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

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Proceeding (Part-B) of
Twenty Seventh National Symposium on Cryogenics and Superconductivity (NSCS-27)

Hosted by
Indian Institute of Technology (IIT), Bombay, Mumbai
January (16-18), 2019

November, 2020

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PREFACE

The 27th "National Symposium on Cryogenics and Superconductivity" (NSCS-27) was organized by the Indian Cryogenics Council and the IIT Bombay during 16-18th January 2019 at IIT Bombay.

We added a few new features to the symposium first time, such as conducting Short Introductory Courses on Cryogenics and Superconductivity for students, researchers and the teachers as a part of the Pre-Symposium Workshop on 15th January 2019, Industry-Academia panel discussions, and a Symposium App for quick accessibility to all the events during the symposium. Two themes selected for Pre-Symposium Workshop were (i) Cryocoolers and (ii) Superconducting Magnets and Materials. The Course Instructors for Cryocoolers were Prof. H. B. Naik of SVNIT Surat and Prof. Kasturirengan ex. IISc Bangaluru. The Course Instructors for Superconducting Magnets and Materials were Prof. V. Selvamanickam of Houston Uni. USA and Dr. R. G. Sharma of IUAC, New Delhi.

The pre-symposium workshop was attended by around 90 young researchers. The symposium portal had around 520 users who signed up. About 280 participants from across the country attended the symposium. We received a total of 191 abstracts out of which 171 were accepted after a critical peer-review. These selected abstracts were categorized into oral and poster presentations based on the reviewers' suggestions. The symposium organizing committee ensured that none of the oral sessions was cancelled or altered. All the papers slated in a oral session were presented by the authors who had confirmed their presence to the organizers well in advance. This way all the oral sessions were carried out without the absence of any oral presenter. Poster sessions were conducted in 2 slots. Each oral session was preceded by plenary and invited talks. A total of 13 invited speakers presented their research work in their respective research areas. Plenary talks were delivered by very eminent scientists which included Prof. Venkat Selvamanickam, Dr. T. S. Datta, Dr. Ziad Ahmad Melhem and Dr. P. P. Kulkarni.

For the ease of knowing the symposium schedule details, a symposium app was developed and made available to the participants. This proved to be helpful to the participants in getting information about various sessions, plenary talks, and short courses. The feedback received shows that the participants found the app extremely useful.

An industry academia panel discussion was conducted with industry experts and research scientists. The discussion gave an opportunity to the young researchers to know the expertise and strength of the Indian industry and interact with them.

The ICC Lifetime Achievement Awards for the year 2018 were given away to Shri P. K. Kush and Prof. R. Nagarajan. Most of the papers presented were very rich in research contents and were of high quality. This symposium was a successful one and has set high standard for future conduct of NSCS. As many as 20 industry booths were put-up during the symposium which were kept open all through the symposium. Not only this, most of the industry persons remained present throughout the duration of the symposium and interacted with the participants.

The Organizing committee extends heartfelt gratitude to all the speakers, participants, exhibitors, and volunteers, for making the symposium a grand success.

Prof. M. D. Atrey
Chair NSCS-27
Department of Mechanical Engineering
IIT Bombay, Mumbai

Prof. Himanshu Bahirat
Co-Chair NSCS-27
Department of Electrical Engineering
IIT Bombay, Mumbai

EDITORIAL

I am happy that Volume 45 of "Indian Journal of Cryogenics" (IJC) is out within 2020 though a bit late because of the treacherous COVID-19. Most of you would know that the Indian Cryogenics Council (ICC) started the publication of IJC in the year 1976 and it is a matter of great satisfaction for the entire ICC fraternity that IJC continues to be published year after year and on time. Credit for this goes to our young researchers who show great enthusiasm in publishing with IJC. It has been our endeavour to improve the quality of the papers published in IJC. Significant improvement was brought about during last few years by my predecessor Dr. R G Sharma who enforced a stricter review by two independent experts. In the event of conflicting reports by the two referees or if the results were found a repetition of the old data, the Editorial Board stepped-in. He also started the publication of one review article by invitation in each issue of the IJC starting with Vol 41 written by the peers who acquired life long experience in their area of expertise.

