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TEST OF A CRYOGENIC HELIUM PUMP*

MASTER

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INTRODUCTION

One way of circulating liquid or supercritical helium in a magnet built with a hollow or Internally Cooled Superconductor (ICS) is by use of a cryogenic helium pump. A developmental helium pump was acquired from Gardner Cryogenics, Bethlehem, Pennsylvania, for testing and possible use in the Large Coil Program[1] at Oak Ridge National Laboratory. It was designed to produce flow in helium, taking it at an inlet pressure of 2-3 atm and a temperature of 3.5-4.5 K and discharging it at a pressure of 4-7 atm. Mass flow rates of up to 20 $g \cdot s^{-1}$ were to be expected by varying the pump drive speed up to 333 rpm.

Although it has since been decided to use the refrigerator compressor instead of the helium pump for circulating supercritical helium for the force-flow coils in the Large Coil Program, the pump was incorporated into the helium flow loop of an ICS magnet test stand. Performance of the ICS magnet using the pump is reported separately.[2] At the completion of the magnet test it was removed from the stand and a simplified, but better instrumented, flow loop was assembled to test the pump.

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PUMP DESCRIPTION

The pump is a one-cylinder piston pump with the cold end 1.52 m (60 in.) below the driving unit. A schematic of the pump body is shown in Fig. 1. The cylinder (1) has a bore of 38 mm (1-1/2 in.). Helium is sucked through the inlet "poppet" valve (4) into the cylinder and discharged through four discharge "flapper" valves (5) into the concentric discharge can (3). Both the inlet and discharge valves are spring loaded. The piston (2) stroke is about 38 mm (1-1/2 in.).

The pump body, the piston rod (6), and the support column (7) are housed inside a 152-mm- (6-in.-) diam sheath. Leakage through piston rings and other parts of the pump equalizes the

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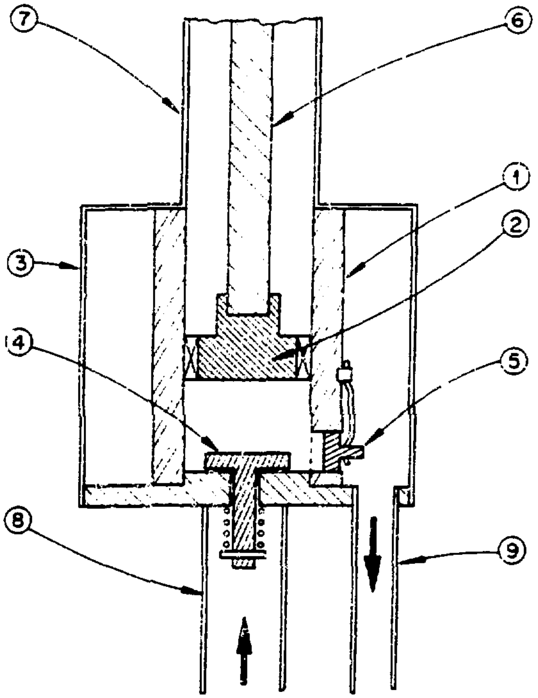

Fig. 1. Pump body cross section: (1) cylinder, (2) piston, (3) discharge can, (4) inlet valve, (5) discharge valves, (6) piston rod, (7) support column, (8) inlet tube, and (9) discharge tube.

helium pressure in the sheath with that inside the pump. The inlet (8) and discharge (9) tubes were originally equipped with demountable couplings to the bottom plate of the sheath such that the whole pump could be removed for service. Due to difficulties in sealing after cooldown, this feature was deleted. Instead, the inlet and discharge tubes are soldered directly to the test loop.

The driving unit is located at room temperature on top of the dewar. It consists of a SCR-controlled electric motor, a right-angle gear reducer, and a rocker to transmit motion of the crank to the piston rod.

TEST SETUP

The helium pump and test loop were located inside a 0.76-m- (30-in.-) ID dewar. A schematic of the flow loop is shown in Fig. 2. The pump (A), located inside a separate sheath, hangs in the dewar. A 5-m-long section of 6.4-mm- (1/4-in.) OD by 0.76-mm (0.030-in.) wall copper tube (B) was used as a load.

Flow was measured by a venturi meter (C), which has a throat of 2.72 mm (0.107 in.) and a throat-to-line ID ratio of 0.32. It was calibrated against a room temperature calorimetric mass flow meter (E) made by Teledyne Hastings-Raydist.*

Helium heat exchangers (D_1 and D_2) are placed immediately before and after the pump. Each heat exchanger has a volume of about 1500 cm^3, 34 times the pump displacement volume. Thus, the heat exchangers also serve as the surge volumes for the loop.

