The Science of Deep Cryogenic Treating of Metallic and some Non-Metallic Materials

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Deep Cryogenic Treating (processing of metals below –244°F) is making serious inroads into both consumer and industrial markets. Some of its applications defy the conventional logic that the only affect it has is to convert retained austenite to martensite. A striking application that illustrates this is the treatment of automotive brakes. Common brake rotors are pearlitic cast iron, without austenitic content. Yet test after test by independent laboratories have shown that cryogenic treatment increases the life of a brake rotor by a factor of two to four times. In a similar manner, carbide cutting tools, mechanical gears and electronics, some plastics, all show interesting effects that are not supported by the conventional theories as to why the process works.

This paper will summarize some of the recent research done world wide, will announce a data base of research created and maintained jointly by ASM and the Cryogenic Society of America. Also the common work done by Air Liquide U.S. LP and Controlled Thermal Processing, Inc. will be explained.

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Influence of cobalt on the cryogenically treated W-Mo-V high speed steel

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The presence of cobalt in high speed steels is of great interest to researchers and the users as well. Although cobalt bearing high speed steels is used on commercial basis, the influence of cobalt in cryogenically treated high speed steels is still under scanner. Some researchers have found the effect of cobalt as negative, as it adversely affects the wear properties and fracture toughness of some high speed steels under certain conditions.

This paper takes a review of influence of cobalt in tool steels with respect to the past research and discusses the experimental results of the effect of cryogenic treatment on 10%Co bearing AISI T42 high speed steel. It has been found that this steel has an advantage due to the presence of Cobalt with respect to wear characteristics after the cryogenic treatment. It is also found that the cycle time of cryogenic processing of this super high speed steel shortens due to the presence of cobalt.

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On electrical resistivity of AISI D2 steel during various stages of cryogenic treatment.

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ABSTRACT

The effect of dislocation densities and residual stresses is well known in tool steels. Measurement of electrical resistivity in order to monitor dislocation densities or residual stresses has seldom been used in investigating the effect of Cryogenic treatment on tool steels.

Monitoring residual stresses during cryogenic treatment becomes important as it is directly related to dimensional stability of tool steels. For high carbon high chromium (HCHC- AISI D2) steels, not only wear resistance but dimensional stability is an important issue as the steels are extensively used in dies, precision measuring instruments.

This work comprises of study of measurement of electrical resistivity of AISI D2 steel at various stages of Cryogenic treatment. Use of these measurements in order to assess the dimensional stability of these steels is discussed in this paper.

TESTING MATERIALS FOR USE IN HIGH PURITY LIQUID ARGON DETECTORS

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Liquid Argon Time Projection Chambers (TPCs) show promise as scalable devices for the large detectors needed for long-baseline neutrino oscillation physics. Over the last several years at Fermilab a staged approach to developing the technology for large detectors has been developed. A Materials Test System (MTS) cryostat has been operated at Fermilab for several years. The TPC detectors require ultra-pure liquid argon with respect to electronegative contaminants such as oxygen and water. The tolerable electronegative contamination level is equivalent to 30 parts per trillion of oxygen. The MTS cryostat has the capability to insert proposed TPC detector materials into argon liquid or vapor and measure the electronegative contamination effect of the material. This paper describes development and operation of the MTS cryogenic system, the material test results, and the implications for selection of materials for TPC fabrication.

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Thermal performance of an exchange-gas vibration isolation system for a general-purpose 4K research cryostat