This issue contains 29 papers presented at the 27th National Symposium on Cryogenics and Superconductivity (NSCS-27) at IIT Bombay, Mumbai during January 2019 and submitted for publication in IJC. Out of a total of 92 papers presented at the symposium and submitted for publication in IJC, 37 papers were published in Vol 44, 2019. About 30 % of the papers submitted, were rejected on the recommendation of our referees. Several articles appearing in this issue belong to very active groups engaged in important national projects in the field of cryogenics and applied superconductivity. I take this opportunity and thank all the reviewers profusely for providing their services which always help us to bring the journal issues on time.

This issue has a review article titled "High T_C Superconducting Power Devices- An Overview" written by Prof. V Vasudeva Rao from IIT. Kharagpur. Prof. V Vasudeva Rao is an eminent academician, working in this field for decades. His earlier work on Superconducting Magnetic Energy Storage Device with LTS and the present work on HTS Motors and Cables is well known to the Indian Cryogenic Community. Hope this article will encourage our young researchers to work in this fascinating field. Our sincere thanks to Prof. V Vasudeva Rao for accepting our request on writing this review article.

I would like to extend my sincere thanks and regards to my colleagues in the journal Editorial Board. My special thanks to Prof. Milind Atrey, President (ICC), Dr. Soumen Kar, Secretary (Technical), ICC and Ms. Tania, Secretarial Assistant (ICC) for their whole hearted support and contribution in publishing this volume. I also thank Dr. R G Sharma for his guidance and advice on critical decisions. Finally, I thank the entire readership of the journal to whom we owe our existence.

We place on record our gratitude to SERB (DST) for its support to the publication of this Journal.

T.S. Datta
Chief Editor
IIT, Kharagpur

November, 2020

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High Tc superconducting power devices- An overview

V Vasudeva Rao

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Thirty years after the discovery of High Tc Superconductivity (HTS), the power devices based on HTS tapes are finding their applications in electrical engineering, due to their technical advantages such as negligible losses and compact geometries. Power grid authorities of several countries including India are exploring to integrate these devices in conventional power grids. With the recent advances in fabrication of long (km level) HTS tapes and development of efficient cryo-refrigerators (KW capacity), it is expected to realize these superconducting technologies in power sector, in a cost-effective manner. The present review paper describes the working principles and present status of different High Tc superconducting power devices such as HTS Cables, HTS-SMES, HTS-SFCL, HTS motors/generators and HTS Transformers along with their indigenous development.

Key words: HTS Tapes, HTS-Cable, SMES, SFCL, HTS Machines

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2020.00002.3 *Vol. 45, 2020*

Jet and shock characteristics of collapsing cavitating bubble in cryogenic environment

Arpit Mishra[1], Joydip Mondal[1], Arnab Roy[2], Rajaram Lakkaraju[3], Parthasarathi Ghosh[1]

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To study the dynamically changing interfacial structures due to the collapse of the cavitating bubble, and the mechanism whereby forces large enough to cause damage are brought to bear against a rigid wall is still somewhat obscure in cryogenic liquids. Study of individual collapsing bubbles is still a cornerstone to understanding the erosive damage process. The high impact pressure resulting from jet water hammer effect and collapsing shock waves due to collapsing cavitating bubble has advantages in stone fragmentation, shock wave lithotripsy and can erode the curved hydrofoil, and can alter the blade profile of any turbo-machinery. In this paper, a collapsing cavitating bubble near straight solid surface dipped in cryogenic fluid has been investigated numerically using compressible framework for different standoff distances. Different jet characteristics, i.e. jet velocity and shock effects etc. have been recorded to quantify the damage and compared with room-temperature fluid combination i.e. air-water.