All pressure taps are brought out to room temperature through stainless steel capillary tubes. Pressures at the pump inlet (P_1), outlet (P_2), load inlet (P_3), and outlet (P_4) are measured with Bourdon tube gages. Differential pressures across the pump (ΔP_p), the load (ΔP_{3-4}), and the venturi (ΔP_v) are measured with diaphragm-strain-gage transducers. Pump head pressure was controlled by throttling valve V_3.

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*Reference to a company or product name does not imply approval or recommendation of the product by Union Carbide Corporation or the U.S. Department of Energy to the exclusion of others that may be suitable.

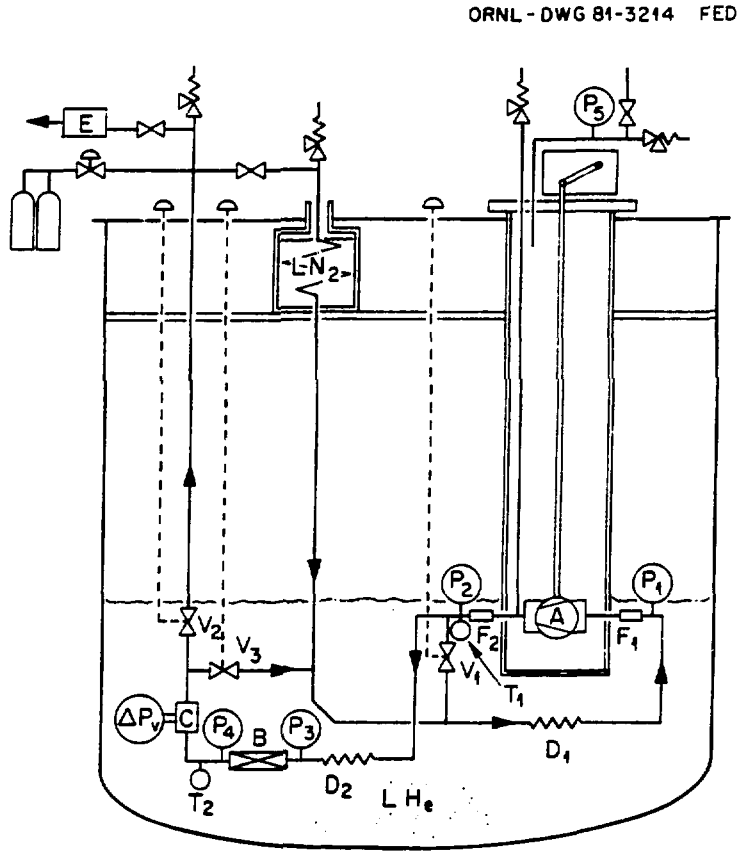

Fig. 2. Test loop schematic: (A) pump, (B) load, (c) venturi meter, (D_1,D_2) heat exchangers, (E) mass flow meter, and (F_1,F_2) filters.

RESULTS

Venturi Meter

The venturi meter was calibrated with helium gas at LN_2 temperature. This was done by filling the dewar with LN_2 and opening the bypass valve V_1. Results showed that, within experimental uncertainties, the tube-to-throat pressure drop ΔP_v can be related to the mass flow $\dot{m}$ by the simple relation:

$$\Delta P_v = \frac{8}{\pi^2 D^4} \frac{\dot{m}^2}{\rho} \left(\frac{1}{\beta^4} - 1 \right) , \qquad (1)$$

where D is the line ID, ρ is the helium density, and β is the ratio of throat to line ID. Pressure oscillations of about 0.14 atm peak to peak were observed across the venturi at helium temperatures. This was probably due to thermal acoustic oscillations in the capillary tubes. This can probably be improved by heat sink of these tubes.

Pump Characteristics

For each pump piston speed ω_p, the performance of the pump was characterized by the mass flow vs pump head.[3] Figure 3 shows results at four different pump speeds. Up to a differential pressure of 1.0 atm the mass flow rates are nearly constant, indicating a constant volumetric efficiency. As the pump head goes higher the mass flow rate starts to drop. The effect is more pronounced at lower pumping speeds. Leakage through the piston ring, other parts of the pump, or the test loop is probably responsible for lower peak differential pressures at lower pumping speeds.