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It is well known that extraordinary levels of vibration isolation from the noise of mechanical cryocoolers can be obtained in small cryostats using 1-atm helium exchange gas combined with a soft bellows. This technique has been used successfully by others in a number of small, special-purpose research and commercial cryostats, enabling, for example, Mossbauer spectroscopy below 5K with a Gifford-McMahon cooler. Our group has an ongoing project to implement this technique in a general-purpose research cryostat, with the long-term goal of achieving vibration performance comparable to the best vibration-isolated helium bath cryostats while maintaining adequate 4K working volume, cooling power, and base temperature. In this report we describe the design, thermal performance, and some operational details of a cryostat incorporating a compact exchange-gas envelope and heat exchangers constructed around a Cryomech PT405 0.5W/4.2K pulse-tube cryocooler. This cryostat is in regular use in our lab and performs well, cooling a large shielded 4K working volume (~35 L) containing a heavy iron-shielded superconducting magnet (total metal at 4K ~20 kg) from room temperature to 4K in about 24 hours, achieving base temperatures <3K (condensing the helium), and maintaining temperature≤ 4.8K for an externally-applied heat load of 0.5W.

Possible approaches to the active electrically small antenna design

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The electrically small antenna (ESA), i.e. antenna with a size that is much less than one wavelength, is very attractive for many applications due to the small antenna size and the wide bandwidth. Next critical step is the development and implementation of an active ESA. This promises a substantial improvement of all characteristics of the antenna including solution of the matching problem. Possible approaches to design of the active superconductor ESA are reported and discussed in detail. Two types of the antenna circuit elements having linear magnetic field to voltage transfer function are proposed and evaluated experimentally. The elements are bi-SQUID and pair of parallel SQIFs connected in differential way. Series array of the elements are used to increase output signal and dynamic range. Prototype of the active superconductor ESA has been fabricated using Nb technology and experimentally evaluated. Flux transformer contribution and the achievable antenna sensitivity are analyzed.

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Cooling system for a frame-store pn-CCD detector for low background application

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The astroparticle physics experiment CERN Axion Solar Telescope (CAST) aims to detect hypothetical axions or axion-like particles produced in the Sun by the Primakoff process. A Large Hadron Collider (LHC) prototype superconducting dipole magnet provides a 9 T magnetic field for the conversion of axions into detectable X-ray photons. After leaving the magnetic field these photons are detected with an X-ray telescope and a novel type of frame-store CCD (charge-coupled device) detector installed in the focal plane of the X-ray optics and built from radio-pure materials. A cooling system based on cryogenic heat pipes filled with krypton and made out of oxygen-free and radiopure copper has been built using a Stirling cryocooler as cold source. The system provides an efficient thermal coupling between the cryocooler and the CCD chip. The CCD can be kept at stable temperatures between 150 and 230 K with an accuracy of 0.1 K. In addition a graded-Z radiation shield, also serving as a gas cold-trap operated at a temperature of 120 K, is implemented to reduce surface contamination of the CCD entrance window to a minimum and to suppress background radiation. This paper describes the cooling system design and the experimentally obtained heat transfer characteristics of the heat pipes with optimized fluid quantity. The overall performance of the complete cooling system is presented.

Experimental Verification of a Precooled Mixed Gas Joule-Thomson Cryoprobe Model

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Cryosurgery is a medical technique that uses a cryoprobe to apply extreme cold to undesirable tissue such as cancers. An effective cryoprobe maximizes cooling power while maintaining a small and therefore ergonomic and noninvasive envelope. Precooled Mixed Gas Joule-Thomson (pMGJT) cycles with Hampson-style recuperators are integrated with the latest generation of cryoprobes to create more powerful and compact instruments. Selection of gas mixtures for these cycles is not a trivial process; the focus of this research is the development of a detailed, component level optimization model for selecting optimal gas mixtures. A test facility has been constructed to experimentally tune and verify this model. The facility uses a commercially available cryoprobe system that was modified to integrate measurement instrumentation that is sufficient to determine the performance of the system and its component parts. Detailed measurements of the heat transfer within the recuperator enable computation of the spatially resolved conductance, which can be used to study the multiphase, multi-component heat transfer process in the complicated recuperator geometry.

The test facility has been used to compare the experimental performance of the system with the predicted results from the pMGJT model over various mixture compositions (R14/R23/argon), charge pressures, mass flows, and operating temperatures. A gas chromatograph is used to monitor the composition shift caused by preferential absorption in oil and condensation in the test facility. The measured and modeled recuperator conductance and Joule-Thomson effect temperature change (ΔT_{JT}) are compared to demonstrate the predictive capability of the model.

