SUPERCONDUCTING ACCELERATOR MAGNET COOLING SYSTEMS

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Summary

A cryogenic system has been designed for ...ing ~1000 superconducting magnets associ... with the proposed "energy-doubler" at the ...al Accelerator Laboratory. This paper ...rts on design parameters, cooling concepts, ... transfer and pressure drops. Even though ...inal design changes are anticipated, the ...t in this work is to complete a refrig...ation design which would accomplish the ...ing necessary for the energy doubler mag...

Design Parameters

From the time that R.R.Wilson[1] first ...posed to increase the energy of the 200/500 ... GeV accelerator by the incorporation of a ...arate superconducting ring of magnets in ... meter long tunnel, emphasis has been ...ed on utilizing existing facilities such ... the main ring tunnel, the service buildings, ...connecting passages and the installed ...ities. Also used is the concept of self-...icient independent modules with the in...connection between modules limited to a ... pipe for the proton beams.

Since there are 24 service buildings lo...ed at approximately 240 meter intervals ... the accelerator, and these buildings ...ly partly occupied with equipment, we ... considered locating the refrigeration ...ment in these buildings and have inves...ated the feasibility that each refrigera... service at least 240 meters of energy ...ler magnets. Depending on refrigeration ...ements and the size of equipment, it ... feasible to reduce the number of re...erators to 12.

Other design parameters chosen at the ... of the project were the following:

1) The magnets will be constructed with ... located outside the vacuum shell of ...net dewar.

... Total refrigeration requirements ...lected to be 5 watts per meter. This ... chosen on the basis of information ... papers by P. F. Smith and Bronca ... 3.

In particular, in the third reference ... time of 33 s the total losses were ... 4.4 watts/meter for a warm iron mag-...ilar to energy doubler magnets. The ... losses were estimated as 3.5 watts/... leaving 0.9 watts/meter for the ac... We, therefore, began our studies by ... following division of the refrigera...ls:

...es in the magnet:	1 watt/meter
...in through insula... and supports of the ...:	2 watts/meter
...ellaneous:	2 watts/meter

The total amount of refrigeration to be provided served primarily as a guide in order to be able to develop concepts for the refrigeration system.

Cooling Concepts

One of the most difficult problems of the cryogenic design of a superconducting accelerator is the transport of refrigeration from a central refrigerator or liquefier to the magnets located at great distances. A basic system might consist of transfer lines carrying liquid and gas, running in parallel with the accelerator. Examination of this system leads quickly to the conclusion that the cost of such a system is very high. Location of small refrigerators at short intervals eliminates the transfer line system. Again, the cost of such a system is high and operational reliability probably is low.

Since the magnets form a completely closed loop, it seems desirable to use the magnet system itself as the transport system for the cryogenic fluids. Reference 4 describes a system in which supercritical helium is pumped around the accelerator loop.[4] Heat exchangers and pumps located at the service buildings remove heat from the liquid. The system depends on the specific heat of supercritical helium for removal of heat from the magnet system. This requires a temperature rise along the path of fluid flow. If the temperature rise is to be kept to a low value, flow rates need to be high. This, in turn, means increased pressure drop and a relatively large amount of heat generated by the pumps moving the supercritical helium. This increases the size and cost of the helium refrigerators. The concept was abandoned because it is difficult to isolate parts of the system in case of magnet failure. Also, the temperature rise of the liquid helium flowing through the magnets limits superconductor capability at the warm end and results in rather short distances between adjacent refrigerators.

Figure 1 shows the schematic flow arrangement of a module of the magnet system, which eliminates the disadvantage of a rising liquid helium temperature along the path of flow. A helium pump compresses liquid helium from a liquid helium reservoir of the refrigerator. The supercritical helium flows through and around the windings of the magnets over a distance of some 120 meters. At the end of the path (halfway between service buildings), the liquid helium flows through a valve and becomes boiling liquid helium. The boiling helium is returned through an annular space around the magnet vessel to the liquid reservoir of the refrigerator. A fraction of the liquid helium is vaporized through heat transfer. Part of the heat transfer takes

