MASTER

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A PRESSURIZED HELIUM II-COOLED MAGNET TEST FACILITY

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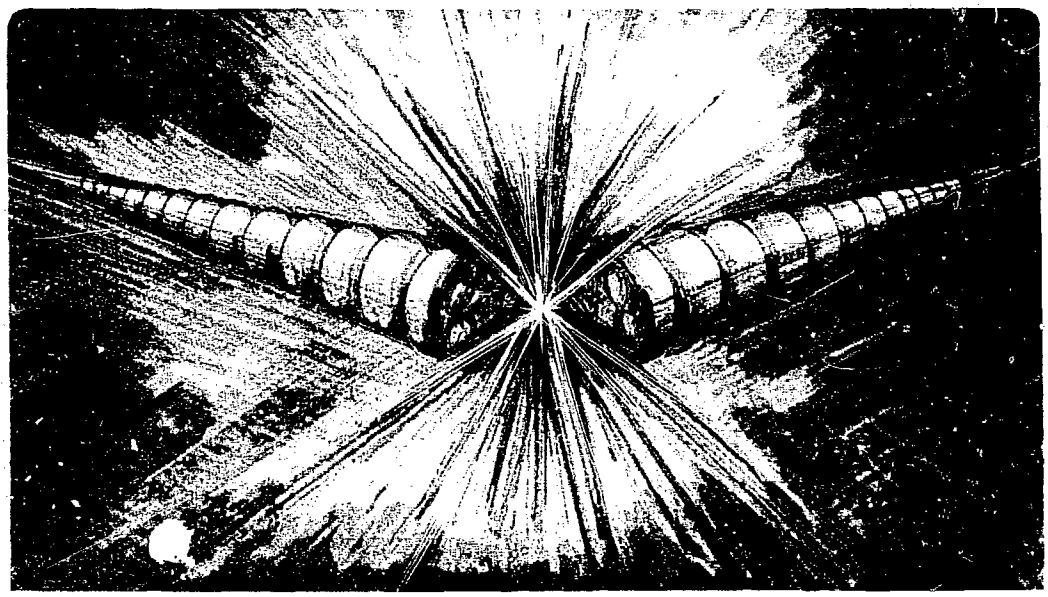

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A facility for testing superconducting magnets in a pressurized bath of helium II has been constructed and operated. The cryostat accepts magnets up to 0.32 m diameter and 1.32 m length with current to 3000 A. In initial tests, the volume of helium II surrounding the superconducting magnet was 90 liters. Minimum temperature reached was 1.7 K at which point the pumping system was throttled to maintain steady temperature. Helium II reservoir temperatures were easily controlled as long as the temperature upstream of the JT valve remained above T_λ; at lower temperatures control became difficult. Positive control of the temperature difference between the liquid and cold sink by means of an internal heat source appears necessary to avoid this problem. The epoxy-sealed vessel closures, with which we have had considerable experience with normal helium/vacuum, also worked well in the helium II/vacuum environment.

INTRODUCTION

A two reservoir system, similar in principle to that of Claudet (1974) and Bon Mardion (1976, 1978), is used. The magnet containing vessel, which is completely filled with liquid, is pressurized to slightly over one atmosphere by a saturated helium bath. This bath, which is located above and closely coupled to the magnet vessel, provides additional functions. It supplies coolant to reduce the lower vessel temperature below T_λ and intercepts the major conduction heat loads from the vessel supports, current leads, and instrumentation leads. Coolant for the lower vessel is withdrawn as a liquid at 4.4 K from the upper vessel, cooled in a counterflow heat exchanger, expanded across a JT valve to a low pressure and temperature, vaporized in a coil immersed in the lower reservoir, and warmed in the counterflow heat exchanger before exhausting to the vacuum system. This process can be followed on the flow schematic of Figure 1. This system is currently in use in support of our magnet development program which has a near term goal (one to two years) of an 8T, NbTi dipole magnet.