Hydrodynamic and thermal effects of drag and heat transfer coefficients under laminar unsteady flow conditions in porous media

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Solid-fluid thermal interactions during unsteady flow in porous media play an important role in the regenerators of pulse tube cryocoolers. Pore-level thermal processes in porous media under laminar unsteady flow conditions have recently been quantified and have been shown to produce significantly larger heat transfer coefficients compared to those in steady flow[1]. Therefore, the objective of this investigation was to study the pore-level hydrodynamic and thermal phenomena during pulsating and unidirectional sinusoidal flow through a generic, two-dimensional porous medium by numerical analysis. Furthermore, an examination of the effects of flow pulsations on the drag and heat transfer coefficients that are encountered in the standard, volume-average energy equations for porous media were determined. The investigated porous media are periodic arrays of rectangular cylinders. Detailed numerical data for the typical 75% porous configuration, with flow pulsation frequencies of 20, 40, and 80 Hz were obtained at Reynolds numbers ranging from 0-1000. Based on these numerical results, the instantaneous as well as cycle-average drag coefficients and heat transfer coefficients, to be used in the standard unsteady volume-average momentum and energy conservation equations for flow in porous media, were derived.

[1]Pathak, M.G., and S.M. Ghiaasiaan (2011). "Convective heat transfer and thermal dispersion during laminar pulsating flow in porous media." *International Journal of Thermal Science,* to appear.

Ideal Thermodynamic Processes of Oscillatory-flow-based Regenerative Engines Will Go to Ideal Stirling Cycle?

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In 1816 Mr. Robert Stirling invented so-called Stirling heat engine. It is long-time thought that the ideal thermodynamic cycle of the Stirling engines is comprised of two isothermal and two isovolumeric thermodynamic processes. To realize the four thermodynamic processes, not only strict movement relationship between compression and expansion pistons must be made but also some additional control on working gas must be given. In recent years, thermoacoustic heat engines without moving mechanical partS have been studied intensively to relieve the difficulty of mechanically driven Stirling machines.

This paper analyzes the thermodynamic cycle of Stirling and thermoacoustic heat engines. Unlike the classical analysis of thermodynamic books, the assumptions for pistons' movement limitations are not needed in our present analysis and only ideal flowing and heat transfer should be maintained. Under such simple assumptions, the meso-scale thermodynamic cycles of each gas parcel in different thermodynamic component are analyzed. It is found that the gas parcels undergo Lorentz cycle in different temperature levels, whereas the locus of all gas parcels is the Ericson cycle. Based on this new finding, the author clearly pointed out that the thermodynamic cycle of ideal "Stirling" and thermoacoustic heat engines is not the Stirling cycle. Furthermore, this new thermodynamic cycle can still achieve the same efficiency of the Carnot heat engine and can be considered a new reversible thermodynamic cycle within two-temperature heat sources.

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Parametric Optimization Study Using REGEN3.2

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A parametric study using REGEN3.2 has been conducted to develop a set of design charts for a variety of common operating conditions of single-stage Stirling-type regenerative cryocoolers. By optimizing the COP over the set of variables including the cold end phase angle, mesh size, average pressure, pressure ratio, regenerator length, and mass flux for fixed values of cold end temperature and operating frequency, a set of optimized parameters are obtained at temperatures between 80 K and 35 K and with frequencies between 30 Hz and 1000 Hz. The results allow approximate optimized designs for temperatures and frequencies intermediate to those studied here via interpolation. In addition, changes in design as a function of cooling power at any of the fixed temperature, frequency points are enabled by a simple scaling relationship. Results of the model are compared with published cryocooler performance values.

