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FERMILAB ENERGY SAVER REFRIGERATION SYSTEM TESTS

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INTRODUCTION

The Energy Saver Refrigeration System is based on the concept of a central helium liquefier (5000 ℓ/hr) providing liquid to 24 satellite refrigerators (966 W @ 4.6°K), which operate as amplifiers with a gain of 12. This concept was tested, cooling two 125 m long strings of superconducting magnets. The test was run using one satellite refrigerator operating as the "central liquefier", shipping liquid helium through a 250 m long transfer line to a second satellite refrigerator, which in turn cooled the magnets. In addition to testing the satellite concept, the heat loads of the magnets and transfer line were also measured.

SYSTEM DESCRIPTION

Cooling of the Fermilab superconducting accelerator is provided by a 5000 ℓ/hr central helium liquefier (CHL) coupled with 24 satellite refrigerators (966W), Figure 1 [1]. Six compressor buildings supply high pressure helium (20 ATM) to the satellite refrigerators via a common 3 inch header. The compressor buildings have 4 - two stage screw compressors, each with its own oil removal system. High pressure helium is cooled in the satellite refrigerator in a series of four heat exchangers by cold - low pressure return gas from the magnet strings (Figure 2). Supplemental shell side cooling can be supplied by a reciprocating 30°K expansion engine (normally off). Cold high pressure helium gas is then expanded through a reciprocating liquid expansion engine to a state of subcooled liquid at 1.8 ATM. Additional liquid helium (LHe) is supplied to the system from the CHL through a transfer line (Figure 1). The LHe is then sent to the load, two 125 m long strings of magnets. The flow from the CHL results in a flow imbalance between the shell and tube sides of the heat exchanger. This additional shell side flow helps the satellite refrigerators to operate as "amplifiers:, with a flow gain of 12.

Currently, four satellite refrigerators and two compressor buildings are operational as a system. The refrigerators have been tested independently for capacity and operated in a system via a 250 m LHe transfer line and with a load of two 125 m long magnet strings.

REFRIGERATOR OPERATION

The satellite refrigerators operate in one of four modes: satellite, liquefier, refrigerator and stand-by. Under normal operating conditions, the refrigerator will be operating in the satellite mode, producing 966 W of 4.6°K cooling with the aid of the CHL LHe flow. In the other three modes, the refrigerator is operated independent of the CHL. The gas expansion engine is operated to supply additional shell side cooling and LN_2 is consumed by the #1 heat exchanger to precool high pressure helium (as shown in Figure 2). Design production for the liquefier and refrigerator modes is 126 ℓ/hr of 1.8 ATM LHe and 623 W of 4.6°K cooling, respectively. The stand-by mode is a combination of refrigeration and liquefication modes used to keep the magnets cooled without the aid of the CHL. This mode is designed to produce 490 W and 26.6 ℓ/hr LHe.

Each of the four operational satellite refrigerators were capacity tested in the refrigerator mode. A load module was used which includes a Joule-Thomson (JT) valve and an electric resistance heater located on the low pressure side of the JT valve. The wattage to the heater was increased until the refrigerator was no longer able to maintain two phase helium (i.e., the return to the shell side of the heat exchanger just began to superheat).

The first three refrigerators which were tested had a vertical heat exchanger train (total length of 10 m). The refrigerators achieved the design capacity of 6 23 W at 4.6°K. Our latest refrigerator incorporates a new horizontal heat exchanger train. A flow oscillation in the #4 heat exchanger and a large pressure drop in a new load module limited our test to 95% capacity at 5.5°K. The flow oscillation was the result of cold return helium flashing when it came in contact with the warm end of the #4 heat exchanger. Flow modulations as high as 40% were recorded. With our understanding of the source of the oscillation and corrections being made to the load module, we feel that we will be able to achieve the design capacity in this refrigerator (and thus subsequent refrigerators).

MAGNET HEAT LOAD TEST

The test system consisted of a compressor building, two satellite refrigerator buildings, a 250 m long LHe transfer line, and two 125 m long superconducting magnet strings (Figure 3). Two compressors in the A0 compressor building supplied 20 ATM helium to the A1 and A2 refrigerator buildings. The A1 refrigerator simulated the CHL by operating in the liquefier mode, sending supercritical helium to the A2 refrigerator via a 250 m long LHe transfer line. The A2 refrigerator operated in the satellite mode, cooling the two 125 m long magnet strings to 4.6°K.

Each superconducting magnet string consisted of 16 dipole magnets, 4 quadrupole magnets, spool pieces, a feed can, and a turnaround box (Figure 4). The turnaround box contains a JT valve which controls the helium flow rate through the magnet string. Liquid helium from the single phase chamber of the string is throttled from 1.8 to 1.2 ATM at the turnaround box by the JT valve into the two phase chamber. The magnets are kept at a constant temperature by having the latent heat of the two phase chamber handle the heat load. Under normal operating conditions, the helium flow will be controlled such that the two phase flow will just begin to superheat (0.1°K) when it is returned to the shell side of the refrigerator.

