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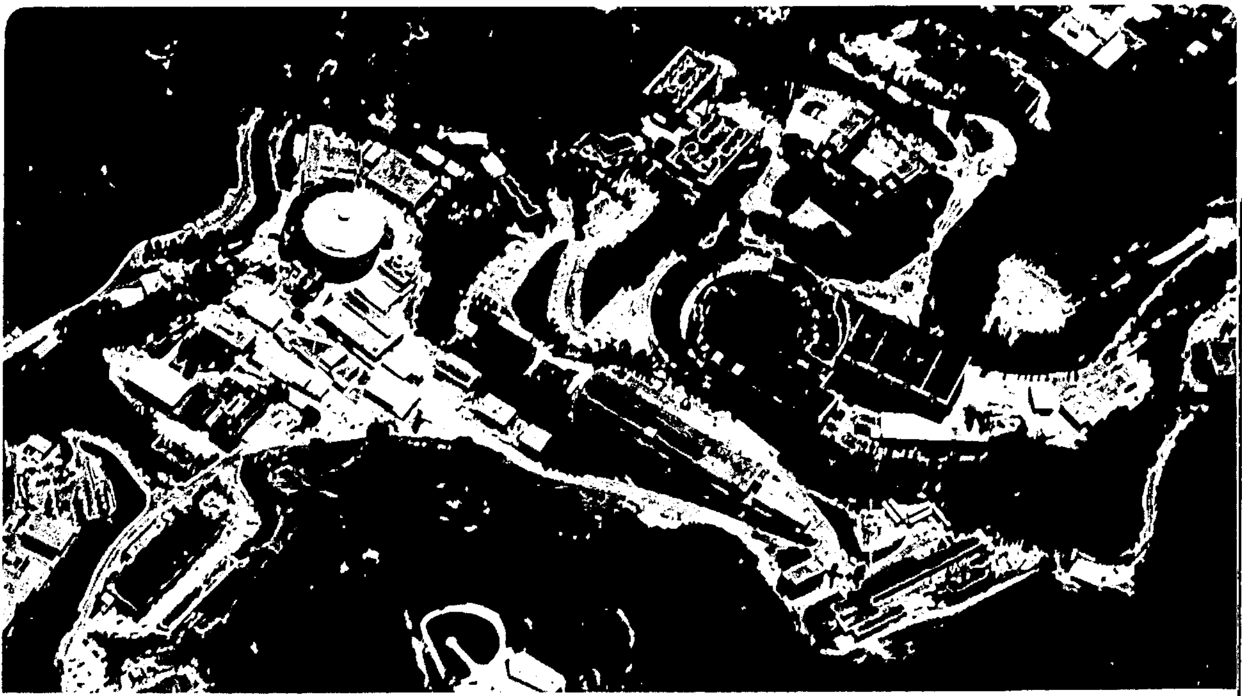

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DESIGN AND TESTING OF A SUPERFLUID LIQUID HELIUM COOLING LOOP

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ABSTRACT

This paper describes the design and preliminary testing of a cryogenic cooling loop that uses a thermomechanical pump to circulate superfluid liquid helium. The cooling loop test apparatus is designed to prove forced liquid helium flow concepts that will be used on the Astromag superconducting magnet facility.

INTRODUCTION

Astromag is a superconducting magnet facility to be mounted on the Space Station[1]. The strong magnetic field in space provides the necessary conditions for particle astrophysics and space physics experiments. The primary goal of Astromag is to investigate cosmic radiation, through precise measurement of charge, mass and energy spectra. To minimize loss of cryogen in the event of a quench, the magnet is not immersed in the helium bath, but uses the enthalpy of the helium gas to re-cool the magnet to superconducting temperatures after a quench. This system necessitates the use of an active system to circulate liquid helium (LHe). For simplicity, reliability, and ease of handling in a weightless environment, the baseline design utilizes a thermomechanical (TM) superfluid LHe ("fountain effect") pump.