Key words: Bubble dynamics, Water hammer, Cryogenic, Jets, Shock impact

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Helium Re-condenser for 1.5T Zero-Boil-Off (ZBO) MRI cryostat

Ravikant Paswan[1], N.K. Suman[2], Vijay Soni [2,] Sankar Ram T [2], S .K. Saini [2], M. Kumar[2], Joby Antony[2], Rajesh Kumar[2], R.G. Sharma[2], M.K. Moharana[1], Tripti Sekhar Datta[3], Soumen Kar[2]

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Superconducting MRI magnet is the most exhaustive commercial application of superconductivity and helium cryogenics. Cryocooler based Zero-Boil-Off (ZBO) technique is inevitable for the present-day scanner. An MRI cryostat for a 1.5T MRI magnet has been designed with the ZBO technique using a fin-based helium recondenser. A cryocooler based test rig has been developed to characterize the performance of the helium recondenser made of OFHC copper. A two-stage GM cryocooler is used to cool the thermal shield and the helium recondenser. Four liters of liquid helium has been produced using the same heat exchanger. The recondensation test of the heat exchanger is performed up to 6 psi of bath pressure. At 1psi, the recondensation capacity is found to be~ 1.5W. This paper briefly discusses the experimental details of the recondensation test along with an analytical calculation.

Key words: Zero-Boil-Off, Helium-Recondenser, Cryocooler

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Design of self-centering support system for 1.5 T MRI cryostat

Navneet Suman[1,2*], Arshad Noor Siddiquee[2], Sankar Ram Thekkethil[1], Vijay Soni[1] Ajit Nandwadekar[1], Santosh Sahu[1], Manoj Kumar[1], S.K. Saini[1], R.G. Sharma[1], T.S. Datta[3] and Soumen Kar[1+]

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Present-day whole-body MRI scanners are of "zero boil-off" type which hardly need liquid helium refill. To realize this requirement, the cryostat housing of the superconducting magnet system and many several sub–systems need highly innovative design. This includes the state-of-art design of the support system for the large cold mass (~ 4 tons) meeting the stringent requirements of minimum heat input to the LHe-bath, possessing high strength to take care of the high thermo-mechanical stresses, heavy load, transportation and keeping the magnet center unaffected through self-regulation. In this paper, we report coupled thermo-mechanical and modal analysis of the support system, performed using ANSYS to study temperature deformation and stress in the support assembly. The design includes mechanical strength, minimum resonant frequency, heat load calculations, maximum pretension force and allowable accelerations for the maximum pre-tension. The design incorporates carbon-glass (HS carbon) rods supporting nearly four tons cold mass during assembly, shipment and the normal operation of the MRI magnet.

Key words: Self-centering, Support system, MRI cryostat

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Application of multiple interacting bubbles for particle fragmentation at cryogenic temperature

Joydip Mondal[1], Arpit Mishra[1], Rajaram Lakkaraju[2] and Parthasarathi Ghosh[1]

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Two-phase flow in cryogenic systems is very common due to unavoidable heat inleak and low boiling points of cryogenic fluids. Although it may be detrimental to transfer lines, fluid handling equipment, etc., the flow conditions can be utilized for controlled erosion and particle fragmentation instead. In this study, the erosive effects possible during vapor formation are identified for a circular material target placed in the vicinity of bubble-array in a cryogenic environment (gaseous nitrogen or GN2 bubbles in liquid nitrogen or LN2). The physical effects observed during the interaction include shockwaves due to fast bubble-expansion, liquid jet-hammering, and lateral shear of the surface. The flow-field analysis is conducted to evaluate the typical magnitudes of these phenomena. Results indicate fluid-hammer pressure of 33 MPa as well as jet impact velocity of 48 m/s, which may be sufficient to dent BCC metals at LN2 temperatures. Further, the values obtained for air bubbles in water are also compared. This study can help to understand better the erosive effects of multiple bubbles for prospective applications.

Key words: Cryogenic, Jet hammer, Lateral shear, BCC metal, Streaming

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Effect of ring and porous plate gas sparger on injection cooling

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Short term storage of cryogenic liquid is possible by injection cooling. In this process the liquid is subcooled by injecting a gas through the liquid. Evaporation of liquid into the gas causes subcooling of the liquid, thereby reducing the boil-off loss of the liquid. The rate and extent of subcooling depends on the bubble dynamics and, heat and mass transfer between gas and liquid. Sparger design (type of sparger, number of holes and hole diameter) is an important parameter which dictates the bubble hydrodynamics and hence, the heat and mass transfer between gas and liquid. The effect of sparger type (Porous and ring sparger) on cooling performance of injection cooling has been studied at different gas superficial velocities. A mathematical model based on lumped parameter approach has been developed and simulated for this purpose. Liquid subcooling was achieved for both the types of sparger. However the rate and extent of liquid subcooling was higher for porous plate sparger. Increase in superficial velocity up to a certain value caused the subcooling rate to drop for ring sparger.