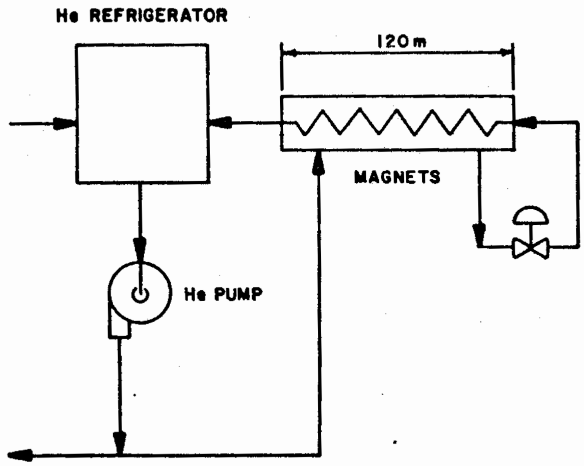

Figure 1.

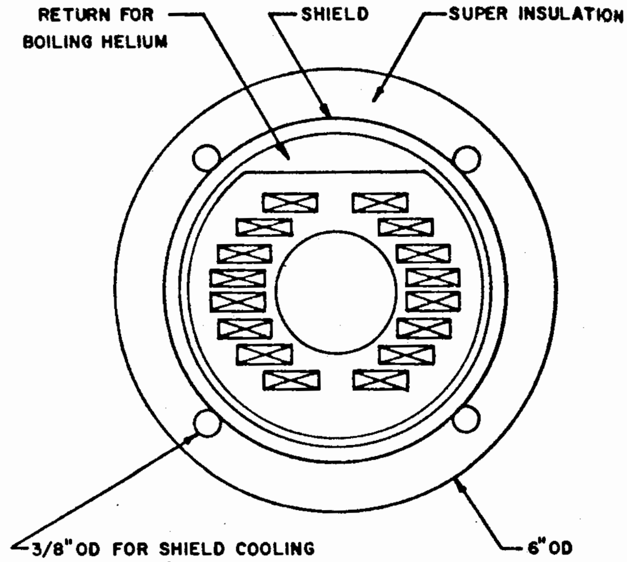

Figure 2.

place between the supercritical helium in the magnet vessel and the boiling helium in the annular space. Heat arriving from the environment also vaporizes part of the low pressure helium.

The system of Figure 1 has a number of interesting features, as follows:

1) With a large surface area for heat transfer between supercritical and boiling helium, it is possible to maintain a constant temperature in the magnet vessels independent of distance from the refrigerator.

2) The heat flowing in from the warm environment never enters the supercritical helium system of the magnets.

3) It is possible to reduce the temperature of the magnets by reducing the pressure of the boiling liquid helium. For instance, maintaining a pressure of .5 atm in the boiling helium system, a boiling temperature of 3.55°K is realized. With good heat transfer a magnet temperature of 3.7 to 3.8°K may be obtained.

The combination of 1) and 2) reduces the flow required for maintenance of a constant temperature to a minimum. This minimum is determined by the total heat flux to the 4°K temperature system divided by the heat of vaporization of liquid helium.

Figure 2 shows a cross section of a bending magnet in which the described flow system is incorporated. Figure 2 also shows a thermal shield which surrounds the 4°K system and which is maintained at 15-20°K. Heat is removed from the shield by helium gas (at approximately 20 atm) flowing from the refrigerator through 2 tubes. The helium gas is returned through the other 2 tubes to the refrigerator. The tubes are thermally fastened to the shield. The helium of the cooled shield removes the bulk of the heat entering from the warm environment. This reduces the required flow rate of 4°K helium and improves the thermodynamic efficiency of the cryogenic system markedly.

The proposed cryogenic system of Figure 1 and 2 has been examined in more detail to determine whether the advantages as described can be realized in practice.

Heat Transfer

In order to maintain the temperature of the magnets at the lowest possible constant temperature, heat needs to be transferred efficiently from the magnet windings to the supercritical helium and then from the supercritical helium to the boiling helium.

