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Cryogenics, Superconductivity and Low Temperature Physics

Published by
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October, 2023

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EDITORIAL

It is a matter of great satisfaction that the volume 47 (2022) of our esteemed journal "the Indian Journal of Cryogenics" (IJC) is out. In all, this issue has 27 papers under different categories. As per the policy of the journal, the papers were accepted for publication on the basis of the positive review reports by at least two of our referees on journal's panel. In the event of conflicting reports, the editorial board takes a final decision. We consistently follow this policy to maintain the standard of IJC. These papers have been selected out of a total of 167 papers presented at the 28th National Symposium on Cryogenics and Superconductivity (NSCS-28) through our screening and review process. We regret the delay in bringing out this issue, caused by the worst pandemic of the century, COVID-19 which brought the whole world to a halt. So was the fate of our National Symposium (NSCS-28) which suffered postponement more than once. The symposium was ultimately organized jointly by the Indian Cryogenic Council and the Indian Institute of Technology, Kharagpur at IIT. Kharagpur during October 18-21, 2022.

The journal owes its timely publication year after year much to our distinguished reviewers who, in spite of their tight schedule, spare time and burn extra oil to carry out the job. I thank all the reviewers profusely. As per the policy of the ICC and the journal we encourage our young researchers to publish papers with IJC and many of them happen to be first timers. We are constantly pursuing with UGC for the restoration of the UGC approval of our journal and its inclusion in the list of UGC approved Journals.

In all, 300 scientists & engineers including a number of scientists from prestigious research centres abroad attended the symposium. A total of 167 oral and poster papers were presented at the Symposium. The papers covered a wide range of topics such as; cryocoolers, space cryogenics, cryogenic refrigeration, superconductivity, heat transfer, cryogenics and superconductivity for particle accelerators, tokamaks, cryogenic materials, Liquid hydrogen, MRI and liquefied natural gas (LNG).

The inaugural talk "Cryogenics for Indian Space Programme" was delivered by Dr. S Somanath, Chairman, Indian Space Research Organisation (ISRO). Other plenary talks by distinguished speakers were on Indian Superconducting Tokamak, European Spallation Source, Advanced HTS Characterization technique and on the Development of Indian MRI. We are planning to have review articles on these topics and publish them in the successive issues.

I would like to extend my sincere thanks to my colleagues in the IJC Editorial Board for their continued guidance. My special thanks to Prof. Milind Atrey, President (ICC), Dr. Soumen Kar, Secretary Technical), ICC and Ms. Tania, Secretarial Assistant (ICC) for their support in publishing this volume. I also thank veteran Dr. R G Sharma and Dr R K Bhandari for their guidance and advice on critical decisions. Finally, I thank the entire readership of the journal and the contributors who opt for IJC to publish their work.

The Editorial Board would like to place on record its gratitude to SERB (DST) for its support to the publication of IJC.

T S Datta
Chief Editor
IIT, Kharagpur

October 2023

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Conceptualization of a dual-mode LOX-LIN plant at BARC

Anindya Chakravarty[1, 2], Mohananand M. Jadhav[1], Abhilash Chakravarty[1], Mukesh Goyal[1], Naseem A. Ansari[1], Rajendran S. Menon[1], Tejas R. Rane[1], Sandeep R. Nair[1], Jitendra Kumar[1], Naveen Kumar[1], Satish K. Bharti[1], Ankit Jain[1], V. Sugadan[1]

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A dual-mode air separation plant, based on a cryogenic process involving a high-speed turboexpander, a pair of multi-stream plate-fin heat exchangers and a common single column rectifier for both the liquid oxygen (LOX) as well as liquid nitrogen (LIN) modes, is conceptualized to be developed by BARC. Apart from either LOX or LIN, provision for obtaining some amount of gaseous oxygen or nitrogen is also there. With the selected process compression capacity and computed distillation column parameters, the product output is expected to be 64.8 l/hr in the LOX mode and 107.1 l/hr in the LIN mode with purity of 96.4 % and 99.5 % by volume respectively. The work described in this article charts out results from the computation for both the modes of operation. From the results generated, heat exchanger terminal temperatures and stream flow rates are computed that serve as inputs for sizing of these devices.