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Numerical Simulations of Oscillating Flow and Heat Transfer in Porous Media Using Lattice Boltzmann Method

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A numerical study is performed for the oscillating flow and heat transfer in porous media using the lattice Boltzmann method (LBM), which is a new method of computational fluid dynamics. The regenerator is a very important component in cryogenic systems, and the structure of regenerator is one kind of porous medium. In the model of this article, the porous media was placed in the center of the two dimensional channel. The coupled lattice D2G9 Bhatnagar-Gross-Krook model is adopted in this study. The boundary treatment is the key step in the calculation process. The oscillatory flow in the channel is driven by a periodic pressure wave. Isothermal boundary condition of the channel wall is considered. Through the numerical simulation, the parameters including pressure, velocity and temperature values are presented in different locations of the channel with time in a whole period. The effects of Womersley number, Reynolds number and Mach number on the flow and heat transfer characteristics are investigated. The numerical experiments results demonstrate that the LBM can be served as a feasible and efficient method for oscillating flows through regenerator porous media, and LBM may be developed as a promising method for predicting fluid flow and heat transfer in pulse tube cryocoolers.

Keywords: Lattice Boltzmann method; Oscillating flow; Porous Media; Heat transfer; Numerical simulation; Womersley number.

A thermodynamic model for the effect of thermal boundary resistance on multistage thermoelectric cryogenic refrigerators

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New efforts are underway to develop thermoelectric materials for cooling of infrared detectors at cryogenic temperatures. In this study, a control thermodynamic model of multistage Thermoelectric (TE) cryocoolers is developed that includes the effect of heat transfer between the cryocooler and the thermal reservoirs as well as thermal resistance between the stages. It is assumed that a reservoir at 80 K is available and a cooling load at about 35 K, typical of the second stage of conventional cryocoolers, is desired. It is shown that under the assumption of availability of TE materials with a reasonably high figure of merit, a multistage TE cryocooler is required. As an example, a control thermodynamic model of a four-stage TE cryogenic refrigerator is developed. The effect of thermal conductance of the heat exchangers at the hot and cold sides of the refrigerator, the thermal resistance between the stages and the effect of the figure of merit of the TE material on the cooling capacity and efficiency of the multistage TE cryocooler is presented. The thermal design challenges of the development of multistage TE cryocoolers with high efficiency for cryogenic applications including the effect of heat leak are discussed.

Thermodynamic Analysis and Experimental Verification on a Novel Looped Pulse Tube Cryocooler

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Compared with the Stirling cryocooler, the pulse tube cryocooler has obvious advantage in reliability. In modern advanced pulse tube cryocoolers such as the inertance-tube pulse tube cryocooler, the reservoir is usually needed to help the inertance tube to obtain larger phase shifting ability. However, this relatively large volume reservoir makes the pulse tube cryocooler not to be as compact as the Stirling cryocooler, and this may loose the pulse tube cryocooler's competiveness in some applications in which the size and weight are highly concerned. To improve compactness, a looped pulse tube cryocooler without the reservoir was proposed in the paper. In the system, the reservoir of a typical inertance-tube cryocooler is eliminated. Instead, the inertance tube is directly connected to the backside of a linear compressor. To compare its cooling performance with that of the inertance-tube pulse tube cryocooler with a reservoir, the same core thermodynamic components including a linear compressor, main hot-end exchanger, regenerator, cold-end exchanger, pulse tube, and secondary hot-end exchanger are used in the both cryocoolers. Firstly, thermodynamic optimizations for the two systems' inertance tubes were made. The optimization results show that the looped cryocooler can achieve a similar or even better cooling performance as the traditional inertance-tube cryocooler. Then, the experiments on both cryocoolers driven by a same linear compressor were conducted to verify the above-mention theoretical analysis. In the experiment, 100Hz pulse tube cryocoolers were extensively tested. The experimental results are in good agreement with the optimization prediction.