SYSTEM DESCRIPTION

The major system components are shown in the flow schematic of Figure 1 and the assembly drawing in Figure 2. The lower vessel is supported vertically from the upper vessel by the various tubular connections illustrated in Figure 2. The upper vessel is in turn suspended from the upper closure of the vacuum vessel. A liquid nitrogen cooled shield encloses these two inner vessels. The helium temperature shield which encloses the lower vessel in Figure 2 has not been used to date. It was felt that this shield, with the present combination of refrigerator and vacuum pump, would not reduce the total refrigeration load. However, if the refrigeration capacity were to be greatly increased without a corresponding increase in the vacuum pumping capacity, the use of this shield would be appropriate. Aluminized mylar insulation is used on the helium vessels and on the nitrogen shield. The two vessels are connected by a 50 mm diameter, teflon seated, relief valve. This valve incorporates a hollow center stem for pressure communication between the two reservoirs. A central rod with a stepped diameter can be moved vertically to change the cross section of the communi-

cation channel from 5 to 10 mm^2. When the enlarged diameter rod is fully inserted into the relief valve stem, the communication channel is restricted to a 0.032 m length of 5 mm^2 cross-section and a similar length of 10 mm^2 cross-section. When one-half is withdrawn, the 0.032 m length of 10 mm^2 cross-section remains. Since this channel is a major source of heat to the lower reservoir, the minimization of its cross section is desirable. The relief valve is spring loaded and will open fully for a differential pressure of approximately 2 bar. All electrical connections to the low temperature vessel are brought in through the upper vessel; this has two desirable results: the heat load is intercepted at the higher temperature, and electrical penetrations between the superfluid and vacuum are eliminated. Leads passing between the two vessels are sealed with teflon glands or, in the case of the instrumentation leads, with a bulkhead fitting. Any leakage is simply between the two vessels and is negligible in comparison to leakage via the communication channel. Each of the two parallel JT expansion valves is a commercial, bellows sealed, 1.4 mm diameter needle valve. Presently the valves are controlled manually, but in the future they will be driven by a proportionally controlled stepping motor. The JT heat exchanger is a counterflow unit in which the liquid follows a helical path created by the insertion of a threaded rod within an externally finned tube (longitudinal fins). The low pressure gas incurs only a very minor pressure drop while flowing on the finned side. Although measurements have not been made, calculations indicate this pressure drop is probably less than 0.1 mm Hg. The cold sink for the magnet vessel consists of a coiled 19 mm OD copper tube within which the low pressure coolant is vaporized. The outer surface of this tube is nickel plated to minimize the Kapitza resistance. The liquid level is maintained near the top of the upper vessel by a CTI model 1400 refrigerator/liquefier which is connected to this vessel by a coaxial transfer line. The refrigerator operates in a mixed mode and supplies both the 4 K refrigeration requirement as well as a liquefaction rate to match the flow through the cold sink. The vacuum pump used with this system is a 147 l/s (311 CFM) lobe type pump (Kinney 310) which, with the apparent 4 K refrigeration load, appears to be approximately the right match for the refrigerator. More liquefication capacity could be utilized during cool down and more vacuum pump capacity could be utilized at 1.8 K. At a cold sink pressure of 1330 pascal (10 torr) the cold sink flow is about 0.25 g/s, which is a refrigeration power of about 5 W. Temperature instrumentation uses carbon resistance thermometers (Lakeshore Cryotronics, carbon glass), as shown in Figure 1. A cold pressure transducer is located in the vacuum space and senses the lower reservoir pressure. A level gage (superconducting wire) indicates the liquid level in the upper reservoir. On both the upper and lower vessels, flanged end closures, with 4.4 or 1.8 K helium on one side and vacuum on the other side, are sealed with a minimum thickness of epoxy resin (50-50 mix of Shell 828 and Versamid 140).