Key words: Evaporative cooling, injection cooling, gas sparger, gas holdup, heat transfer coefficient, mass transfer coefficient, gas bubbling, terminal velocity

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2020.00008.4 *Vol. 45, 2020*

Experimental investigation of thermal stratification subject to multi-species ullage

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Cryogenic fuel tanks are subjected to external thermal loads which raise the temperature of the fluids thereby leading to convection currents of warmer layers of fluid from the wall boundaries to the liquid-vapour interface. The heat in-leak into the tank causes an increase in the mass of high temperature fluid termed as stratified propellant mass. Stratified propellant mass is considered a penalty for launch vehicles. Hence, accurate prediction of formation of stratified propellant mass and methods to nullify it in a cryogenic tank is important. Results indicate lower temperature for liquid layers when a non-condensable gas is used. Some variations in the temperature of top liquid layers with respect to pressurant gases are also observed.

Key words: Cryogenics, Thermal Stratification, Multi-phase Heat Transfer, Noncondensable Gas

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Numerical and experimental investigation of 80K thermal shield assembly of 1st Pre-Series Cryoline (PTCL) of ITER cryolines

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The Pre-Series Cryoline (PTCL) is a representative segment of ITER torus & cryostat cryolines with the same cross-section (1:1) and roughly 1:5 scale in length. It was tested in ITER-India Cryogenic Laboratory, IPR, Gandhinagar to verify the thermal and mechanical performances. To evaluate the thermalization of 80K thermal shield installed in PTCL, the temperature of twenty critical locations was recorded during the PTCL test. Steady state measurement of PTCL test shows that the average temperature on a thermal shield was ~5K higher and the heat load at 80K was ~104W higher than the estimated values by numerical analysis. The detailed investigation was performed to determine the possible causes of variance between estimated heat load and experimental heat load. The study result shows that transverse radiation is very critical for heat load at 80K.The revised heat load result obtained from numerical analysis considering transverse radiation with conduction (220.67W) differs only two percent from PTCL experimental heat load. Paper summarizes the PTCL experimental heat load at 80K and the effect of transverse radiation due to the bare surface of fixed supports, vacuum barriers, and sliding supports.

Key words: ITER Cryoline, thermal shield, heat load, sliding support, Multi-layer insulation

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Analytical investigation of the cryogenic propellant outflow from a cryogenic storage tank for different ground test conditions

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Generally, the pressure inside the propellant tank has to be maintained within the acceptable limits to avoid cavitation at the pump inlet. Heat and mass transfer processes occurring inside the tank has a considerable effect on the amount of pressurant gas entering to pressurize the tank. Ullage collapse leads to an increase in mass and mass flow rate of pressurant. Experimental data on tank pressurization is limited because of the enormous costs of performing large scale tank experiments using cryogenic fluids under controlled conditions. In this paper, collapse factor or pressurant gas mass has been investigated for certain combinations using Epstein and Anderson's correlation and dimensional analysis and compared with the available experimental data. In some cases, operating pressure is kept constant while, in other cases, inlet gas temperature is kept constant. Combinations of pressurant and propellant like GH_2- LH_2, GN_2-LOX, GHe –LOX are taken into account.

Key words: Collapse factor, Pressurant gas, Propellant, Analytical, Epstein

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Design study of superconducting quarter wave resonator for post acceleration of radioactive Ion beam facility at VECC, Kolkata

Uttam Bhunia[1], Arup Bandyopadhyay[1], Pratanu Chakraborty[1] , Manas Mondal[1], Vaishali Naik[1], R. E. Laxdal[2], Z. Yao[2], B. Waraich[2], B. Matheson[2], and E. Glenwright[2]

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A Superconducting (SC) resonator (QWR) designed to operate at 113.6 MHz with geometry beta of 0.055 is under development for the post-acceleration of Rare Isotope Beam (RIB) at VECC, Kolkata. The QWR section of the post accelerator is composed of two cryostat module each containing four hermetically sealed QWRs having separate vacuum from cryostat. Each QWR module will accelerate beam up to q/A=1/7 with accelerating gradient of 5.0 MV/m in CW mode. In this paper, the design of the QWR has been reported considering issues like sufficient operational margin, beam dynamical requirements, mechanical fabrication, etc. The simulations performed with FEM code show that the tuning system can adjust and compensate the frequency drift due to external vibrations and helium pressure fluctuation during operation. In order to minimize the undesirable beam steering effect due to vertical component of electric field, studies has been made to optimally position QWRs inside cryostat.