Key words: Dual-mode air separation plant, high speed turboexpander, multi-stream plate-fin heat exchangers, liquid oxygen, liquid nitrogen

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Vapour cooled Current leads-operations and control for Nb_3Sn coil test

Rohit Panchal[1], Rakesh Patel[1], Dashrath Sonara[1], Gaurang Mahesuria[1], Hiren Nimavat[1], Atul Garg[1], Dikens Christian[1], Pradip Panchal[1], Gaurav Purwar[1], Arvind Kumar Tomar[1], M. Ghate[1], P. Raj[1], Upendra Prasad[1] and Vipul Tanna[1]

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Current leads are essential components to power the superconducting magnets from room temperature 300 K power supply end to 4.5 K terminals of superconducting magnets. At IPR, recently we have carried out Nb_3Sn superconducting coil test and validation using indigenously developed 10 kA rated vapour cooled current leads (VCCLs). These VCCLs are operated reliably in different scenario such as initial cooldown, electric current (ramp up, ramp down and log time steady state condition), cold with no current and quench etc. A dedicated 12 kA / 16 V Switch Mode Power Supply (SMPS) was used to power the superconducting magnet via current leads. One pair of VCCLs are used to test Nb_3Sn proto type coil. This paper describes operation and control of VCCLs for Nb_3Sn coil test with results obtained during the experiment.

Key words: VCCL, Nb_3Sn magnet, Power supply, Dewar, PID

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Cooling plates heat loss estimation for 50 kJ HTS SMES using coupled magneto-thermal transient analysis with a varying ramp rate

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A Superconducting Magnet Energy Storage (SMES) system made out of a High Temperature Superconductor (HTS) having a solenoidal structure is in the form of a single or double pancake assembly. Due to the flat tape-like structure cooling plates made of copper are often employed to provide cooling to the internal layers of tapes. These plates are directly connected to the cryocooler or exposed to cryogen. These plates act as a heat sources in the refrigeration system due to AC losses that occurred during the charging and discharging of the magnet. The cooling plate was made up of copper having high electrical and thermal conductivity. A magneto-thermal coupled simulation was performed to estimate the heat loss. The graph between the current ramp rate and total loss is obtained. Based on this, an increase in temperature rise was determined. Higher ramp rate tends to increase the cooling plate temperature significantly in comparison with low ramp rate.

Key words: HTS SMES, Cooling Plates, Heating

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Conceptual design of open source IoT based software solution for Cryogenic experiments

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Accurate Data Acquisition and Control (DAC) system is the basic element for operation and control during Tokamak experiments. This research is about the software solutions for the instrumentation system that is free of cost, open source and multi-domain utilities applicable to cryogenics test facilities without the need of high cost license procurement for SCADA. A DAC system supports slow and fast operation and control. Using this architecture, it can be feasible to replace high cost SCADA software with its own open source tools for ease of communication and interfaces of heterogeneous hardware. This work introduced multi-domain technologies that facilitate the goal of bringing control system User Interface (UI) to the web for IoT application. Python libraries are used as a future tool for IoT implementation which has been established by this modular architecture using EPICS toolkit. Any Modbus supported instrument control system can be accessed and operated using a web browser as an IoT application which can run on secure public encryption. This solution can interface most of the industry standard PLCs on IoT platforms which can run on credit card sized single board computers. This conceptual DAC software can be used for control of cryogenic test facilities.