SYSTEM OPERATION

The refrigerator cools the system from room temperature. During cool down, the relief valve connecting the two reservoirs is opened, allowing the coolant gas to flow into the lower reservoir. This gas is extracted from the bottom of the reservoir and returned warm to compressor suction. When a temperature of about 20 K is reached in the magnet, cold return flow is initiated in the coaxial return line with a gradual reduction of the warm return flow from the bottom of the lower vessel. When ~4.4 K is indicated in the bottom of the lower reservoir, the warm return flow is terminated. The warm return line is now either plugged with a plastic rod, which seats near the top of the lower vessel as shown in Figure 1, or used to transfer liquid from a storage dewar. When the system has been filled, the relief valve is closed and subcooling of the lower reservoir begins. Figures 3 and 4 illustrate some temperature histories for selected thermometers during two separate cool downs from room temperature taken during early runs in which the cool down rate was purposely kept low. The cool down time to 1.8 K was approximately halved in later runs. The early portion of the cool down is limited by the liquefaction rate of the refrigerator and by a desire to prolong the life of the ancient vacuum pump. The later part of the cool down, in which the vacuum pump is relatively lightly loaded, is limited by the vacuum pump displacement. The very distinctive signature of the helium I to helium II transition, which is shown to repeat in Figures 3 and 4, is the subject of another paper at this conference (Caspi 1980).

The two thermometers adjacent to the JT valve are located in the vacuum space on the outside of the tubing and therefore will not have the same precision as thermometers immersed in the liquid. This is thought to be the explanation for the crossing of cold sink temperature (thermometer downstream of the JT valve) and the bath temperature as the λ point is approached. The step changes in the cold sink temperature represent manual changes in the JT valve setting and correspond to changes in the cold sink vapor pressure. A system instability is recorded in Figure 3 when the cold sink and bath temperatures converge (at approximately 624 minutes). The resulting incomplete vaporization within the cold sink causes the JT entrance temperature to drop below T_λ, and the JT valve ceases to restrict the flow. The temperature suddenly drops at the bottom of the upper reservoir and rises in the lower reservoir. The temperature drop in the upper reservoir is thought to be due to a counterflow convection on the liquid side of the JT heat exchanger with superfluid penetrating into the upper reservoir from the heat exchanger. This instability was corrected by closing the JT valve entirely and waiting for the cold sink flow to decay. This instability can, of course, be avoided by controlling the JT valve to maintain a temperature difference between the bath and cold sink, with a programmed heat input to the bath as necessary.

The isothermal character of the bath is seen in Figure 4 which illustrates how cycling of the magnet current with associated eddy current heating gives rise to the saw toothed temperature histories and a direct measure of the eddy current heating. The cyclical response of the cold sink temperature is also shown in Figure 4.

Because of the relatively low thermal conductivity of the helium I, the helium I-helium II transition cannot occur in the communication channel but must occur in the bath above. To further balance the heat flow in the communication channel, the gradient from T_λ to 4 K should occur in a very thin layer. Temperatures were measured near the bottom of the upper bath as indicated in Figure 1. For the data shown in Figure 3, the thermometer is located approximately 0.003 m above the bottom and the temperature is about 4 K. In subsequent runs, with thermometers in contact with the bottom and on top of a 0.01 m thick fiberglass block which is held tightly to the bottom, the temperature falls to T_λ under some conditions. This suggests that a λ temperature film coats the lower surface and fiberglass block. On the other hand, Claudet (1974) has found the λ temperature layer to be quite thick. As more experience is gained with the present apparatus, perhaps a more conclusive statement can be made.

The system has been operated with various insertion depths of the communication channel restriction with no measurable difference in the pressure response of the lower reservoir.

