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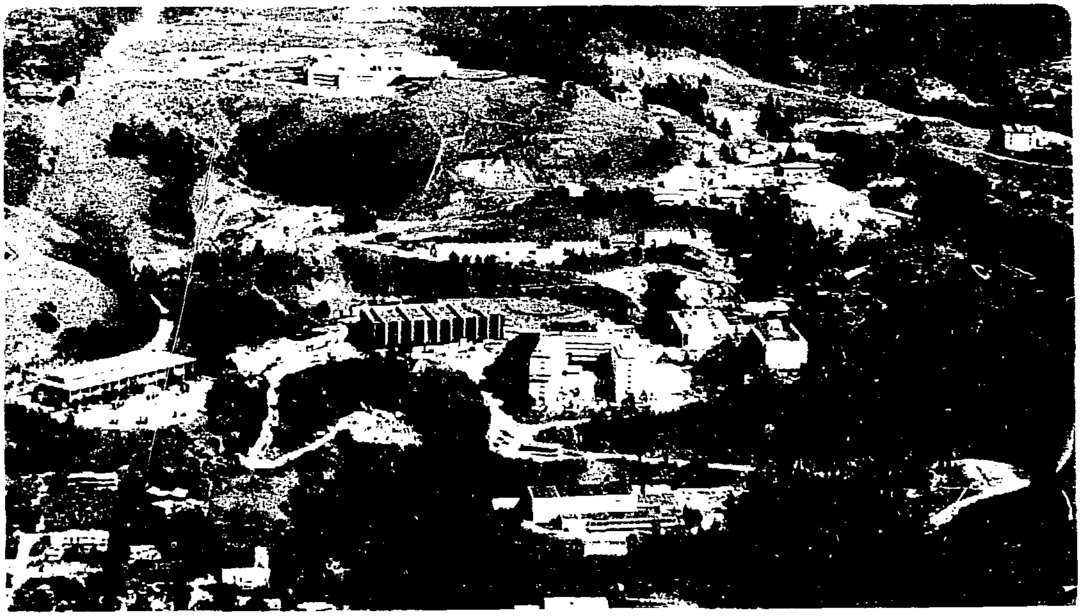

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THE CONSTRUCTION AND TESTING OF A DOUBLE ACTING BELLOWS LIQUID HELIUM PUMP

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This paper describes the double acting reciprocating bellows liquid helium pump built and tested at the Lawrence Berkeley Laboratory. The pump is capable of delivering 50 gs^{-1} of liquid helium to supply the two phase cooling system for a large superconducting magnet. The pump is driven by a torque motor at room temperature; the reciprocating motion is transmitted to the pump through a shaft which operates between room temperature and 4 K. This report describes the design details of this liquid helium pump. The helium pump has operated in a helium bath and in pumped forced flow helium circuits. The results of these experimental tests are presented in this report.

INTRODUCTION

The TPC experiment superconducting magnet is cooled with forced two phase helium in tubes around the superconducting coil.[1] It is desirable that helium enter the cooling tube at as low a quality a possible.[2] (Quality is defined as it is for steam. A quality of zero is saturated liquid; a quality of one is saturated vapor.) Two phase helium may be circulated by either the refrigerator compressor or by the means of a liquid helium pump. The TPC superconducting magnet uses the refrigerator compressor as the primary circulator and a liquid helium pump is the back up circulator.

The concept of liquid helium pumps is not new;[3,4,5] but comercially available helium pumps did not fit our requirements and they were expensive. This report describes the reciprocating double acting helium pump built and tested by LBL for use on the TPC magnet. The result was a pump which can pump up to 50 gs^{-1} over pressure rises of 1 atm. The volumetric and adiabatic efficiencies of this positive displacement pump are quite high when the pump is used as a circulator.

DESCRIPTION OF THE PUMP

The LBL helium pump utilizes two bellows with a 108 mm ID. These bellows each consist of 30 hydroformed stainless steel convolutions. These bellows can be flexed up to 27 mm without damage. The room temperature fatigue life for the bellows when the stroke is 25.4 mm is rated at over 10^7 cycles at a temperature of 300 K. Since the bellows operate at 4 K, the fatigue life can be expected to be greater than 10^8 cycles.

The LBL reciprocating pump is driven by a variable speed and torque controlled d.c. gear motor as illustrated in Figure 1. The pump stroke can be fixed at 12.7, 19.9 or 25.4 mm depending on the eccentric cam selected in the drive mechanism. The theoretical displacement volume per up and down stroke is 222, 348, and 444 cm^3 depending on which of the three cams is chosen. The actual pump displacement is less than theoretical because pressure in the pump deforms the bellows. (For example, when the pump exit pressure is 0.68 atm greater than the inlet pressure, the actual displacement is about 95 percent of the theoretical displacement volume.)

Figure 2 shows a cross-section of the pump chamber with its components identified. The ported block, to which the discharge check valves are connected, is rigidly attached to the support and guide tube which is stationary. All other parts move with the actuator rod and shroud as the drive shaft moves up and down. The pump drive shaft must carry driving forces in both directions, it must be designed for buckling as well as tension compression forces. A view which shows the pump in pieces is shown in Figure 3.