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Numerical Analysis and Experimental Investigation of an Inertance Tube Pulse Tube Refrigerator

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Pulse Tube Refrigerator is the key focus of research in the cryocooler industries, owing to its simplicity in design and high reliability. Various phase shifting devices like orifice, inertance tube, double inlet mechanism, etc. are used to improve the performance of a Pulse Tube Refrigerator. Likewise, in an Inertance Tube Pulse Tube Refrigerator (ITPTR), the optimum phase shift between the mass flow rate and the pressure pulse is maintained using an inertance tube and a compliance volume. It is therefore very important to understand the fluid dynamics inside the pulse tube and the regenerator with respect to the intertance tube geometry. In the present work, a numerical approach is adapted to model the flow inside the system using one dimensional continuity, momentum and energy equations for gas and regenerator material. Using this technique, point by point information of all the primitive variables like mass flow rate, pressure and temperature can be obtained for an ITPTR. A finite difference technique along with appropriate boundary conditions is used to obtain the solution. The mass flow rate and pressure variations are assumed to be periodic in nature. Experimental results, obtained from the units developed in our laboratory, are compared with the numerical results.

Cryogenic Distribution for the Facility for Rare Isotope Beams*

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The Facility for Rare Isotope Beams (FRIB) will be a new National User Facility for nuclear science funded by the Department of Energy Office of Science and operated by Michigan State University. The FRIB accelerator linac consists of superconducting radio-frequency (SCRF) cavities operating at 2 K and SC magnets operating at 4.5 K all cooled by a large scale cryogenic refrigeration system. A major subsystem of the cryogenic system will be the distribution system whose major components will include a distribution box, the transfer lines and the interconnect valve boxes at each cryogenic device. An overview of the conceptual design of the distribution system including engineering details, capabilities and schedule are described.

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The 10kV High Tc Superconducting Power Substation

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A superconducting power substation has been successfully built in Baiyin City, Gansu Province. The substation consists of a 75m/10kV superconducting power cable, a 630kVA/10kV/400V superconducting power transformer, a 10kV superconducting fault current limiter and a 1MJ/500kVA superconducting energy storage system. In this presentation, the cryogenic system and the operation of the substation would be reported.

Second Law analysis of cryogenic transfer lines

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Simple or complex transfer lines are auxiliary elements present in any cryogenic system. The presently constructed transfer lines may comprise several process pipes filled with different fluids being in significantly different thermodynamic states. The heat that leaks to cold process pipes may significantly influence the thermal budget of the cryogenic system and in consequence the required supply power of the refrigerator. Transfer lines are multi-dimensional thermo-mechanical objects that can be thermodynamically optimized with the use of the Second Law analysis. This optimization must take into the account the strength of the line and its mechanical stability. This paper presents thermodynamic models of simple and complex transfer lines. The lines are split into a number of constructional nodes which enable calculations of entropy generated in elementary heat transfer and fluid flow processes. Transfer line elements and constructional nodes responsible for high rate of entropy generation are identified. Constructional solutions reducing the entropy generation within the mechanical constraints are proposed and discussed.

Preliminary system design and analysis of an optimized infrastructure for ITER prototype cryoline test

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The prototype cryoline (PTCL) for ITER is a representative cryoline of all the complicated network of cryolines for the project. The PTCL is being designed with four process pipes at temperature level 4 K, two process pipes at 80 K and will be manufactured in 1:1 scale with a configuration of straight, T, Z, Elbow and Curved sections including vacuum barriers. The test objectives are focused to demonstrate high quality level in engineering and manufacturing of cryolines as per the ITER functional requirements. The measured physical parameters will assess the confirmation for acceptable heat loads, stresses and mechanical integrity in normal, off-normal and accidental scenarios such as break of insulation vacuum etc. Therefore, the necessary infrastructure along with the control system have to be properly designed, analyzed and optimized within the imposed constraints to fulfill the test objectives. The PTCL will be tested at 4.5 K with scaled mass flow rate having the thermal shield at 80 K. Several options, to mentions a few (i) Using helium refrigerators (ii) Cooling directly with liquid helium (iii) Cooling up to 80 K with gaseous helium and then using liquid helium to achieve 4.5 K etc. have been studied and analyzed as well as compared to recommend the best suitable and optimized test infrastructure. General process flow diagram have been developed and analyzed for operating modes to support the logical approach. Option (iii) have been found the best suitable with an 80 K helium system having helium compressor and heat exchangers. The paper will describe the system approach along with instrumentations and controls, study results, optimization and its usefulness in the present context within the constraints of economics and time.