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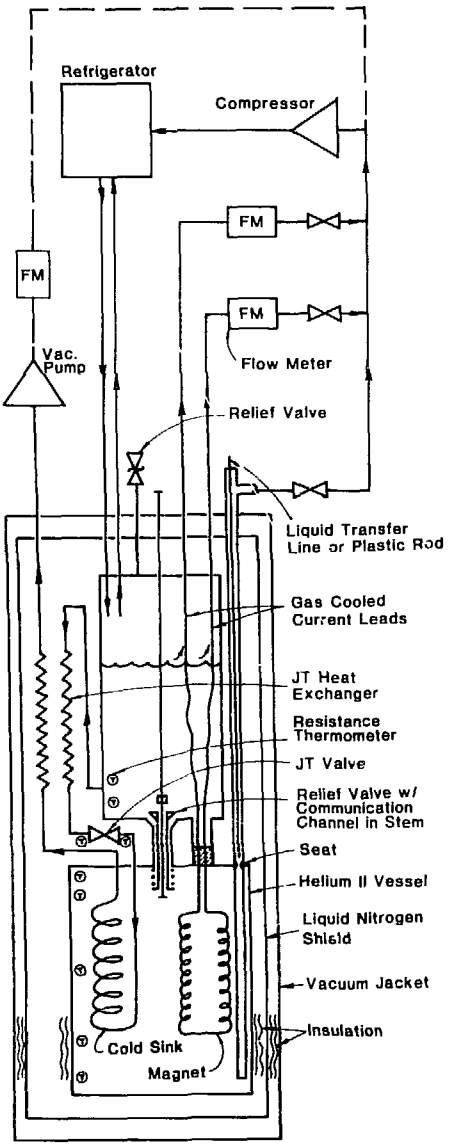