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The helium heat load was measured independently on the upstream (upstream with respect to the beam direction) and downstream magnet strings. The flow rate through the magnets was reduced using the turn-around box JT until the returning two phase helium began to superheat. Temperature (vapor pressure thermometers), pressure, and flow rate (LHe venturi) data was taken at half hour intervals to assure system stability.

With the magnets under a good vacuum($< 5 \times 10^{-7}$ Torr), the helium heat load was measured to be 150 ± 15 W per magnet string. A series of measurements were also made at various qualities of magnet insulating vacuum [2]. We found that the helium heat load began to significantly increase with insulating vacuums poorer than 1×10^{-5} Torr. With a vacuum level of approximately 5×10^{-5} Torr, the helium heat load doubled.

Transfer Line Heat Load Test

The Energy Saver Refrigeration System includes a liquid helium transfer line made up of twenty five 250 m long sections.[3] The line originates at the CHL, passes through each of the 24 satellite refrigerator buildings and returns to the CHL (see Figure 1). Supercritical helium at 4.6 to 5.5°K and 3 ATM is circulated through the line to each satellite refrigerator. Currently, one section of transfer line between the A1 and A2 refrigerators has been tested (Figure 3).

A cross section of the transfer line is shown Figure 5. The line consists of four concentric pipes (commercial 304 schedule 5 and 10) forming two vacuum spaces, a LHe passage, and a LN_2 passage. A vacuum jacketed 1 1/2 inch pipe forms the LHe passage. It is wrapped with super insulation and supported by G-10 spacers. Subcooled LN_2 at 3 ATM flowing between 2 1/2 and 3 1/2 inch pipes provides a thermal shield for the LHe and is supplied to the refrigerators and magnet shields. The outer vacuum jacket also has super insulation and G-10 spacers supported from the outer 6 inch pipe.

Heat load tests were performed on the helium and nitrogen circuits of a 250 m long section of transfer line between the A1 and A2 refrigerator buildings. The A1 refrigerator operated in the liquefier mode, sending 9-10°K gas at 3 ATM to the A2 refrigerator. Liquid helium was not used in the test since it would undergo a very small change in temperature over the length of the line, which would be difficult to measure accurately. Steady state is also easier to maintain with the lower density helium, since the travel time through the transfer line is shorter. For instance, at a mass flow rate of 1.0 g/s the travel time for a particle through the line is 12.1 hours at 5°K and 1.7 hours at 10°K.

During the test, venturi flowmeters, temperature sensors, and pressure taps at each end of the line were monitored to assure steady state conditions. An average helium heat load of 9.0 ± 1 W (0.036 W/m) was measured . The average nitrogen heat load was measured to be 140 W (0.56 W/m), although considerable variation in this value ($\pm$ 25% or more) can be realized due to changes in weather conditions.

References

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2. H. Jöstlein et al., "Heat Leak Measurements on Fermilab's Energy Saver Magnet String and Transfer Line"' Fermilab Report TM-1026 (1981)

3. C. H. Rode et al., "Fermilab Tevatron Transfer Line", to be presented at the 1981 Cryogenic Engineering Conference, San Diego