Forced flow supercritical helium in a closed heat transfer loop submitted to pulsed heat loads

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The superconducting magnets of the tokamak JT-60SA are cooled by means of forced flow of supercritical helium. Cold circulators generate the pressure head required for circulating the helium flow through the superconducting cables. The closed loops transfer heat from the magnets to the refrigerator through heat exchangers immersed into a thermal helium bath. An experimental loop was designed and scaled down to 1/20 of the volume, mass flow rate and the absorbed power of the JT-60SA central solenoid cooling circuit. This design for conserving the transit times in the helium pipes, aims at observing the thermally induced transients in the closed loop of the central solenoid circuit. Indeed the heating section simulates the variable loads coming from the magnet circuits. The supercritical helium loop is driven by a centrifugal helium pump with a nominal mass flow rate of 50g.s^{-1} at 4.4 K and 0.5 MPa. A series of experiments was performed with pulsed loads in isochoric loop: large pressure and temperature changes in the circulating loop were observed. The cold circulator could be characterized under pulse operation and its performances are addressed. Numerical models have been developed to compare with the experimental data. First regulations at the interface of the refrigerator were tested to smooth the pulsed loads with the liquid thermal buffer. Knowledge of the pulsed loads effects on the cryogenic components is important in view of a safe operation of the cryogenic system.

Adaptability of optimization concept in the context of cryogenic distribution for superconducting magnets of fusion machine

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Cryogenic distribution system (CDS) plays the vital roles for reliable operation of large-scale fusion machines in Tokamak configuration. Managing dynamic heat loads from the superconducting magnets, namely, toroidal field (TF), poloidal field (PF), central solenoid (CS) and supporting structure (STR) is the most important function of CDS along with static heat loads. Two concepts can be foreseen for the configuration of CDS: singular distribution and collective distribution. In the first concept, each magnet is assigned with one distribution box, in turn the sub-cooler bath. In the collective concept, it is possible to share one common bath for more than one magnet system. The preferred concept greatly depends on the dynamic heat load profiles with respect to plasma pulses. The present study has been made with the objective on the adaptability of the collective system with respect to the singular system in the overall process. The case study has been performed with dynamic heat load profile generated from the simulated plasma pulses and applied to both the concept in the same time domain. The choices of combination from the four systems, namely, TF, PF, CS and STR are also part of the study without compromising the system functionality. Process modeling and detailed simulations have been performed for both the options using Aspen HYSYS®. Multiple plasma pulses per day have been considered, so as to verify the residual energy deposited in the superconducting magnets at the end of the plasma pulse. Preliminary 3D modeling using CATIA® has been performed along with the first level of component sizing. The paper will describe the process models, simulation approach and 3D system realization as well as study results on the adaptability of the concept.

The experiments of 200-meter superconducting DC power cable in Chubu University and the estimation for longer cable cooling

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After the 200-meter superconducting DC power cable experimental facility had been completed in 2010, the experiments had been done twice in 2010. The cryogenic pipe was made mainly by the straight pipe to reduce the heat leak and the pressure drop of liquid nitrogen (LN2) circulation. The bellows pipe is used for the inner pipe of the cryogenic pipe to absorb the thermal shrinkage, expansion and bending, but its length is about 3% for the total length. The pressure drop is ~ 1 kPa for the flow rate of 10 liter per minute, and this value is almost one tenth of the other AC cable experiments. The terminals of the cable ends are movable to absorb the shrinkage of the cable in the cooling-down phase and the expansion in warming-up phase. The displacement of each movable terminal is about 300 mm, and the position of the terminal is controlled by the computer monitor system. The displacements of two movable terminals are not symmetry because the LN2 was flowed into the cryogenic pipe from the one-side terminal. The vacuum pumping of the cryogenic pipe is also important to realize high vacuum degree, and it reached to the order of 10^{-4} Pa without baking for 200-meter. In order to reduce the heat leak from the terminal, Peltier current lead (PCL) is used, and the PCL is also effective to balance the current of each HTS tape because the PCLs are connected to the individual HTS tape. We summary the results of two experiments and estimate the pressure drop for future long cable from the experimental data.