Key words: Superconducting cavity, QWR, Beam acceleration

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Design, development, installation and commissioning of long distance cryogenic transfer lines

S. Sathish Kumar, Abhik Bhattacharya, Ramachandra, Madheswaran M, Ramesh Naidu V, P. Govindan and Deviprasad Karnik

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A long distance cryogenic transfer line,100m long, was designed and commissioned to interconnect six distantly located Liquid Nitrogen (LN_2) storage Dewars, using super insulated pipes. Various technical aspects such as the pressure drop, the cool down time, heat-in-leak analysis and different insulation types were studied in detail for the realization of this transfer line. A novel approach was adopted for the theoretical calculation of cool down time. The same was also determined experimentally and compared. Vent valves were installed along the line at appropriate locations to relieve excess pressure and facilitate free flow of LN_2 during the initial cool down. Safety measures like pressure relief valves and rupture disks were provided to avoid excess pressure build up in closed sections. Since its commissioning, 10,00,000 litres of LN_2 have been transferred successfully with about 84% transfer effectiveness and the performance of transfer line was found to be in-line with our analysis.

Key words: Cryogenic transfer lines, Super Insulated Pipes, LN_2, cool down time

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Numerical analysis of cooldown of large magnets for low energy beam line for Facility for Antiproton and Ion Research

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The superconducting magnets of the Low Energy Beamline are of superferric type. The cooling of the magnets will be done by a liquid Helium bath. Thermal shield and 4K cold mass will be cooled by one common circuit of helium flow. The main constraint for the cooldown is to limit the thermal stresses of the components. In order to satisfy this condition, a gradual cool-down should be performed in order to maintain a small temperature gradient. For cooldown helium flows into the system at a pressure of 16.7 bar. Helium is supercritical at this pressure. The work presents the mathematical model for transient heat transfer. The mathematical model is then solved numerically and the temperature evolution of the cold mass studied. Effect cool down rate of helium and the mass flow rate on the maximum temperature difference and the cool down time is studied.

Key words: Superconducting magnet, Cryogenics, Heat transfer, cool down

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A mathematical model for the characterization of fluid transients in cryogenic propellant feedlines

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A mathematical model formulated based on the method of characteristics is presented in the current article to predict fluid transients occurring due to the sudden closure of the valve in cryogenic propellant feed systems. The applicability of the developed model was evaluated by comparing its predictions with the results available in the literature for cryogenic fluid as well as for water. From the results, it was found that the dampening of the pressure wave largely depends upon the modelling of unsteady friction. Further, the mathematical model was used to investigate the effect of valve closing strategies viz; instantaneous, concave, linear and convex closure on the fluid transients. It was observed from the study that the peak pressure of the oscillations could be reduced by use of linear closure of the valve.

Key words: Fluid transients, cryogenic feedlines, method of characteristics, valve closure laws, mathematical model

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Augmentation scheme of 80 K helium test facility to 65 K using sub-cooled liquid nitrogen

Hitensinh Vaghela, Ketan Choukekar, Pratik Patel, Vinit Shukla, Anuj Garg, Srinivasa Muralidhara, Vikas Gaur, Shk Madeenavalli and Bikash Dash

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The recent trend of High Temperature Superconductor (HTS) developments and HTS based applications has led to the exploration of various method for achieving cryogenic temperature suitable for the HTS applications. Liquid nitrogen (LN2) is a widely accepted choice for HTS applications, however, there is always an urge to reach a temperature lower than 77 K (normal boiling point of LN2) for wider usage of HTS using LN2. In a way forward for creating test facility for HTS and other cryogenic tests, an existing Prototype Cryoline (PTCL) test facility at ITER-India cryogenic laboratory (IICL) has been augmented to deliver 80 K helium for small scale experiments and tests at 80 K. The facility is proposed to be further augmented to achieve 65 K by sub-cooling of LN2 by bath evacuation method. The paper describes the details of the augmentation of the IICL. The LN2 sub-cooling system and its integration to the 80 K helium system have been proposed with supporting process analysis. The equipment sizing of the proposed LN2 sub-cooling system has been inferred based on the process calculations. It is shown that 65 K helium at application end can be achieved with the proposed scheme.