Key words: Internet of Things, EPICS, MODBUS, SCADA, Open Source

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Preliminary studies on the development of planar inductor-based sensors for RRR measurement of thin-film Nb-coated samples

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Bulk Niobium (Nb) based superconducting RF (SRF) cavities are the main component of a particle accelerator. The thermal performance of these SRF cavities can be estimated by the Residual Resistivity ratio (RRR) of the Nb used for its fabrication. RRR is the ratio of resistivity at 300K to resistivity at just above the critical temperature. More and more research is happening in thin film (TF) SRF cavities. RRR plays an important role in determining the Q factor of these cavities. The conventional method to measure RRR is by a four-probe resistance measurement technique. This technique is destructive and gives an average value of RRR over the entire length. Hence, a method that is more local and non-destructive is required. This work uses a planar inductor as a sensing element and TF Nb on a Copper (Cu) substrate as the target. The slope of the lift-off line (SLOC) is obtained from the impedance characteristics of a planar inductor by changing the distance between the sensor and the target (lift-off) at various frequencies. SLOC can be used for indirectly evaluating the resistance of the target. When this is cooled to a low temperature, there will be a change in the slope of the LOC, which can be directly correlated to the RRR of TF Nb. The impedance characteristics of the planar inductor are modeled in Ansoft Maxwell, and their results are discussed here.

Key words: Superconducting RF cavity, Residual Resistivity ratio, Eddy current, Planar inductor

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Comparative studies on journal bearings for turboexpanders of a dual mode LOX-LIN plant at BARC, Mumbai

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Medium and large capacity Liquid Oxygen (LOX) and Liquid Nitrogen (LIN) plants are available in the international market. However, there exist a market space for a dual mode air separation plant (either LOX or LIN).A turboexpander based dual mode cryogenic air separation plant is conceptualized by CrTD, BARC, Mumbai. The process employs a commondistillation column for both LOX and LIN modes. The design speed of the process turboexpander ranges from 1,00,000 to 1,30,000 rpm for various modes of operation. Specialized gas bearings are required for the turboexpander. This article describes a comparative study on various kinds of gas journal bearings for the turboexpander. The aim is to find a suitable bearing which can provide adequate stiffness to the turboexpander rotor for all operating scenarios. The variation of stiffness characteristics (direct as well as cross-coupled component) with shaft eccentricity direction and shaft speeds are compared for different bearings.

Key words: Dual-mode air separation plant, high speed turboexpander, journal bearing, gas bearing

Development and testing of joints in high temperature superconducting power cable

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The development of long length HTS power cables require joints between HTS tapes and former, HTS cable and current leads of termination units, and also between two separate HTS cables. These joints should offer minimum electrical resistance which is the fundamental need for power transmission using superconductors. This paper explains the jointing techniques utilized in the setup for India's first seven-meter-long HTS power cable rated at 11 kV and 1 kA. Initially, the joints between the HTS cables and that between the cable and current leads were produced using simple soldering method with low temperature solder materials. However, this resulted in an increase in the net circuit resistance (6 mΩ) and undesirable boil-offs while operation of the cable. The issue was resolved by using HTS jumper tapes across the joint, thus bringing the net circuit resistance to within 0.1 mΩ and observable reduction in boil-off, increasing the duration of experiment from 170 minutes to 240 minutes for the same volume of LN_2 used.

Key words: Current leads, HTS power cables, Joint box, Jointing techniques

Extraction of high purity oxygen using waste gas recovery of existing liquid nitrogen plant

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The Stirling cycle-based liquid nitrogen plant incorporates the carbon molecular sieve-based Pressure Swing Adsorber(PSA) system to extract the nitrogen gas from the compressed atmospheric air condensed in the Stirling cryo-generator. However, the waste gas from the above PSA system is oxygen-rich nitrogen gas. It is an attempt to recover the above oxygen-rich waste gas and separate the enriched oxygen gas for medical use without affecting the production of the Stirling liquid nitrogen plant. The waste gas at room temperature is collected, condensed and distilled using a cryogenic distillation column. The above concept was successfully demonstrated in a prototype setup at the Low Temperature Facility (LTF) of Tata Institute of Fundamental Research (TIFR), Mumbai, which can produce 83 to 85% pure oxygen using waste gas capture techniques. The ongoing work is to enhance the oxygen purity above 90%, enhance the yield of liquid oxygen, and optimise the liquid nitrogen consumption. The paper presents the methodology and techniques adapted to achieve the unique possibility of extracting oxygen from waste gas without affecting the performance of the existing liquid nitrogen plant