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Heat dissipation in accelerator superconducting cables with ceramic insulation in normal and supercritical helium

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In order to improve the heat transfer from superconducting cables to surrounding during raping rate or beam losses a ceramic insulation with high porosity was tested. Two experimental mock-ups with different values of compressive load – 10 MPa and 20 MPa for reproducing the mechanical and thermal conditions in superconducting cables were used. The experiments were performed at normal (T=4.23 K and p=1 bar) and supercritical helium conditions (T = 4.23 K and p = 2.0 to 3.75 bar). The volume dissipated heat in the conductor was changed in a wide range from 0.1 W m^{-1} to about 6 W m^{-1} of conductor length. The paper shows the first results of the temperature rise within the stack of cable as a function of heat load for the different thermodynamics helium conditions and the two different compressive loads. Results are also compared with previous results obtained with all polyimide insulation.

Heat transfer through cyanate ester epoxy mix and a trifunctonal epoxy (TGPAP – DETDA) electrical insulation at superfluid helium temperature

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In the framework of the European project, EuCARD, aiming at constructing a high magnetic field accelerator magnet of 13 T with Nb_3Sn superconducting cables, new electrical insulation are thermally tested. This technology will use "conventional" electrical insulation in combination with pressurized superfluid helium as coolant. Two materials, cyanate ester epoxy mix and a trifunctonal epoxy (TGPAP – DETDA) have been chosen as potential candidates. The knowledge of their thermal properties is necessary for the thermal design and therefore the samples have been tested in pressurized superfluid helium (He II) where heat is applied perpendicularly to the fibers between 1.55 K to 2.05 K. Overall thermal resistance is determined with temperature and compared with other electrical insulation systems used in accelerator magnets.

Effect of optimized Superfluid Helium flow at the inner coil face on Cooling and Stability in superconducting accelerator magnets

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For a future luminosity upgrade of CERN's Large Hadron Collider, improved cooling of the so-called inner triplet quadrupole magnets is required. A main issue in the design of the new magnets is an improvement of the effective heat removal from the windings. The present, rather limited heat deposition by beam loss, causes a small temperature rise at the conductors. However, in the new magnets drastically enhanced steady state beam loss will reduce the stability margin severely, asking for a much better thermal design. Heat removal through channels filled with superfluid helium is reasonably understood in simple 1D geometries. On the contrary, in more complex 3D systems, the heat flow through solid and porous materials and helium channels in combination with distributed heat sources is hardly explained. This work focuses on correct FEA modeling and simulation of conduction and flow in the few millimeters thick annular space between the inner layer coil windings and the beam pipe. The fundamental properties of superfluid helium show that the temperature distribution is strongly dependent on heat flux and therefore on the dimensions and the variations therein of the channel as well as on the spatial distribution of the heat source. Realistic boundary conditions are applied as well as the effect of improved heat transfer through a new cable- and ground insulation. A sensitivity analysis is conducted to identify the design drivers in the relevant temperature range from 2 to 10 K, thus including the phase transition from superfluid to normal helium, convection of normal helium and the phase transition to helium gas.