Key words: 80 K helium, sub-cooled liquid nitrogen, process simulation, test facility, HTS

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Experimental investigations on high-frequency thermoacoustic engine

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In Current work, experimental investigations are carried out on a high-frequency thermoacoustic engine used for driving a pulse tube cooler. During the course of work, two different working gases namely Helium and Nitrogen, two different lengths of engine stack, two heater housing configurations and two different configurations of the ambient heat exchanger are experimentally tested and almost four times better performance in terms of pressure amplitude is observed with the combination of better component configurations for the current experimental setup. All the while, the performance of the engine is assessed by pressure amplitude and onset temperature only. Moreover, this experimental work provided better guidance for designing and fabricating an efficient engine used to drive the pulse tube cooler.

Key words: High-Frequency, Experimental Investigations, Thermoacoustic Engine, Pressure amplitude, Onset Temperature

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Thermopneumatic analysis of single stage gifford-mcmahon cryocooler

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The thermodynamics, fluid mechanics, pneumatic and dynamic aspects of a single stage GM cryocooler is governed by a set of non-linear differential equations and have been solved to estimate the performance parameters by using finite volume method. The influence of waiting time of the rotary valve on the refrigeration power and COP has been investigated. Longer is the waiting time means both valves will be closed for a long period, this increases the irreversibility inside the expansion space and, thus, decreases its performance. It is observed that refrigeration capacity and COP attain its maximum value at about 20° and 80° of waiting time respectively. It is also found that the refrigeration power and COP of the straight-line shaped opening is higher than that of square opening. The results may be needful for the effective design of rotary valves of a GM cryocooler.

Key words: GM cryocooler, COP, refrigeration capacity, rotary valve

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Design and investigations on rotary valve for GM type pulse tube cryocooler

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The rotary valve is one of the key components of GM-type pulse tube cryocooler and the cooling performance of GM-type pulse tube cryocooler depends on the rotary valve performance. In order to get better cooling power during steady-state operation of GM-type pulse tube cryocooler, the pressure ratio should be sufficiently high. The efficient rotary valve design should provide such a high-pressure ratio during the operation at steady state condition. The investigations are aimed at getting better pressure ratio and hence better cooling power. The present work involves the design of a rotary valve for two stage pulse tube cryocooler for 20 K applications based on the mass requirements at steady state operation and valve timing with the help of numerical modeling. With 3.65 pressure ratio,18.52 K no load temperature and 1 W cooling power at 19.51 K was obtained at optimum valve timing without using any rare earth materials in second stage regenerator.

Key words: Rotary Valve, Pulse Tube Cryocooler, Gifford McMahon

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Case study of sintered regenerator performance in StirLIN-4 nitrogen liquefier

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Stirling liquefier works on Stirling cycle to produce cooling effect. Sintered Regenerator is a key element of Stirling liquefier which directly affects the liquefier performance. Sintered regenerator is a regenerative heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. The sintering process bonds together tangent metal surfaces at their points of contact without the addition of any filler metal or bonding agent. It is necessary to maintain regenerator porosity for optimum performance of liquefier. Hence Preliminary study has been carried out to find the properties of SS wire mesh matrix, how it is sintered, problems causing degradation of sintered regenerator performance. The main objective of this paper is to study different methods of maintaining sinter regenerator porosity for optimum performance.