Key words: Stirling Cryo-generator, Condenser, Liquid Air, Cryo-Distillation, Oxygen

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Design and manufacturing of ITER cryolines and warmlines: an Indian contribution

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The span of around 3.5 km which is two-third of total network of ITER cryolines and 5.2 km of ITER warmlines have been designed and manufactured in India. The cryolines for ITER has been designed to meet constraints like thermal budget of 0.25 to 1.5 W/m for 4 K lines & 2 to 7 W/m for 80 K lines and unique load cases such as insulation vacuum loss, incidental pressurization, seismic events, etc. The warmlines operates at ambient temperature, whereas few of them operate at elevated temperature during nominal operation mode. Strict manufacturing controls and conditioned manufacturing environment have played a critical role in meeting functional, safety, quality and regulatory requirements. The paper outlines the experiences and key challenges perceived during the various phases of design and manufacturing of captioned cryolines and warmlines as well as the approach towards meeting the overall requirements. The experiences gained during the design and manufacturing of cryolines and warmlines have been conducive for acquiring and accomplishing similar tasks with developed Indian resources.

Key words: ITER Cryolines, warmlines, design, manufacturing

VECC penning trap operation at Cryogenic temperature

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In a Penning trap, charged particles reside in a dynamic confinement in 3D space by a time-independent homogeneous magnetic field and a quadrupolar electro-static potential, undergoing axial, cyclotron and magnetron harmonic motions. The precision measurements of the frequencies of these harmonic motions provide information on several fundamental properties of the trapped charged particles, such as mass, g-factor etc. However, such high precision measurements become possible only at ultra-low electronic noise conditions achievable at 4K. The present configuration of the VECC, Penning trap assembly comprises a 5-electrode cylindrical trap and two annular magnets providing a magnetic field of ~0.1T. The detection electronics comprising a helical resonator and a low noise cryogenic amplifier followed by the electronics to detect the weak beat signal were developed at VECC, Kolkata. The trap signal and its characteristics were observed and studied at 4K. The challenges in operating the Penning Trap at 4K are presented here.

Key words: Penning trap, resonant detection, helical resonator, cryogenic amplifier, cryogenic electrical feed through

Magnetic shield effect for 8 MW high temperature superconducting synchronous motor

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The airgap topology based High Temperature Superconducting (HTS) Synchronous motors have reduced size and weight compared to similar MW rating conventional motors. This is due to unprecedentedly higher magnetic flux densities produced by superconducting rotor pole coils in the airgap of the motor. These HTS synchronous motors have ferromagnetic material based annular magnetic shield over the airgap based stator windings. This magnetic shield not only shunts the working magnetic flux of the motor, but also plays a key role in determining the radial and tangential magnetic flux at airgap which is one of the key inputs for electrical design of HTS synchronous motor. In this paper, the effect of absence and presence of magnetic shield on airgap magnetic flux densities and on maximum perpendicular magnetic field on HTS tape of pole coil of an 8 MW HTS synchronous motor is studied with the help of FEM simulation.

Key words: Magnetic Shield, HTS Synchronous Motors, FEM, Flux Density

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Comparative study and sensitivity analysis on different coil design approach for 1 T HTS extremity MRI magnet

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A comparative study for 1.0 T magnet containing double pancakes (DPs), for extremity MRI was carried out by taking two distinct coil design approaches (Multi-coil and Compensate solenoid) with COMSOL Multiphysics. The DP coils were made up with 4 mm wide 2G-HTS tape manufactured by SuNAM (SCN04200). The magnet was operated at 50 A and 65 K with parameters such as inner diameter, outer diameter and magnet length that were restricted to 200 mm, 500 mm and 350 mm respectively. A field homogeneity of 50 ppm over a diametric spherical volume (DSV) of 80 mm has been selected for both design approaches. The major parameters such as peak axial and radial field, 5G stray field, magnetic field inhomogeneity, length and outer diameter of magnet and total consumption of HTS tape are compared for the best configuration of two design approaches. Also, a sensitivity analysis corresponding to the field homogeneity is performed by varying the 1 turn in the constituent DP coils.

