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Selection of Pressure Level and Flowrate of Liquid Helium Through the Magnet

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I. Introduction

The Conceptual Design Report specifies a pressure level of 4 ata and a flowrate of 100 grams/sec in the magnets. This note investigates the effect of a lower pressure level on the system. At a pressure of 2 ata, specific heat of the liquid helium is larger than at 4 ata and consequently flowrate may be reduced. This in turn reduces the pressure drop and power dissipated by the liquid helium circulating pumps will decrease.

The 20 K shield cooling system and 4 K liquid helium magnet system are coupled through some 1600 valves. These valves will relieve pressure in the single phase system during a quench of the magnet system. Operation of the 20 K shield system at a higher pressure than that of the magnet system may lead to leakage of 20 K gas to the magnet fluid system. It appears that the expected leak rates probably may lead to an increase of magnet temperature of the order of 60-70 mK. In a worst case scenario, pressure in the particular magnet sector may be raised to reduce the effect of the leak.

Operation at 2 ata is also beneficial in case of a quench. Maximum pressures reached, will be lower. During recooling and filling of the quenched magnets, vaporized liquid will flow to the 6 inch warm vapor collector, rather than to the 20 K shield.

II. Discussion

II. 1. Operation at 2.0 or 4.0 ata.

We will compare two operating modes at 2 ata and 4 ata, on the basis of the following assumptions:

1) Maximum temperature of liquid helium before a recooler is 4.250 K.

2) Heatload between recoolers is 50 W.

3) Temperature rise of liquid between recoolers is 0.139 K.

4) Temperature approach between coldest single phase liquid and boiling liquid in the recooler is 0.036 K.

5) Specific heat of liquid helium at 2 and 4 ata and 4.2 K are 4.301 and 3.585 Joules per gram per K respectively.

The increase in specific heat at 2 ata allows a reduction of 16.4% in flowrate through the magnets. This in turn reduces total pressure drop off set by the liquid helium circulating pumps by 0.2 ata. At a pump efficiency of 0.50, savings in heatload generated by the pump will be 218.5 watts per sector. This is roughly equal to 4.65% of the refrigerator maximum capacity.

II. 2. Connections between 4 K magnet system and 20 K shield line.

There are approximately 1600 valves connecting the 4 K magnet system and the 20 K shield line. These valves are opened in case of a quench, to prevent overpressurization of the magnet cryostat.

With the 20 K shield line operating at a higher pressure than the 4 K system, leakage of 20 K helium gas represents a heatload of 120 Joules per gram of leakage. A leakage of 1 g/sec from 2.67 ata to 2.0 ata at a temperature of 20 K requires a $C_v = 0.065$. This is roughly equivalent to a hole with a flow area of about $2 mm^2$.

This is a rather large leak, even for a one inch valve, and typically we can expect the valve to leak at most 0.2 grams per second. Load on the downstream recooler then will be of the order of 50 + 24 = 74 W. This leakage rate also increases the temperature of the magnet liquid by some 67 mK, before it reaches the recooler.

II. 3 Operation at 2 ata during steady state reduces the maximum pressure, which will be reached during a quench. For instance, liquid in the nonquenching magnets is compressed to 93.8% of its original volume at a pressure of 6 ata. This means that a volume of 250 meters length is made available for temporarily storing quenching fluid. Valves between 4 K and 20 K systems possibly could be somewhat smaller, which in turn would reduce the postulated leaks discussed under II.2.

II. 4 Relationship between pressure in magnets and that of the liquid helium distribution header.

For normal operation of the magnets fluid is circulated through the magnet and the liquid helium distribution headers in a series arrangement. In order to accomplish this, the pressure in the liquid helium distribution header, at the point where liquid is added to it from the magnets (midpoint between refrigerators), needs to be always below that of the magnet string. The difference in pressure needs to be large enough to provide for a reasonable control of the valves at these points. At the refrigerator location points, liquid helium is pumped into the magnets from the liquid helium distribution header. A large pressure differential at this point results in a large pumping load.

The above holds true for all operating modes of the system. One of these is the transport of liquid helium from one refrigerator station to the next. Figure 1 illustrates the variation in pressure in the liquid He distribution header, for the case where 1000 liters per hour of liquid helium is transported between adjacent refrigerators. It should be noted, that Fig. 1 is based on a distribution header, which is open over 360°. In going around the ring past the other 6 refrigerator stations (not shown), local flowrates need to be adjusted slightly in order to make the final point A be at the same pressure level as point B.

III. Conclusions

1. The magnet system should be operated at a pressure level which is comfortably above the pressure of the liquid in the liquid helium distribution headers.

2. If the liquid helium pumps employed in the magnet system are designed to deliver a differential pressure of at least 2 ata, magnets system and liquid helium distributor pressure may be selected to suit any desired operating level.

3. To provide the capability of selecting pump throughput independently of differential pressure, reciprocating pumps should be used.

4. The magnet system may be operated at a lower pressure than that of the 20 K shield. In that case, recovery from a quench may have to be carried out by flowing helium from the magnets to the warm gas header during the recooling of the magnets.