Key words: Stirling Cycle, Liquefier, Sintered Regenerator, Heat Exchanger, Wire mesh

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Porosity and heat transfer characteristics analysis of stirling cryocooler regenerator using darcy permeability and forchheimer coefficient

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Darcy Permeability and Forchheimer Coefficient are important parameters considered when flow through a porous media and oscillatory flows are studied. Both of these terms are due to micro scale or pore scale flow phenomenon which results in macroscopic pressure gradient. In this paper calculation of Porosity and Heat Transfer characteristics of Stirling cycle Cryocooler using Darcy Permeability and Forchheimer Inertia Coefficient, as a function of Wire Diameter is presented. The basic objective of this work is to optimize the current regenerator at TIFR by predicting porosity and heat transfer characteristics solely by using the geometry. CFD simulation study of pressure/temperature/velocity along the length of the Regenerator have been done by using Porous model in ANSYS R15.0 and the porosity of Regenerator was calculated using REGEN 3.3 Numerical Analysis Software for Regenerators.

Key words: Porous Regenerator, Stirling Cryocooler, Porosity, Darcy Permeability, Forchheimer Coefficient

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Performance analysis of conduction cooled HTS based magnet coil

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Development of cryocooler technology makes it possible to have conduction cooled superconducting magnet system. We have designed and fabricate a laboratory-scale conduction -cooled pancake type High Temperature Superconducting (HTS) magnet at VECC. Kolkata. It consists of fifteen number of double pancake coils each inserted between copper plates which is mounted on a cold-plate made of OFHC copper and thermally connected with the cold head of the cryocooler. Each pancake coil is individually tested at liquid nitrogen temperature prior to assembly. The magnet is successfully cooled, energized and carried out different performance tests. The paper describes the results of measurement and its performance has been analyzed to enhance the magnetic field.

Key words: HTS magnet, Current lead, Magnet quench, Conduction cooled

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I-V characterization of HTS tape under tensile stress using cryogenic UTM along with FEM analysis

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An indigenous Cryogenic Universal Testing Machine (C-UTM) capable of creating tensile strain in 2G HTS tape under superconducting state is developed. Stress-strain property of superpower make SCS4100 HTS 2G tape is measured using this and were used for FEM analysis. A suitable instrumentation was done to measure I-V characteristic (4-Probe method) of HTS 2G tape under tensile strain using developed cryogenic UTM. I-V characteristics of 2G HTS tapes is used for developing HTS 2G tape based devices such as cables, motors, generators, Superconducting Fault Current Limiters(SFCL) and Superconducting Magnet Energy Storage(SMES).

Key words: HTS 2G Tape, Stress-Strain test, FEM, C-UTM, Superconductor

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Experimental investigations on power frequency electrical breakdown characteristics of liquid nitrogen for HTS power devices

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The discovery of high temperature superconductors (HTS) led to a breakthrough in the development of superconducting power equipments. Now, in addition to liquid helium, other cryogens like helium gas, neon gas, liquid nitrogen (LN_2) etc. can also be used for cryo-cooling purposes. Among all the cryogens, liquid nitrogen is most abundantly available with the least cost. The liquid nitrogen serves as a cryogen and also acts as insulation for high temperature superconducting power equipments working at high voltages. Hence, it becomes essential to characterize the power frequency breakdown strength of LN_2 for designing the HTS based power devices. In the present work, to evaluate the breakdown strength of LN_2 at power frequency (50 Hz), a test setup has been designed and developed for characterizing the power frequency breakdown strength of LN_2 at atmospheric pressure using standard test procedures and the results are presented.

Key words: High Tc Superconductor, Electrical Breakdown, Liquid Nitrogen, HTS Power Devices

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Characterization of SS-Laminated 2G-HTS tapes for SFCL applications

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Second-generation (2G) HTS tape with stainless steel (SS) lamination is found suitable in limiting the fault current. The feasibility of tape to be used in SFCL has been characterized by AC conditions. DC measurement has been done to measure critical current (I_c) and the quality index (n), which signifies the quality of the superconductor. The prospective fault currents at various voltages ($20V_{rms}$, $40V_{rms}$, and $60V_{rms}$) have been measured. Amodular SFCL unit has been developed using 75cm of HTS tape. The SFCL unit limits the fault current by about 7 times within 160 milliseconds and the corresponding recovery time recorded is 8.5 seconds. This paper briefly explains the test results of the AC characterization of SS-laminated HTS tape.