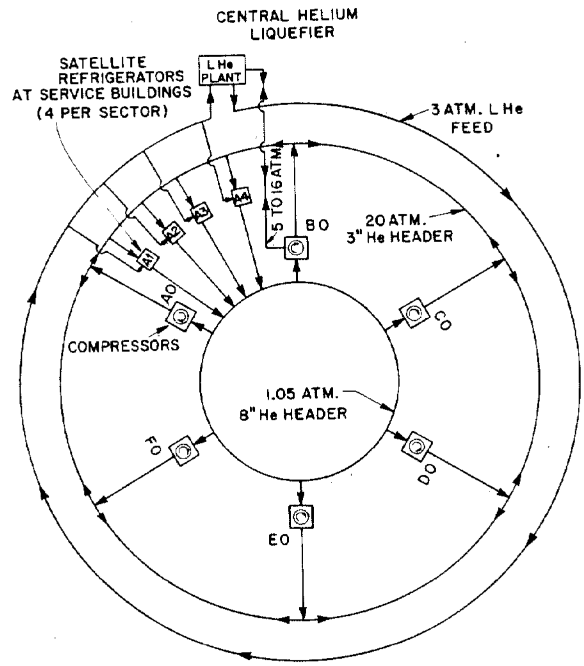


Figure 1 Helium Cryogenic Refrigeration Circuit

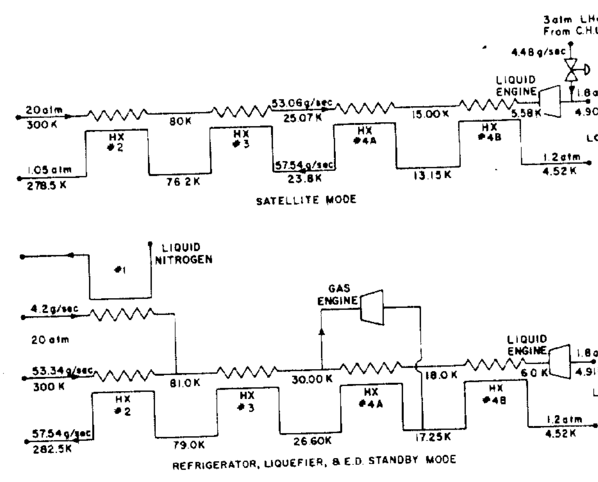


Figure 2 Satellite Refrigerator Flow Circuit

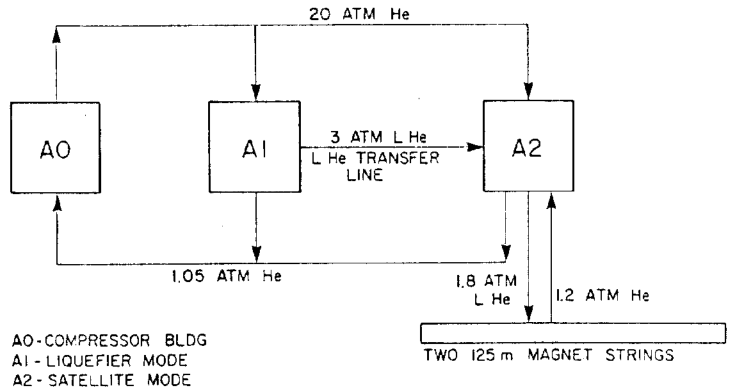
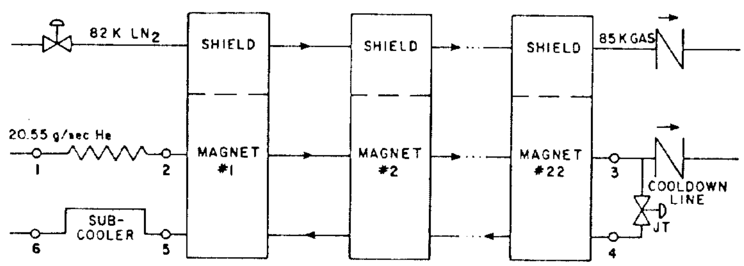


Figure 3 Satellite Refrigerator Test Layout



POINT	T(K)	P_{atm}	$H_{J/g}$	%LIQUID
1	4.90	1.8	14.22	100.
2	4.50	1.8	11.20	100.
3	4.60	1.8	11.75	100.
4	4.47	1.25	11.75	96.
5	4.42	1.2	27.99	10.
6	4.52	1.2	31.01	0.1 K SUPER HEAT

Figure 4 Cryogenic Magnet String Flow Circuit (1/48 of the ring)

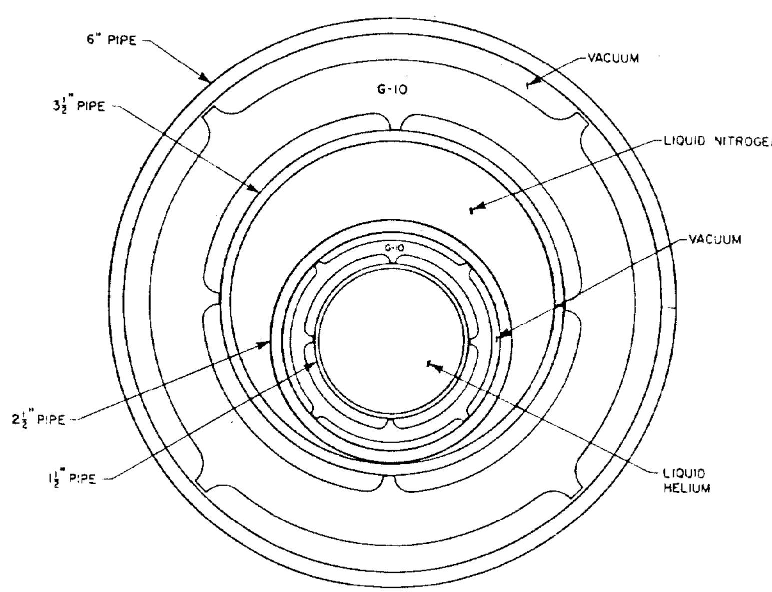


Figure 5 LHe Transfer Line Cross Section