Key words: HTS Magnet, Multi-Coil Design, Compensated Solenoid Design, Homogeneity

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Analysis of active pressurization methods for a cryogenic propellant tank

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A numerical study was conducted on active pressurization methods of a cryogenic liquid hydrogen tank used in the upper stage of a space launch vehicle. SINDA/FLUINT program which integrates complex flow and conjugate heat transfer problem was used for the study. The study encompasses four different ullage pressure control schemes and brings out the merits and demerits of each, considering output parameters such as pressurant mass requirement, pressurant temperature and tank pressure variations. The model was validated with fight-recorded data of ullage pressure. Each scheme is unique in the manner of their coupling between the pressurization system components like heat exchanger, control valves and active control orifices. The study shows that pressurant temperature and, consequently, the heat exchanger configuration is critical in maintaining the tank pressure within the required levels.

Key words: Pressurization system, cryogenic, ullage, control orifice

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Numerical modelling of a pressure wave refrigerator

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A pressure wave refrigerator (PWR) is an unsteady flow device that uses shock waves and rarefied waves to generate refrigeration. The working principle of a PWR is similar to that of a standard shock tube. High-pressure gas is injected periodically into a stationary receiving tube through a rotary valve. A shock wave is formed at the injection point that moves forward, and at the same time a rarefied wave travels backwards, producing refrigeration. In this paper, a two-dimensional numerical model is developed using Ansys Fluent™ (version 19.2) to analyse a PWR. The numerical model is validated with the experimental data available in literature. Studies have been conducted under varying parametric conditions such as length of the stationary receiving tube, rotational speed of the rotary valve, and inlet over-pressure. The performance of a PWR is adversely affected by the reflected shock wave. A damping tank with a restrictor is placed at the end of the receiving tube for attenuating the reflected shock waves. These results will help us understand the behaviour of a PWR and the critical issues in designing such a system.

Key words: Pressure wave refrigerator, shock wave, expansion wave, CFD simulation

Thermal performance assessment of tungsten based magneto-resistive heat switch at different oblique plane angles for space application

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Cryogenic heat switches are critical components of many space cryogenic systems. These heat switches are commonly used to control heat flow between two surfaces and are classified into many categories. Among them, a magneto-resistive heat switch (MRHS) is used for controlling the heat flow at a very low temperature of below 10 K. Tungsten is the material for magneto-resistive heat switch due to its lower critical (T_c = 0.015 K) and high Debye temperature (310 K).Tungsten-based magneto-resistive heat switch (MRHS) works on the principle of controlling the heat flow at an applied magnetic field. This makes it suitable for space applications where there is a need for regulating the heat flow at a cryogenic temperature of below 10 K. So, in the present study, the thermal performance of MRHS at different oblique plane angles in detail by developing an analytical model. Initially, an analytical model is developed using conductivity tensors for predicting the thermal conductivity on three mutually perpendicular planes (X, Y, Z) passing through a point and then finding expressions for thermal conductivity on different oblique planes. Later, the developed model was compared with the experimental data available in the literature and observed reasonable agreement with a maximum possible error of 8.30 different angles in the Tungsten material of the magneto-resistive heat switch is analyzed in detail using temperature, magnetic field, and switching ratio as performance parameters. Further, it is realized that the developed model procedure can be adopted to assess the thermal performance of different heat switches used for space applications.

Key words: Low Temperature; Magnetic field; Switching ratio; Analytical model; Magneto-resistive material; Thermal performance

Enhancement in energy resolution of silicon surface barrier detector at low temperature

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Silicon Surface Barrier detector has been used to study the invariance of alpha decay rate under lattice compression using unstable Astatine ions implanted in different catcher foils. To study the change in alpha decay rate with high precision, it was necessary to achieve a good energy resolution of the detector. The detector and preamplifier were placed inside the vacuum chamber and cooled up to 213 K. An enhancement in the energy resolution of Silicon Surface Barrier detector has been achieved from 110 keV at 300 K to 40 keV at 213 K for 5869.5 keV alpha line.