The suction poppet valves are positioned by inertial and dynamic fluid forces, the configuration as shown is for a down-stroke mode. The arrows indicate the direction of fluid flow as it enters the lower cavity and is expelled from the upper. This double acting bellows action results in a more constant flow rather than the intermittent flow that a single bellows would produce. In an up-stroke mode, the lower poppet is seated and the upper poppet is unseated, reversing the fluid flow as shown. Flow into the pump cavities is distributed equally by sixty 1/16-inch diameter holes oriented in a circle in the suction valve retainers.

Both discharge ports are fitted with lift plug check valves which prevent back flow into the pump cavities from the exit heat exchanger. Both of these valves were quite tight. The assembled pump, shown in Figure 4, is surrounded by a copper tube split flow heat exchanger which shares a common liquid bath with the pump. This bath provides suction liquid head for the pump and it removes the pump work.

TESTS OF THE LBL HELIUM PUMP

The helium pump was tested using water, liquid nitrogen, and liquid helium. The water tests measured the actual displacement in pump differential pressures of 0.07 atm and 0.68 atm. The actual displacement per stroke was found to decrease with pressure. Unfortunately, data was not taken for pressure difference beyond 0.68 atm. The bellows themselves are rated for pressure differentials across the pump of 2.7 atm at room temperature. This rating should increase to 4 atm at 4 K. The first tests with water and liquid nitrogen showed volumetric efficiencies above 90 percent when the pump speed was above 15 or 20 strokes per minute. Below these speeds the upper inlet valve does not close properly. The volumetric efficiency drops below 50 percent.

The first tests were made with a test assembly built into the control dewar. The helium pot built into this system was small so accurate flow measurements were not made at mass flows beyond 27 gs^{-1}. Measurements were made with the 12.7 mm, 19.9 mm and the 25.4 mm cams. Most of our data, however, was taken with the 25.4 mm (1-inch) cam. Figure 5 summarizes the measurements of volumetric efficiency and helium mass flow as a function of pump strokes per minute for pressure differentials of 0 and 1 atm. The loss of volumetric efficiency at low pump speeds can be attributed to leakage past the intake valves (particularly the upper inlet valve which loafs at low speeds.) The reduction of volumetric efficiency with pressure differential can be attributed to valve leakage, bellows deformation and helium compressibility. Our test apparatus did not permit tests to be performed at pressure differentials above 1 atm.

Measurements of adiabatic efficiency are difficult to make. These mesurements were not made directly. Estimates of adiabatic efficiency came from calorimetry made on a whole system. The helium pump was tested with the TPC magnet control dewar and transfer lines.[2,6] The pump delivered helium at mass flow rates from 5 to 45 gs^{-1} during various runs. At a mass flow of 40 gs^{-1} the adiabatic efficiency appeared to be about 50 percent.

At a flow rate of 8 gs^{-1} the adiabatic efficiency appeared to drop to 25 or 30 percent. This is consistant with the drop in volumetric efficiency measured in earlier tests. Figure 6 illustrates the effect of pump work on total system heat load for a pumped circuit using the LBL helium pump. When the 12.7 mm cam was used instead of the 25.4 mm cam, the pump work was reduced along with the mass flow through the system.

The first test of the TPC magnet showed that the helium pump could do far more than it was designed to do.[1,5] The helium pump was not designed to cool a superconducting magnet down even from 80°K. The pump was designed as a low pressure differential liquid helium circulator. During the May 1980 cooldown of the TPC magnet, the helium pump was used to cooldown 1800 kg of superconducting coil and transfer lines from 95 K to 4.8 K. During the cooldown the pump delivered liquid helium to the warm magnet at rates up to 8 gs^{-1} over pressure differentials as high as 4 atm. The pumped liquid helium flashed to gas and the sensible refrigeration in the gas removed most of the 30 MJ of thermal energy contained in the magnet when it was at 95 K. When the magnet was cooled down to 4.8 K the pump circulated helium through the TPC magnet cooling system at the rate of 18 gs^{-1} over a pressure differential of 0.4 atm. The estimated pump work was between 15 and 20 Watts.

ACKNOWLEDGEMENT

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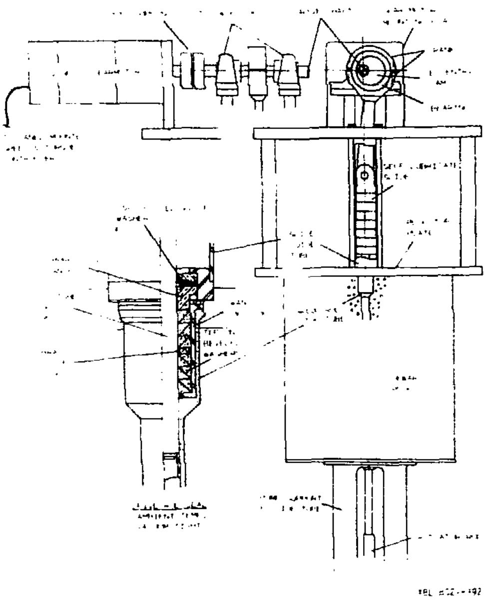