Key words: 2G-HTS Tape, SFCL, Critical Current, Recovery Time

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Quench characteristics of superconducting magnets of low energy beam line for FAIR facility

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Quench analysis of quadrupole and sextupole of FAIR magnet has been carried out through OPERA Quench solver. The peak temperature and maximum voltage generation within the coil have been evaluated. If the peak temperature and voltage exceed the certain limit, it will damage the electrical integrity of insulation and even melt down the conductor. The various protection schemes have been used to reduce the peak temperature and voltage drop to ascertain permissible limit for safe and trouble free operation of the magnet. The role of quench back on transient parameters like current and temperature has also been carried out in this paper.

Key words: Superconducting magnet, Quench simulation, FAIR

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Optimum location of R-SFCL in an IEEE bench-marked four-machine, two-area test system

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Increased demand of power generation capacity in distributed electrical power systems has led to an increase in fault current levels exceeding the maximum designed short-circuit ratings of the switchgear. In this work, we have modeled a HTS based R-SFCL using E-J characteristics of the superconductor and implemented at various key locations in a smart grid. A Graphical User Interface (GUI) of MATLAB is developed to evaluate the effectiveness of the proposed method on an IEEE benchmarked four-machine two-area test system. Three phase faults of different ratings are studied with and without SFCL at various key points of the smart grid, monitoring the power flows. Such studies on optimum location of SFCL are important to maximize the effectiveness of fault mitigation in an extended network of Power Grid.

Key words: R-SFCL; HTS; Simulink; Fault; Quench; Power system

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Multiphysics analysis of operational stresses in a 1.5 T MRI magnet

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Actively shielded magnets such as MRI magnets experience high operational stress due to various forces acting on it.An accurate prediction of the various stresses during operation and its effect on the final magnetic field is crucial for the proper design of an MRI system. In this paper, the contribution of different forces in the final operational condition of the magnet is discussed. Based on thesimulations, the required winding stress for each coil is estimated. In cases where winding stress alone cannot manage the magnetic stresses, over-binding is also provided to nullify the effects of stresses due to the higher Lorentz forces.

Key words: MRI, Superconducting magnets, Stress, Lorentz forces

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Critical current density and pinning mechanism in Hetero structure of Bi-2212 and MgB_2 superconductors

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The systematic studies on hetero structure of Bi-2212glass ceramic and MgB_2 superconductors are reported. Bulk multilayer superconductors were prepared with varying thickness of MgB_2 layer. X-ray diffraction and dc magnetization studies confirm the presence of both superconducting phases in hetero structured samples. Critical current density is found to be maximum in bilayer sample of Bi-2212 and MgB_2 superconductors. In tri-layer sample inverted anisotropy in J_c is observed because of multilayer growth process. The J_c at high magnetic field is attributed to different pinning mechanisms.

Key words: High T_c Superconductors, Bulk multi layers, Surface Morphology, d.c. Magnetization, Critical current density, and Pinning mechanism.

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Indirect estimation of helium pressure at cryogenic temperatures

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To enhance robustness of automated Temperature vs parametertype of measurements in a cold exchange gas based sampletemperature control system, a second control loop is being addedto compensate for pressure variations. For this purpose, a methodfor indirect estimation of He gas pressure has been devised andtested. The method depends upon the property that in the closedloop sample temperature control system, the heater power at thesteady state changes with the partial pressure of the cold Heliumgas

Key words: Pressure estimation, Automation, Cryogenic Measurements

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Development of simple capacitance and diode based void fraction sensors for cryogenic two phase flow

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This paper deals with the development of capacitance and diode-based void fraction measurement sensors for cryogenic two-phase flow in a flexible cryogenic transfer line (20.5 mm ID and 3 mm long) designed and fabricated in-house. Most of the capacitance sensors are prepared on the inner glass tube. These sensors can be subjected to breakages while handling and also making end connections for these sensors are not easy. So, an attempt has been made to develop void fraction sensors by avoiding glass tubes. Simple capacitance and diode-based sensors are designed and calibrated for experimental studies on two-phase flow. Numerical analysis has also been done for liquid nitrogen (LN2) and nitrogen gas (N2) flows in the transfer line using ANSYS fluent software and validated with experimental results.

Key words: Cryogenic, Void fraction, Capacitance sensor, Diode sensor, Liquid nitrogen

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