Key words: Cryogenics, Silicon Surface Barrier detector, Energy resolutions, Decay rate, lattice pressure

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Development of lab scale conduction cooled HTS magnets

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The compact high temperature superconducting (HTS) magnets are promising candidates for high field applications. The development of a HTS magnet includes bending of tapes at a radius greater than the critical bending radius for winding, stacking of double pancakes, inter-turn and ground insulation, optimization of inter-double pancake and terminal joints, mechanical support against expected electromagnetic forces and appropriate cooling mechanism for stable operation at desired magnetic field. HTS magnets of inner bore diameter ~50 mm having two double pancakes and an inter-double pancake joint are manufactured and tested down to 10 K and produced central magnetic field up to 1 T. The double pancakes of these magnet winding packs are manufactured with insulated and non-insulated HTS tapes, using an in-house developed winding machine. Commercial BSCCO (thickness 0.2 mm) and REBCO (thickness 0.14 mm) HTS tapes of width ~4 mm have been used for the winding packs of these magnets. The optimized inter-double pancake (IDP) hybrid joint resistance of ~47 nΩ at 10 K, self-field is achieved for 0.1T magnet. The development of winding pack processes, optimization of IDP joint resistance, testing procedures and test results of HTS magnets are detailed out in this paper.

Key words: HTS magnets, joints, critical current, magnetic field, winding

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Machine learning algorithms for two-phase heat transfer and pressure drop estimation for Joule Thomson Cryocoolers

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Mixed Refrigerant Joule Thomson (MRJT) Cryocoolers operating with Nitrogen Hydrocarbon (N2-HC) mixtures are quite popular for low-temperature applications in the range of 80-230 K. MRJT cryocoolers require very high effectiveness heat exchangers for the system to operate at the design temperature. Estimation of two-phase heat transfer coefficients and two-phase pressure drop is critical for the design of heat exchangers used in MRJT cryocoolers. The application of machine learning algorithms is quite promising in the estimation of two-phase heat transfer coefficients and pressure drop even though they are applicable for a limited data range. In this paper, Artificial Neural Networks (ANNs) are used to regress the two-phase heat transfer and pressure drop for the experimental data available in the literature. A large data set containing more than 10,000 data points are taken from literature and a part of the data is used for training the ANN and another part is used for validation. The results are compared with experimental values as well as existing conventional methods. The mean magnitude of relative error (MMRE) of proposed models with experimental data is presented.

Key words: ANN, Cryocoolers, two-phase heat transfer, pressure drop, mixed refrigerants

Numerical simulation of high temperature gas condensation in a flowing Cryogenic liquid for semicryogenic engine applications

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Condensation of high-temperature gaseous oxygen, on mixing with sub-cooled liquid oxygen flowing in a curved pipe, is studied using CFD simulations. The present configuration of two-phase flow is encountered in the booster pump exit line of liquid oxygen-kerosene rocket engine. The turbine driven hot gas, which is mostly gaseous oxygen, is mixed with liquid oxygen at the exit of the booster pump and subsequently condenses downstream. The gaseous oxygen has to be fully condensed before reaching main pump inlet to avoid performance degradation of main pump. The present study investigates the two-phase flow behavior and heat transfer characteristics associated with the condensation of gaseous oxygen mixing with liquid oxygen. Effect of liquid subcooling in the range of 20K - 50K on the gas condensation is investigated and presented.

Key words: Condensation, Sub-cooled flowing liquid, Cryogenic flows, CFD simulations

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8-Channel cryogenic temperature monitors with RS-232 interface & TRV data-logger