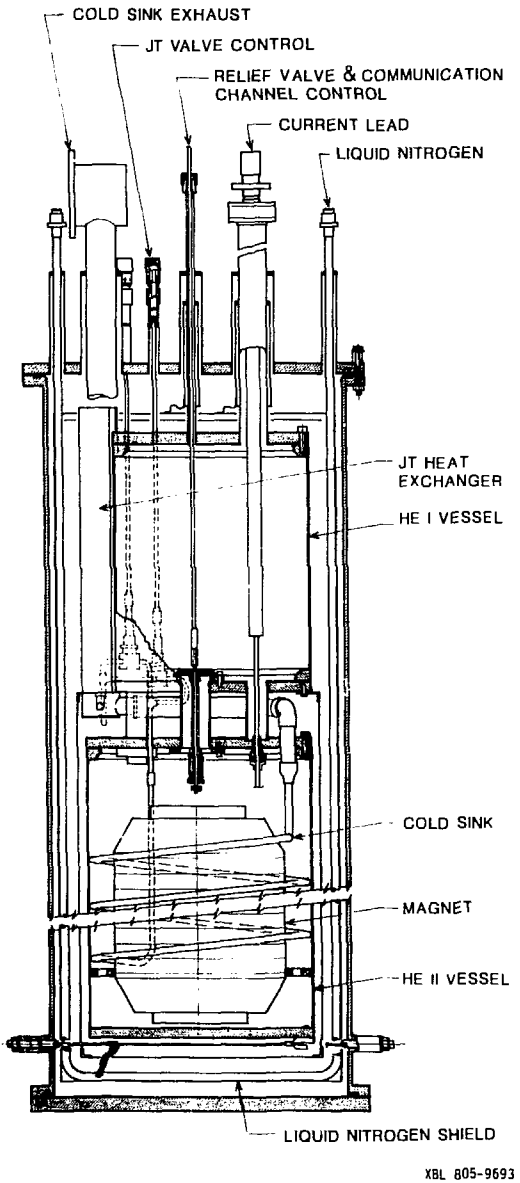

Fig. 1 System schematic

Fig. 2 Cryostat assembly

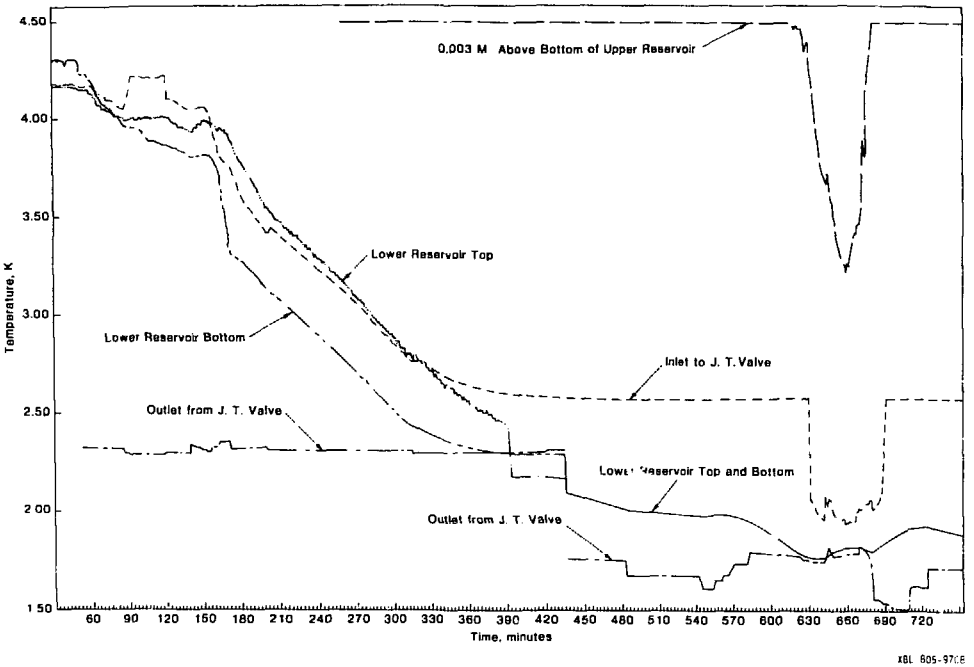

Fig. 3 Some temperature histories within the cryostat, Run 1

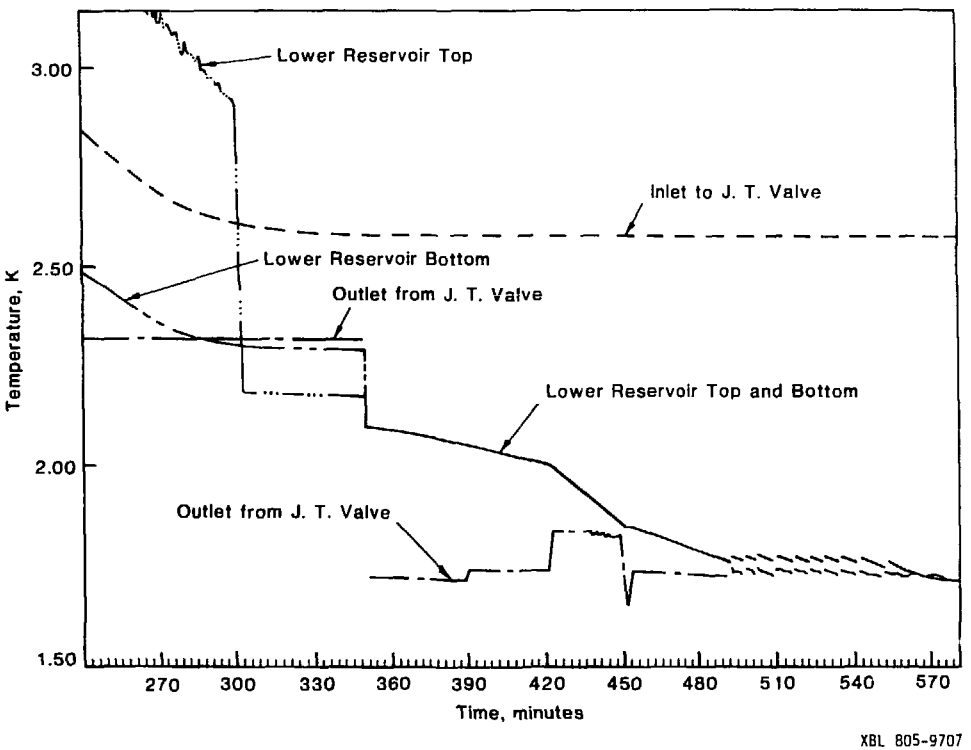

Fig. 4 Some temperature histories within the cryostat, Run 2