Below the λ-point (~2.17 K), liquid helium can be described as a mixture of two fluids, a "normal" component, and a "superfluid" component which has zero viscosity. The ratio of superfluid to normal component is a function of temperature, starting at 0 at the λ-point, and increasing with decreasing temperature. Because it has no viscosity, the superfluid component can pass nearly unrestricted through a filter with very small pore size, while viscosity makes the filter a barrier to the normal component. By supplying heat at the upper surface of the barrier, we can maintain a temperature gradient, and hence a superfluid concentration gradient, across the barrier. In response to the concentration gradient, superfluid flows towards the heat source, and normal fluid flows away from it. Because of the barrier, this results in a net flow of fluid through the barrier. It is this kind of thermomechanical pump which we are building for Astromag.

By means of a heat exchanger, we will use the waste heat from the magnet itself to drive the pump. To meet our needs for Astromag, the pump must be able to keep the magnet at a temperature below 4 K under a maximum heat leak of approximately 5 watts, and must work properly with a heat leak as low as 0.2 watts.

MODEL COOLING LOOP

In order to study the problems and trade-offs associated with such an approach, we have built and begun testing a thermomechanical pump and simulated cooling loop. The cooling loop apparatus is composed of four primary components: porous ceramic cylinder (TM pump), copper coiled counterflow heat exchanger, wire heating source to simulate the waste heat from the magnet, and a valve to serve as a variable flow restriction (Figure 1). Cooling loop performance is monitored with temperature and pressure sensors. To initiate mass flow, measured heat loads are added to the cooling loop through a second wire heater, located close to the porous ceramic cylinder. Superfluid LHe in the liquid helium reservoir flows through the porous ceramic cylinder toward the heat source.

Under steady state conditions the heat exchanger replaces the lower wire heater as the heat source which drives the TM pump. LHe flows from the TM pump to the heater and flow restriction which simulate the magnet, passes through the heat exchanger, and is returned to the LHe reservoir. During tests, a data acquisition system records temperature and pressure data from the sensors shown in Figure 1.

TEST APPARATUS

The superfluid liquid helium (SFLHe) pump consists of a cylindrical stainless steel housing, with a porous ceramic filter and a heat exchanger within a heat exchanger housing at the bottom of the cylinder. Pump action is driven by thermomechanical effect from the temperature difference across the ceramic filter. The ceramic filter forms the inlet of the pump, and the LHe flow must be warmed and recirculated through the heat exchanger to maintain the temperature gradient across the filter. The filter is enclosed in