Solid cryogens to refrigerate bulk MgB_2 superconducting permanent magnets

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The need to refrigerate superconducting apparatus with an enough safety margin can be fulfilled by the use of a solid cryogen working at temperatures very far from its solid-liquid transition and lower then the critical temperature of the superconductor. We have tested as solid cryogen the nitrogen, to refrigerate MgB_2 bulk cylinders and plates, in order to simulate operative conditions that are faced in the superconducting permanent magnet applications.
We use an ad hoc Cryogenic Levitation Apparatus (CLA), firstly, to cool down at about 20K the superconducting system embedded in a container with liquid nitrogen and, afterword through the levitation apparatus, to leave up and isolate the superconductor and its container from the cold head of the cryocooler. This system allows to realize quasi-adiabatic conditions and gives the opportunity to measure the temperature increase in different geometries and isolation conditions. Several refrigeration mixtures, based on the solid nitrogen, are considered in order to improve the heat capacity of the refrigerant.

Introduction of the cryogenic system for our 220kV 800A saturated iron-core superconducting fault current limiter

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Cryogenic system is one of the key components for HTS equipment. For practical HTS power devices, such as cables and fault current limiters, their cryogenic systems have to have high efficiency, low fabrication and operation cost, and high reliability. We have been working on Saturated Iron-core Superconducting Fault Current Limiter (SCSFCL) for years. We had a 35kV 1.5kA SCSFCL installed and commissioned for live-grid operation at the end of 2007. This year, we completed a 220kV 800A SCSFCL fabrication. This device will be installed at Shigezhuang substation in Tianjin, China for live-grid operation.

To design and build the cryogenic system for the 220kV SCSFCL, we put emphasis on operation stability, low investment, operation and maintenance cost, as well as electric insulation safety. As a result, a low heat leakage, compact, stable, open cryogenic system was built for the 220kV 800A SCSFCL.

The cryogenic system has two LN_2 containers. One is an annular cylindrical dewar housing the magnet. The other is a 10 stere industrial liquid nitrogen tank. Liquid nitrogen is periodically supplied from the tank to the dewar according to the level of liquid nitrogen in the dewar. Vaporized nitrogen is released into the air. The superconducting magnet works at about 77K in normal operation. A pump is used as backup for lower working temperatures.

In this paper, the design and the major parameters of the system are introduced. Some experimental data are also reported.

A Helium Thermosiphon Cooling Loop for the APS Superconducting Undulator

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A thermosiphon cooling system is being pursued as part of the superconducting undulator magnet development at Argonne National Laboratory. Analyses carried out at the University of Wisconsin – Madison address several unique features for the helium-filled cooling loop including sub-cooling associated with the hydrostatic head, a heat load deposited primarily along the horizontal channel, and two-phase flow characterization at extremely low quality conditions. Results of the analyses are compared with experimental measurements of a full-scale cooling loop. Both the analyses and measurements address the design objective of maintaining the superconducting windings well below their current sharing temperature, by exploring the flow induced heat transfer to the single and two-phase regions of the helium cooling loop.

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Development and Demonstration of a Supercritical Helium-cooled Cryogenic Viscous Compressor Prototype for the ITER Vacuum System

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As part of the vacuum system for the ITER fusion project, a cryogenic viscous compressor (CVC) is required to collect hydrogenic exhaust gases from the reactor vessel and compress it to a high enough pressure by regeneration for pumping to the tritium reprocessing facility. Helium impurities that are a byproduct of the fusion reactions pass through the CVC and are pumped by conventional vacuum pumps and exhausted to the atmosphere. Before the development of a full-scale CVC, a representative prototype was designed, fabricated, and tested. With cooling provided by either cold helium gas or supercritical helium, hydrogen with trace amounts of helium gas was introduced into the central column of the cryocondensation pump at 100 Pa and 80 K at flow rates of 8 mg/s. After the heat exchange between the two flow streams was benchmarked with an open stainless tube, comparison of the enhancement of the heat transfer through the addition of twisted tapes or an internal petal fin to the hydrogen/helium mixture was conducted. The thermal profile within the cold helium flow stream and the hydrogen/helium gas mixture was measured and utilized to determine the effectiveness of the heat exchange between the two streams. These results were also utilized in a computational fluid dynamics code to develop design parameters for the full-scale CVC.

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