocooler, is playing a pivotal role in research. Three most important components of cryocooler are, pulse tube, regenerator and linear compressor. Based on the relative position of regenerator and pulse tube we have various configurations like, inline,u-shaped, coaxial and annular. The most important component of a cryocooler is a pulse/pressure generator,called linear motor compressor. These compressors use a current carrying wire within a magnetic field to impart a linear force in the axial direction to the piston while conventional rotary compressors use a crankshaft to provide this force.Our area of interest is designing and developing a stirling type,split coaxial pulse tube and suitable linear compressor (moving coil type).The model used for preliminary design is isothermal.The design and fabrication was done in Walchand College of Engineering and testing was done in Cryogenics lab,IIT,Mumbai. The results in hand show lowest temperature achieved is 105.2 K.

Optimization of binary gas mixture as working fluid for the thermoacoustic prime mover

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The thermoacoustic prime mover (TAPM) is an attractive alternative to the conventional drive used in the pulse tube cryocoolers (PTCs), owing to no moving components, less wear and tear, less vibrations, simplicity in construction and use of environmentally friendly working fluids. In our objective to develop such a system, we have designed and developed twin standing wave TAPM. This paper presents the results of an experimental investigation using binary gas mixtures as working fluid. The gas mixtures of different working fluids, namely nitrogen, argon, and helium are used in the experimentation. The measurement shows that the performance of the twin standing wave TAPM improves as the working gas Prandtl number decreases. The operating frequency, pressure amplitude, temperature difference between the stack ends have been studied at different operating pressures and by varying gas mixture composition. However this needs optimization of binary gas mixture composition. The experimental studies show that for the best performance of TAPM, correct binary mixture of working fluids should be used. Among the binary mixtures the pressure amplitude is high when argon is used as the working fluid. However temperature difference across the stack is higher for argon. In view of this an optimal mixture of Helium 60% and Argon 40% can be chosen to obtain best performance of TAPM.

Integration of cryopump instrumentation for SST-1 NBI

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A positive ion neutral injector (PINI) capable in delivering 5MW (55kV, 90A) ion beam power is being operated for SST-1 neutral beam injection (NBI). The production and neutralization of the ion beams in the injector require a gas throughput of 20 torr l / s in the plasma box and 50–100 torr l / s in the neutralizer section. It is necessary to maintain operating pressure of vessel at 10^{-5}torr to reduce the re-ionization loss of beam within tolerable limits. Conventional Turbo molecular pumps cannot maintain this vacuum level at required gas feed rate so two cryo condensation pumps are being operated to achieve require vacuum in vessel. In order to monitor and optimize the performance of cryopumps, it is necessary to measure the temperature at various locations in LN2 and LHe path. It is also required to monitor the level of LHe and LN2 in cryopumps. Several temperature and level sensors are mounted at various places in cryopumps and integrated with PLC and SCADA based control system.

This paper presents the details of sensor mounting, signals conditioning, scheme of their integration with PLC & SCADA and results in detail.

Performance of inertance type G-M pulse tube cryocooler

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Cryogenic engineering is concerned with design and development of low temperature systems and components because low temperature is the governing parameter in any cryogenic application. Inertance

pulse tube cryocooler provides superior performance than orifice pulse tube cryocooler due to its simplicity, less cost and directional characteristics.

Major of the work for inertance pulse tube cryocooler is recorded for high frequency stirling cryocoolers. Ample amount of research has not been carried out for low frequency GM type pulse tube cryocooler. An experimental setup has been modified and developed for experimental investigations on G-M type inertance pulse tube cryocooler. The necessary instrumentation for measurement of cold end temperature and recording of pressure waveform is provided.

Experiments were carried out to investigate the effect of average pressure, frequency, diameter and length of inertance tube, on the performance of inertance pulse tube cryocooler. The performance of inertance pulse tube crycooler was evaluated for the frequency range of 3 Hz to 8 Hz. The lowest no-load temperature was recorded as 66.8 K at 6 Hz operating frequency and 20 bar average pressure. The optimum inertance tube diameter was found 1.5 mm and length 2.75 m.

Stirlin*GUIDE* - graphical user interface design and education of stirling type machines

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The work presented in this paper aims to develop a user interface which can be used to investigate the performance of Stirling type machines. This interface provides a simulation of the cryocooler and computes the net refrigeration effect, total work input and Coefficient of Performance (COP) based on the design parameters given by the user. The program is developed based on the cyclic analysis for Stirling cryocooler and isothermal model for pulse tube cryocooler. The results in terms of various losses and variation in pressure, volume, mass flow rate, phase angle etc. can be obtained in graphical form. The gross refrigeration effect and net work input obtained can help the user to estimate first order performance of the cryocooler. Thus, StirlinGUIDE can be used to optimize the Stirling type machines. The program also incorporates a separate educational interface along with the design tool for the students of Cryogenic Engineering courses.