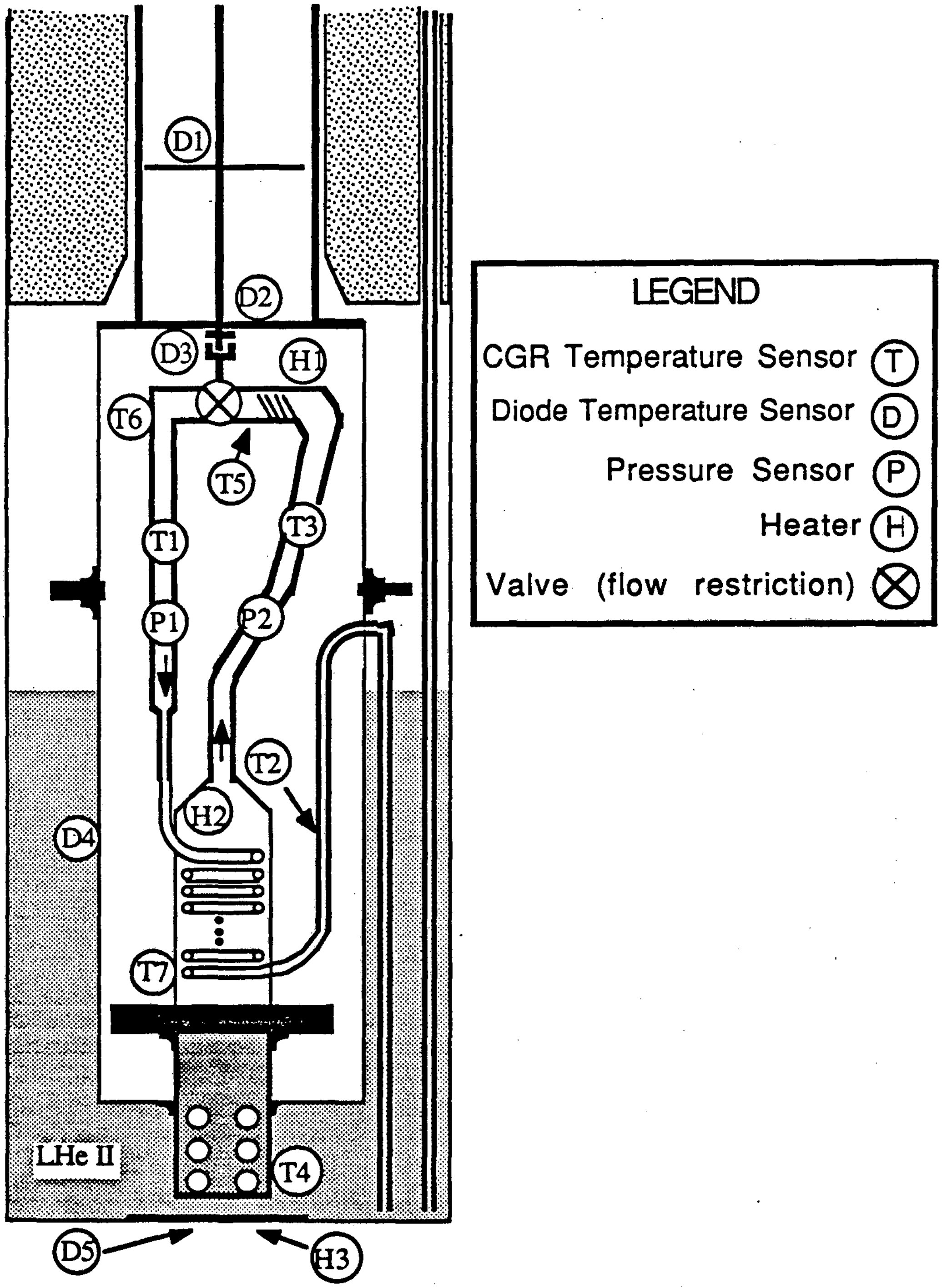

Figure 1. Cooling loop test apparatus, with sensor positions shown (Note that the sensors are not numbered sequentially.)

a protective nickel guard, which is welded to the bottom of the pump housing, making a vacuum-tight seal. The lower part of the filter guard has holes in it to allow LHe to reach the filter. The outflow line from the heat exchanger connects to a 0.64 cm (1/4") diameter stainless steel tube which passes through the pump housing, soldered to make a vacuum-tight seal.

The pump housing is a 15 cm o.d. x 0.21 cm wall thickness stainless steel cylinder, with a 2.54 cm (1") flange at the top, as shown in Figure 1. It is closed at the bottom by a plate welded to the cylinder. The bottom plate has a circular hole in it, to accommodate the stainless steel filter guard. At the flange it bolts to the housing cover, which is a similar cylinder, closed at the top with a chimney consisting of a 10 cm diameter pipe passing through and welded to the top of the housing cover. The housing cover bolts to the pump housing at the flange, and a vacuum seal is achieved via a copper gasket.

The ceramic filter is approximately 5 cm in diameter, but it is not perfectly round, and the filter guard has several thousandths of an inch of clearance to prevent it from damaging the filter when it contracts at low temperature. The filter guard is 8.74 cm long, and the lower 5 cm section (the part sticking out of the pump) has an array of 0.64 cm holes cut in it to allow LHe to reach the filter. Below the pump housing, on the side of the filter guard a temperature sensor is taped. Another temperature sensor is attached to the housing of the heat exchanger. Attached to the filter guard by a flange sealed with a copper gasket is a 14 cm extension cut from the same piece and with the same diameter as the filter guard. This forms the heat exchanger housing.

