

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 re cooler is 4.250 K.
- 2) Heatload between re coolers is 50 W.
- 3) Temperature rise of liquid between re coolers is .139 K.
- 4) Temperature approach between coldest single phase liquid and boiling liquid in the re cooler is .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 .2 ata. At a pump efficiency of .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 2mm^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 re cooler 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 re cooler.

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.

III. Conclusions

1. The only good reason for operation of the 4 K magnet system at 4 ata is the occurrence of a leak between the 4 K system and the 20 K shield line.
2. A system which normally operates at 2 ata, may be operated at 4 ata at the expense of a few hundred watts of refrigeration per refrigerator. In order to make this possible, liquid helium pumps need to be designed to deliver fluid at a differential of at least 2 atm.
3. Operation at 2 ata will make things easier in case of a quench. Recooling of magnets after a quench will then be carried out by flowing warm gas to the 6" IPS gas collection header instead of the 20 K shield.

Appendix

Liquid helium pump work for 2 cases.

Case 1

<u>In</u>	<u>Out</u>	<u>Out</u>	<u>Out</u>
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
	$\Delta H= .525$	$\Delta H= .89$	$\Delta H= .60$

With an efficiency of .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

<u>In</u>	<u>Out</u>
p= 1.8	p= 2.4
T= 4.25	T=
H= 10.084	H= 10.475
S= 3.384	S= 3.3384
	$\Delta H= .391$

With an efficiency of .5, work of pump is .782 Joules per gram of liquid circulated. Per refrigerator we circulate $83.66 \times 4 = 334.4$ grams per second. Total work is $334.4 \times .782 = 261.5$ W.

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