Design and analysis of a high capacity stirling type pulse tube cryocooler for a helium recondensation system

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This paper reports the system design and analysis of high capacity Stirling type pulse tube cryocoolers (PTC) intended to provide a cooling power of 10 W at 80 K for a small helium recondensation system. In the initial phase of the work, the regenerator and pulse tube were optimized using Sage software. The effect of the transfer line whose length is comparable to the wave length of the helium pressure wave is investigated. It is found that there is a magnification in the pressure amplitude at the expense of the PV power. Also a no load temperature of 74 K was achieved. A detailed inertance tube optimization and

analysis is done and the cooler is tested with the optimized inertance. The performance improved with a no load temperature of 72 K.

Design aspects of linear motor for a two-stage stirling cryocooler

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Two-stage cryocoolers are used to maintain a lower temperature than that can be achieved in one stage. These are also used to have more than one temperature in electronic instruments. A two-stage expander has a large dead volume compared with that in a single stage; therefore two compressors are used to provide the alternating pressure. A dynamically balanced opposed piston compressor not only makes the system quiet in operation but also eliminates vibration. The reciprocating motion of the piston is obtained from a moving magnet type linear motor. The design of the linear motor to power the piston is a critical one for the efficient and reliable operation of the cooler. In this paper, various configurations of linear motor have been identified and electromagnetic analysis has been performed. The design of the motor involves the size estimation followed by the optimisation of different geometrical and electromagnetic parameters. Based on the analysis of existing structures of linear motors, a novel structure has been identified which would meet the characteristics such as high air-gap flux density, small volume, light weight and simple installation.

ESR and magnetization studies of Fe_2O_3-Bi_2O_3-ZnO-PbO glasses

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The Electron Spin Resonance (ESR) and Magnetization measurements were undertaken in the temperature range 5-323 K to understand the spin dynamics in a new glass system with composition $(Fe_2O_3)_x$ *(70* Bi_2O_3 *20 ZnO 10 PbO)*$_{1-x}$ *(x = 5 and 10 mol%). At high temperatures the ESR spectra consists of a narrow resonance at g ~ 2. As the temperature decreases a second resonance peak emerges at a temperature,* T_f *which is ~ 203 K. With further decrease in temperature, the second resonance peak progressively shifts towards lower field values. The ESR data shows the formation of magnetic clusters. The temperature dependent magnetization data exhibits a spin glass-like transition and a superparamagnetic blocking at a temperature which increases with decrease in x value. The unique magnetic transition of the present glass system is attributed to an inhomogeneous distribution of magnetic moments in the glass. There exist dilute and concentrated regions of magnetic moments. The former is responsible for a spin glass-like transition and the latter for superparamagnetic behavior.*

Effect of cryo-ageing and talc additions on polypropylene

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Polypropylene and its composites are generally used in a large extent in industries as well as consumer goods. PP talc filled composites has excellent stiffness, impact balance for low temperature applications. Thus it is mandatory to examine the PP and talc filled PP (TFPP) response at low temperature.The structural and mechanical properties are crucial for beneficial usageof polypropylene at low temperature. Hence this paper investigates the effect of low temperature on the selected virgin PP and differently filled TFPP. The samples are kept in liquid nitrogen (-196 $^{\circ}C$) for 24hours.The treated samples are then allowed to attain the ambient temperature (25 $^{\circ}C$) and tested for studying the effect of thermal ageing. The mechanical and structural properties of 'un-treated' and 'treated' samples are studied in a comparative manner. Mechanical properties are evaluated by the tensile test, wear test and hardness test. Structural characterization by X-ray diffraction and Fourier transform infrared spectroscopy revealed the change in various aspects like % crystallinity, crystallite size. The wear tracks as a result of abrasive wear during test are observed under optical microscope. These results are compared to find out the change in properties of TFPP after thermal ageing.

Effect of density on the electrical properties of MgB_2 superconductor

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The pellets of commercially available MgB_2 powder were prepared at three different compaction pressure values. The change in compaction pressure changed the bulk density of the sample. Superconducting properties were not affected much with change in preparation condition even though samples show difference in density, porosity and grain size. The normal state electrical properties are found to be dependent on preparation conditions. There is a correlation between room temperature resistivity and residual resistivity ratio (RRR) and resistivity exponent, n values.

Low temperature magnetization studies of $Bi_{1-x}Ca_xMnO_3$

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The detailed magnetization studies of $Bi_{1-x}Ca_xMnO_3$ (x= 0.65, 0.70, 0.75, 0.80, 0.85 and 0.90) samples synthesized by sol-gel technique were carried out in the temperature range 5 – 325 K. The magnetization

data has been used to get information about magnetic interactions. The results on the present samples are compared with the results on bulk samples to assess the effects of grain size on the estimated values of charge ordering temperature (T_{CO}), antiferromagnetic (AFM) ordering i.e Neel temperature (T_N). For samples with 0.65 d x d 0.80, the magnetic phase is dominated by FM interactions in the temperature range $T > T_{CO}$ and coexistence of FM and AFM correlations in the temperature range $T_N < T < T_{CO}$. The signature of PM to canted-AFM (C-AFM) transition at ~ 120K is observed for all compositions. Whereas for samples with x = 0.85 and 0.90, the AFM interactions dominate in the temperature range T > 120 K and canted-AFM ordering is observed below 120 K.

CONTENTS OF VOL. 39

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