The top of the heat exchanger housing is closed with a stainless steel adaptor (welded to the heat exchanger housing) which reduces the diameter to 1.3 cm (1/2"). A resistor, used to initiate the superfluid He flow, is threaded through a 0.32 cm hole in the adaptor, and the hole is sealed with epoxy. The heat exchanger consists of this heat exchanger housing, plus 60 cm of 0.64 cm diameter tubing coiled inside of the housing. The copper tubing is soldered to the heat exchanger housing at its entrance and exit from the heat exchanger. The outlet of the heat exchanger (one end of the 0.64 cm copper tubing) is soldered to a 15 cm long piece of 0.64 cm diameter stainless steel tubing which contains a temperature sensor before it passes through a hole in the side of the pump housing. The 0.64 cm diameter stainless steel tube protrudes about 0.5 cm out of the pump housing, and is soldered in place to preserve the vacuum seal. This tube is coupled to another 0.64 cm stainless steel tube which extends down to the bottom of the test cryostat where it is bent for the outlet to aim back towards the center of the cryostat.

The outlet of the pump is soldered to a test load, consisting of 1.3 cm (1/2") dia. stainless steel tubing with a heated section, a variable flow restriction, four temperature sensors, and a pair of pressure sensors. The outlet of the test load is connected to the inlet of the heat exchanger, to maintain the temperature gradient which drives the pump. The heated section is just a short length of copper tube with resistive wire wrapped around and epoxied to it.

Above the test loop at the bottom of the 10 cm diameter pipe is a pair of thin copper baffles, to reduce the radiative heat leak. The resistor and sensor wires are threaded through small holes in these baffles. Each baffle also has a hole to allow free passage of the valve control rod. The flow restriction is a mechanical valve operated by hand at the top plate of the test apparatus. The control rod of the valve consists of two sections, which can be disengaged from each other to minimize heat conduction down the control rod during pump operation.

ANALYSIS

One can analyze the cooling loop by iteratively calculating the fluid mechanics and heat transfer around the loop. At the porous plug, a temperature gradient across the ceramic causes, via the thermomechanical effect, a pressure change which drives fluid through the porous plug, and hence around the loop. This kind of thermomechanical pump has been discussed elsewhere (*e.g.* DiPirro and Boyle[2], Hofmann et al.[3]). The pressure rise across the porous plug is $\Delta P = \int_{T_i}^{T_o} \rho\, S\, dT$ and the mass flow produced is $\dot{m} = \dot{Q}/S_o T_o$, where T_o and T_i are the outlet and inlet temperatures of LHe flowing through the porous plug, ρ is the density of LHe, and S is the entropy, and $\dot{Q}$ is the heat supplied (by the heat exchanger) at the porous plug to maintain the temperature gradient.

To predict the cooling loop behavior, we start with an assumed temperature rise across the porous plug, and calculate the corresponding pressure rise. Based on this pressure rise, we can calculate the fluid flow around the cooling loop. From the mass flow and the power supplied by the heater (H1), we can calculate the temperatures elsewhere around the cooling loop, and the efficiency of the heat exchanger. This supplies $\dot{m}$ and $\dot{Q}$, allowing us to re-calculate T_o, and iterate to arrive at a self-consistent result.

COOLING LOOP TESTS

The first test of the cooling loop was conducted at LBL on 9 May 1989, with only sensors P1, P2, T1, T3, and T4 operating (see Figure 1). In this first test of the apparatus, test conditions were not well controlled, but we were able to establish that the cooling loop does function, with LHe flowing in the loop, as determined by the