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A cost-effective 8-Channel Cryogenic Temperature monitor with an embedded RS-232 server & TRV data logger software has been successfully developed and tested at IUAC for the simultaneous measurement and logging of temperature, sensor-resistance, and sensor-voltage. This is a low-temperature device (4K to 350K) with multi-sensor support. These are recently developed for building a new distributed, 40-channel Linac thermometry and 8-channel vacuum monitoring application at IUAC. Each channel of this device can be independently configured as a Temperature or Resistance or Volt (TRV) meter using a front-panel keypad. It also offers various features like an ethernet interface, flash storage, multiple calibration curves, implementation of custom curves, a VFD display, 8 fast voltage outputs, and distributed connectivity directly to the Cryogenics control room. Each channel has 3 independent current sources (a total of 24, configured from 10 uA to 2 mA). This feature is helpful to study the self-heat effects of sensors for a variety of sensor calibration applications. The low-temperature measurement, which ranges from 4.2K to 350K, supports a wide range of sensor-curves for Silicon diodes (DT470 & DT670), Pt100, Pt1000, Carbon ceramic sensors, and any new custom sensor, etc. A 12-bit A/D converter reads sensor inputs. 6 such devices have been deployed near beam hall. A 48-channel PC-based data logger software with unlimited historical trends and a real-time viewer for the acquisition of temperature/resistance/voltage parameters are also developed. Hence these new TRV devices are now placed far off from the radiation areas (Linac beam hall) for quick access and also far from the control room (nearly 50 meters away from the device). Besides their low cost, these devices can be used in place of M/s Lakeshore 218 models in low accuracy applications as an import substitution in the future.

Key words: Cryogenics, RS-232, Data logger, Acquisition, Sensor

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Development of a distillation column for a dual-mode LOX-LIN plant at BARC

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A dual-mode air separation plant producing either liquid oxygen (LOX) or liquid nitrogen (LIN) using a common single distillation (rectification) column for both the LOX and LIN modes, is conceptualized by BARC. The present work describes the sizing & optimization of a packed bed distillation column for LOX & LIN modes of operation. The basic calculation of the number of theoretical stages is a precursor to a more detailed analysis of a packed bed column using the HETP & HTU-NTU methods employing correlations for mass transfer coefficients. The results from the cryogenic process calculations act as inputs for the design of the column. A single, optimized column catering to all possible modes of operation provides flexibility and compactness, increases plant availability and at the same time reduces capital cost.

Key words: Dual-mode air separation plant, rectification, packed bed, HETP, HTU, NTU

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Effect of magnetic fields due to electric currents in an HTS power cable and estimation of stress

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Second generation High Temperature Superconducting (HTS) tapes are generally wound around a former in a helical manner for HTS power cables. The high current flowing through the individual tapes results in a magnetic field around each tape. The effect of the magnetic field is attraction between the tapes resulting in forces induced by each tape on its neighbors. The stresses induced may result in reduction of the critical current of the tapes thus degrading performance of the HTS power cable. The objective of this study is to numerically analyze the effect of magnetic fields as a result of electric current flowing in the cable and estimate the stresses in the cables. A parametric study with different pitch winding angles and different electric currents has been carried out to determine the stresses induced inside the HTS tapes.

Key words: Magnetic field, HTS tapes, HTS power cables, stresses

Investigation of helium flow impedance issues in the capillary based experimental cryostats

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The helium flow impedance is one of the hassles that occasionally occurs in the capillary-based experimental setups of commercial and homemade systems due to the choking of impurities in its fine capillary tubes, thus creating a problem with cooling below 4.2K. The capillary-based systems such as SQUID, PPMS, VSM, STM, and 4He VTI experience such clogging issues. Usually, this clogging is attributed to the trace amounts of hydrogen in the liquid helium. This clogging demands the warming up of the entire experimental system, followed by flushing and purging with high-purity helium gas to restore its normal performance. Despite warming up and cooling down, this clogging issue cannot be overcome entirely and gets repeated in a few days. Frequent warming up of the sensitive experimental setup having a superconducting magnet is a painful and laborious job, leading to cryostat downtime and the substantial quantity of expensive liquid helium in re-cooling it. The paper presents in-depth details on the detection techniques of hydrogen traces in the helium gas stream and the methodology adopted to rectify the helium-flow impedance issue cost-effectively, which has worked without the reoccurrence of capillary blockage issues since 2016.