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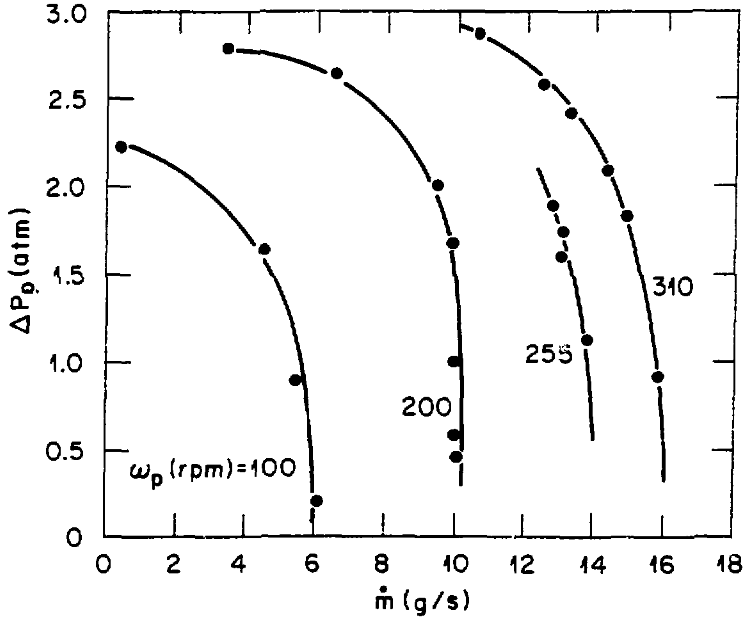

Fig. 3. Pump characteristics. Discharge pressure = 3.5-7.5 atm; T_2 = 4.2-4.3 K.

The above feature can also be illustrated in the mass flow vs pump speed plot shown in Fig. 4. At high pumping speed, a linear mass flow vs pump speed relationship is observed up to a 2.5-atm pump head. The extrapolation of mass flow vs pumping speed results for a pump head less than 1.0 atm to a full design pumping speed of 333 rpm would give a mass flow of 17.3 g • s^{-1}, or 13% lower than the specification.

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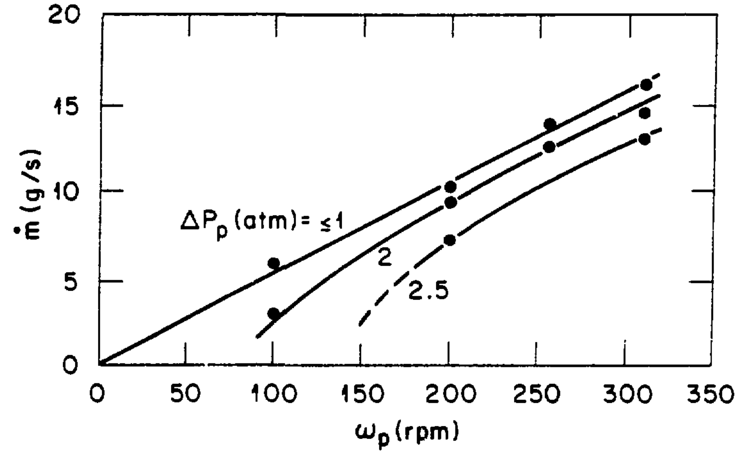

Fig. 4. Mass flow rate as a function of pump speed. Single straight line fits data for pump head pressure up to 1.0 atm.

The above results were obtained with a pump discharge pressure in the range of 3.5–7.5 atm. Pressure variation across the pump was about 0.95 atm peak to peak. This was damped to about 0.36 atm across the load.

Thermal Efficiency

The pump thermal efficiency η was estimated by comparing the useful fluid power W to the measured additional cryogenic loss when the pump was running,[4] $Q_r - Q_s$, i.e.,

$$\eta = \frac{W}{Q_r - Q_s} . \qquad (2)$$

The measurement of $Q_r - Q_s$ consisted of measuring the total helium boiloff rate with the pump running and stopped using a mass flowmeter at room temperature. The fluid power is given by

$$W = \frac{\dot{m} \times \Delta P_p}{\rho} . \qquad (3)$$

The results showed that at $\omega_p = 310$ rpm, the pump efficiency was $\eta = 0.76$. At $\omega_p = 200$ rpm, it dropped to $\eta = 0.56$.

CONCLUSION

A commercial cryogenic helium pump has been tested successfully. Despite flaws in the demountable connections, the piston pump itself has performed satisfactorily. A helium pump of this type is suitable for the use of flowing supercritical helium through ICS magnets. It has pumped supercritical helium up to 7.5 atm with a pump head up to 2.8 atm. The maximum mass flow rate obtained was about 16 g $\cdot$ s^{-1}. Performance of the pump was degraded at lower pumping speeds.

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