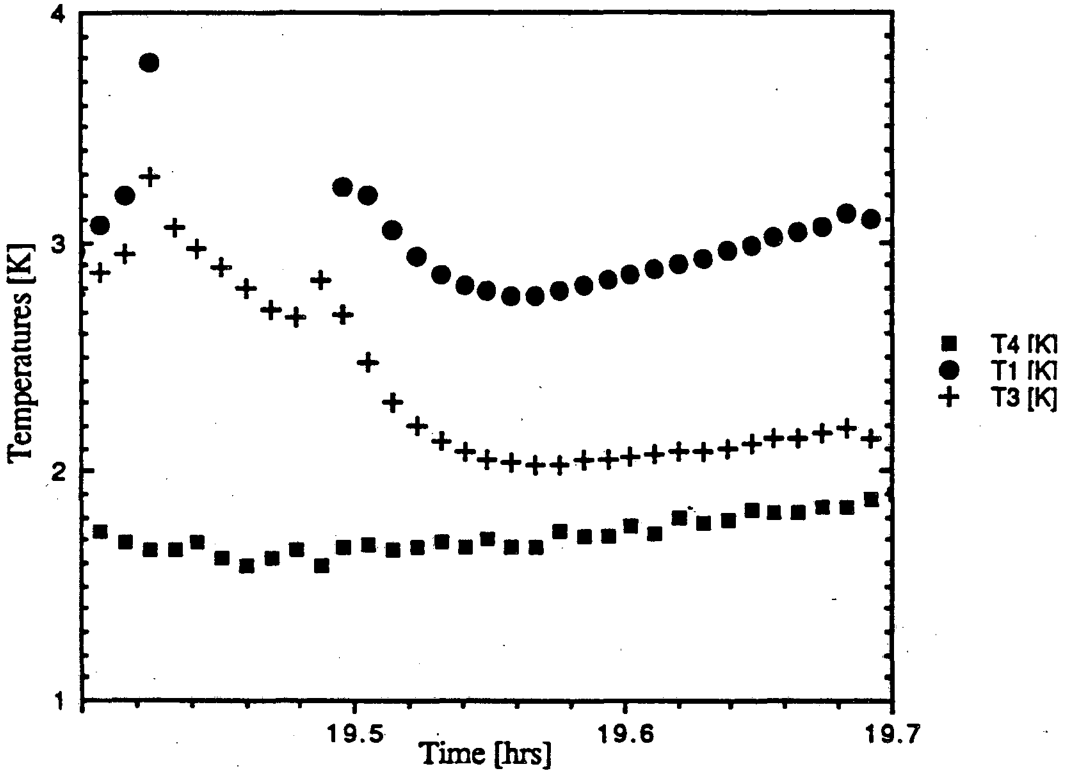

Figure 2. Sample temperature data from a preliminary test of the cooling loop. With the heater supplying 1 W, temperatures T_1 and T_3 are cold and nearly constant, indicating that there is LHe flowing in the cooling loop. Future tests will have more sensors operational, enabling us to analyze the cooling loop behavior in more detail.

temperature and pressure values available. Figure 2 shows some sample temperature data with the TM pump in operation.

With forced flow of superfluid helium demonstrated, an objective for further tests is greater control of the flow rate and temperature variations. Increasing the number of temperature and pressure sensors along the loop will improve our understanding of the temperature distribution and fluctuations. Some fluctuations in the liquid helium bath occur when the large vacuum pump used to remove He vapor reacts too slowly to changes in the heat flow into the system, allowing the bath temperature to vary. Under some conditions, we have also observed oscillations in the temperature and pressure which may be due to the feedback inherent in the cooling loop design. Since the initial test, we have modified the test apparatus to include more temperature sensors, better real-time monitoring of test data, and improved control of the vacuum and cryogenic system. We will conduct further tests in August, 1989, and compare the behavior of the cooling loop system with expectations based on theoretical analysis.

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REFERENCES

[1] Ormes, J. F., Israel, M., Wiedenbeck, M., and Mewaldt, R., eds. "The Particle Astrophysics Magnet Facility - ASTROMAG" (Report of the Astromag Definition Team) NASA-GSFC, (May 1988).

[2] DiPirro, M. J. and Boyle, R. F. "Lab Tests of A Thermomechanical Pump for SHOOT", *Advances in Cryogenic Engineering*, 33, 487, (1988).

[3] Hofmann, A., Khalil, A., and Kramer, H.P., "Heat Exchangers for He II Cooling Loops With Self-Sustained Fountain Effect Pumps", Cryogenics 27, (December 1987).

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