Key words: Liquid Helium, Flow Impedance, Capillary, Clogging, Hydrogen

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Numerical analysis of the effect of nanoparticles on thermal characteristics of biological tissue during a cryosurgery

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In the present study, different types of nanoparticles, such as Au, Fe_3O_4, and Al_2O_3, have been considered. This problem has been simulated using the ANSYS Fluent 18.1 version of the CFD software package. The three-dimensional cubical shape of biological tissue with a single cryoprobe has been considered in the present study. First, the current numerical results have been verified with the results available in the literature under the same operating conditions. Then, the grid-independent study was performed to select the optimum grid size. After that, the effect of earlier mentioned nanoparticles on the ice–ball formation and temperature distribution inside the biological tissue have been investigated to select suitable nanoparticles. The effect of the volumetric concentration of nanoparticles is also studied. A comparative study between the biological tissue with and without nanoparticles has been conducted. The present study may help to improve cryosurgery's efficacy.

Key words: Cryosurgery, biological tissue, Cryoprobe, Ice ball, and Nanoparticles

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Performance evaluation of sintered and stacked mesh regenerator for stirling cycle based LN2 plant

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The Stirling type Cryogenerator for Liquid Nitrogen facility consists of a regenerative type of heat exchanger (Regenerator). The regenerator isa Stainless-Steel wire mesh stack sintered at a high temperature. The regenerative heat exchangers are prone to impurity accumulation in the porous region due to wear and tear of the sealing and guide rings from the neighboring components throughout the operation, resulting in a decrease in the capacity of liquefaction. In view of this, the regenerator must require cleaning regularly. As tried in our laboratory, the impurities are difficult to remove entirely from the porous region. As a result, the regenerator mustbe replaced with newones once it gets saturated with contaminants. At present, such regenerators require import at a substantial cost in foreign exchange. This work aims to manufacture such a sintered regenerative heat exchanger in our laboratory and test its performance. The present work involves the fabrication and sintering of SS wire mesh, assembling it in the liquid nitrogen Cryogenerator and monitoring liquefaction performance. Also, testing and comparison of stacked mesh regenerator against the sintered regenerator

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

Performance prediction of cryogenic/semi-cryogenic rocket engines by using multi-sensor data fusion techniques

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This paper proposes a computational technique for predicting the performance of a liquid rocket engine under varying operating conditions using ten sets of ground test data. Measuring various parameters from multiple location points during a ground test generates a significant amount of data, and the proposed technique aims to reduce the number of ground tests, especially for semi-cryogenic and cryogenic rocket engines. The technique employs multi-sensor data fusion (MSDF) to combine data from multiple sensors and extract unique features that cannot be achieved using the data from a single sensor. The paper provides a tutorial on data fusion applications and process models and their application to rocket engines. The proposed data fusion technique can effectively study the dynamic response of the engine and predict missing data or unknown values. The paper uses a deep neural network, specifically a long short-term memory-Recurrent neural network (LSTM-RNN), to analyze sample data from ISRO and predict the thrust of a rocket engine. The comparison with measured data shows an accuracy of around 97-99 percent.

Key words: Deep neural networks, Multi-sensor data fusion, rocket engine performance, Subsystems, LSTM-RNN

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Cryogenic characterisation of polyurethane foam for thermal insulation of cryogenic tanks of launch vehicles

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PUR foam was characterized for density, thermal conductivity, compressive and tensile strength. Among these properties, compressive and tensile strength were evaluated at 300 K, 77 K and 20 K. Results indicated that density of PUR foam in the range of 31 to 35 kg/m^3 with a compressive strength of 2.0 to 2.5 ksc was obtained. Thermal conductivity of PUR foam was in the lower range of 0.030 to 0.035 W/mK, making it suitable choice for thermal insulation. Thermal stability was analysed using thermogravimetric analysis and the PUR foam was stable up to 220 ^{o}C. Specific heat of PUR foam was obtained in the range of 1200 – 1400 J/kgK. Low temperature characterization indicated that compressive strength is ranging from 5.0 to 8.0 ksc. This effect may be due to the higher stiffness of PUR foams at cryogenic temperatures, making it suitable for thermal insulation of cryogenic tanks in launch vehicle applications.

Key words: PUR foam, cryogenic, insulation, space, launch vehicle

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