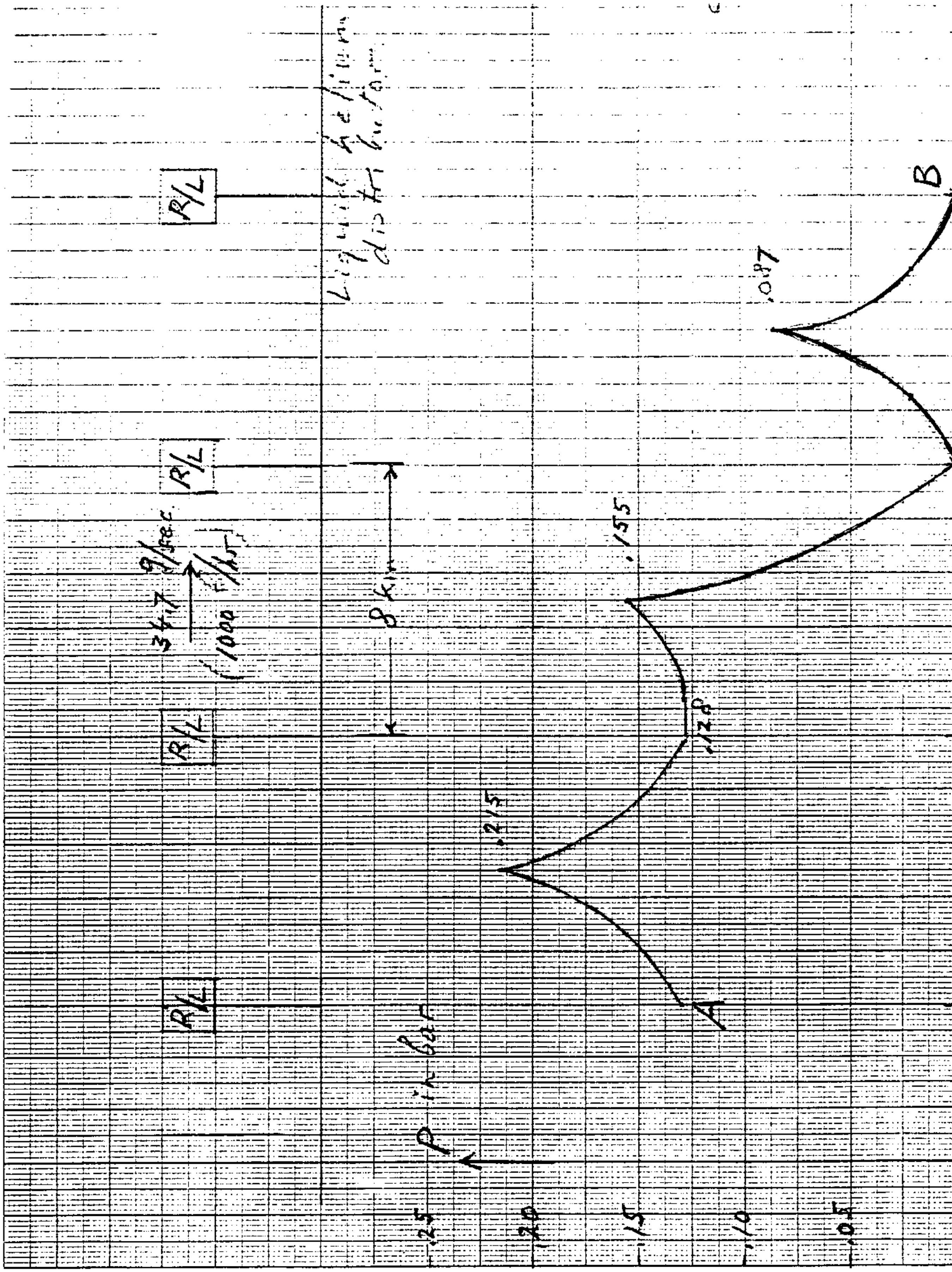

Figure. 1.

Appendix

Liquid helium pump work for 2 cases.

Case 1 (Magnets operating at 4.0 ata)

In	Out	Out	Out
P = 3,3 ata	p = 4.0	p = 4.5	p = 4.1
T = 4.25K	T =	T =	T =
H = 10.54	H = 11.065	H = 11.43	H = 11.14
S = 3.223	S = 3.223	S = 3.223	S = 3.223
	%H = 0.525	%H = 0.89	%H = 0.60

With an efficiency of 0.5, work of pump is 1.2 Joules per gram of liquid circulated. Per refrigerator we circulate 400 grams. Total work is 480 watts.

Case 2 (Magnets operating at 2.0 ata)

In	Out
p = 1.8	p = 2.4
T = 4.25	T =
H = 10.084	H = 10.475
S = 3.384	S = 3.3384
	%H = 0.391

With an efficiency of 0.5, work of pump is 0.782 Joules per gram of liquid circulated. Per refrigerator we circulate 83.66 x 4 = 334.4 grams per second. Total work is 334.4 x 0.782 = 261.5 W.

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