Fig. 1 The Warm End Drive And Seal For The Reciprocating Helium Pump

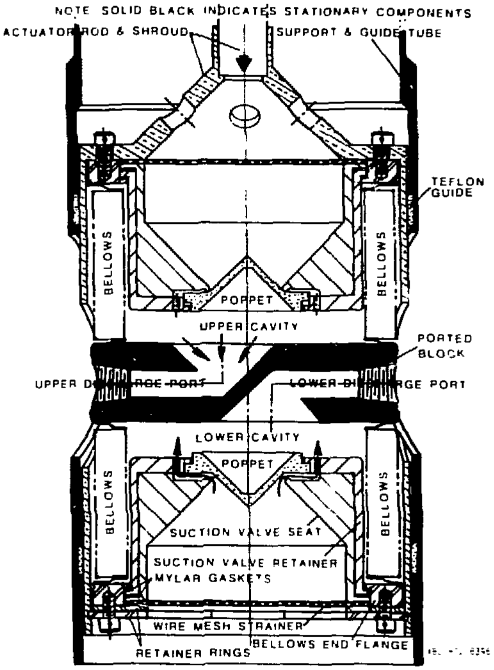

Fig. 2 Cross-Section View Of The Helium Pump Chamber

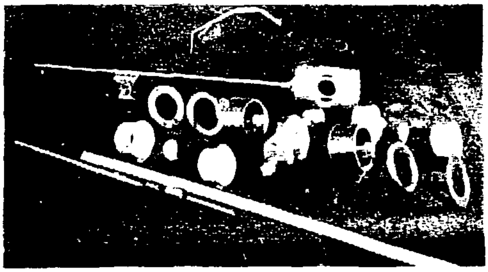

Fig. 3 Exploded View Of The Helium Pump In Pieces

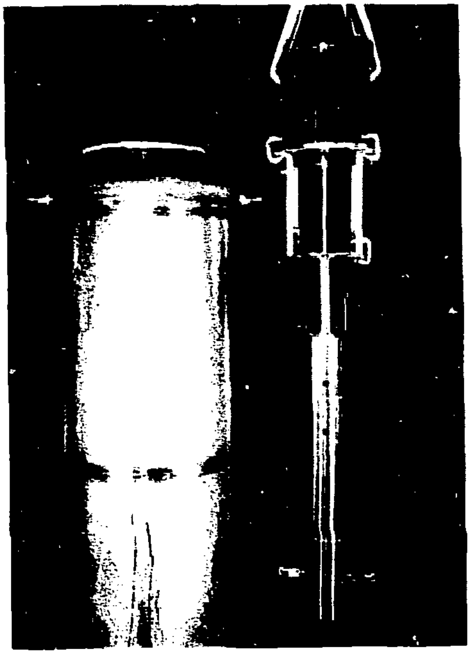

Fig. 4 The Assembled Helium Pump (Without Heat Exchanger & Control Dewar)

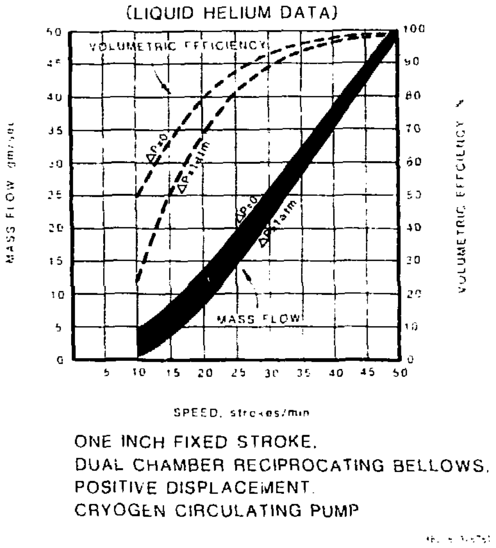

Fig. 5 Volumetric Efficiency and Mass Flow VS Pump Speed and Pressure Differential

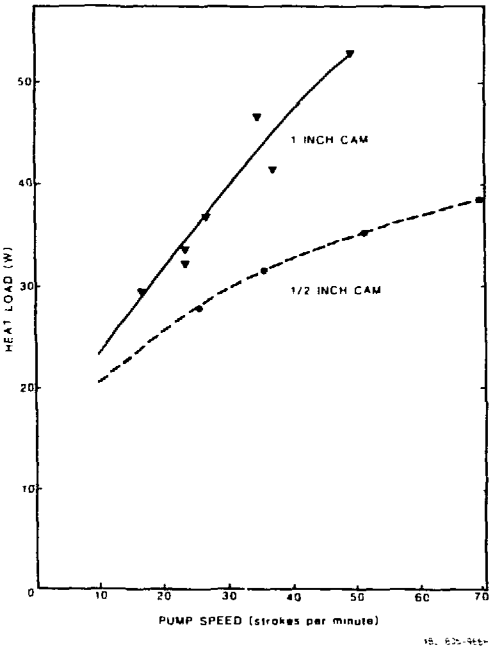

Fig. 6 Total Heat Input Into A Helium Flow Circuit As A Function Of Pump Speed