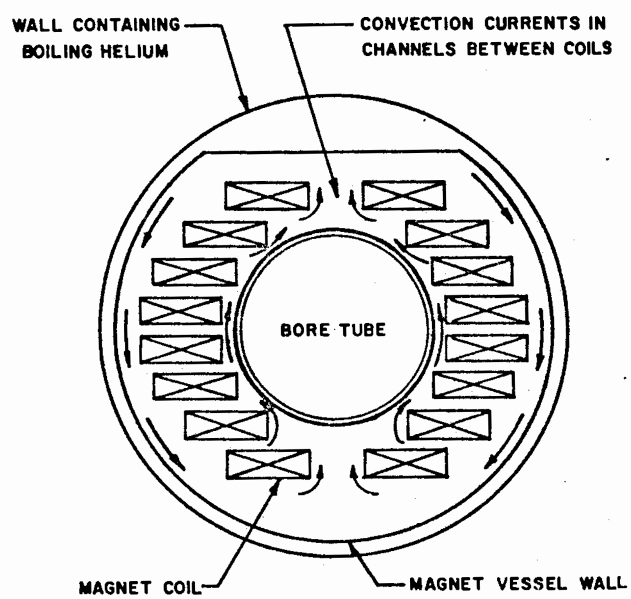

Figure 3.

Figure 3 shows how heat is removed from the magnet windings by the supercritical helium present in cooling channels between the windings. As soon as heat is added to the helium from the windings, its density decreases ther hand, helium located outside the is cooled by the boiling liquid he- the annulus surrounding the magnet Its density increases. The change of the two columns of helium sets tion currents and helium starts to . Calculations have been made to the flow rates obtainable as a func- channel dimensions and temperature the fluid flowing through the chan- the windings. If the heat to be re- of the order of 1 watt per meter of length, the temperature of the windings aintained at a temperature .1 to .2°K bulk fluid temperature outside the . The bulk fluid outside the magnet is cooled by the boiling liquid he- rounding the magnet vessel. The heat coefficients have been determined configuration shown in Figure 2. Al- the wall of the magnet vessel is made less steel, the surface area available transfer is so large that the tem- difference between the boiling liquid critical helium can be maintained at The mass flow rate in the boiling elium channel is an important para- ich determines the type of flow in nnel. Reference 5 discusses the type which may be expected in a channel ixture of liquid and gas is present.[5] is a plot of various types of flow as a function of two parameters de- by fluid properties, fraction of li- gas, and dimensions. For good heat it is necessary that the type of flow channel carrying the two-phase helium le or froth. The two lines (flow rates nd 314 lb/h) indicate that in vapor- proximately 50% of the liquid helium ng through 120 meters of channel, the flow is always bubble or froth.

Pressure Drop

er the minimum flow rate required for tory heat transfer has been determin- ure drop in the flow system may be ed. The dimensions as shown in Figure 2 were used with a flow rate as determined for maintenance of satisfactory heat transfer. Table I shows the pressure drop of the high pressure flow in the magnet vessel and the boiling helium in the annulus surrounding the magnet vessel for a distance of 120 meters.

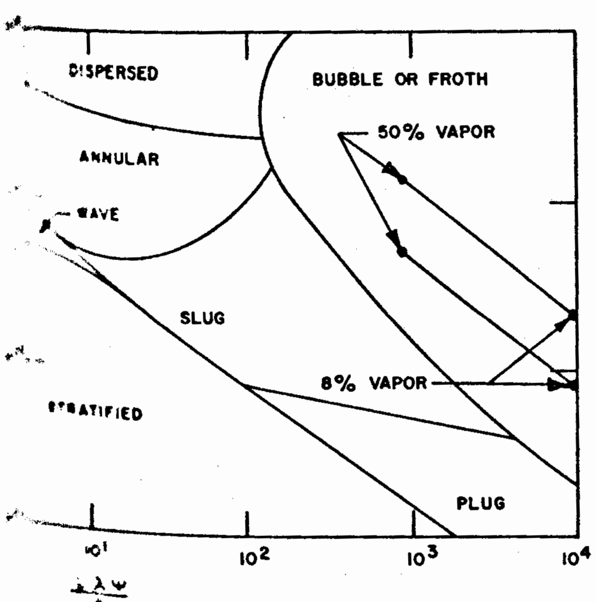

Figure 4.

T A B L E I

Pressure Drop of Supercritical and Boiling Helium Streams

Flow rate of liquid helium:	115 lb/h
Pressure drop of super-critical helium:	1.65 psig
Pressure drop of boiling liquid helium:	.56 psig

Refrigerator Requirements

Magnet supports and insulation have been determined with sufficient detail to permit a reasonably accurate estimate of refrigerator requirements. Table II shows the various heat loads at the 4 and 20°K temperature level for a refrigerator serving a module with a total length of 240 meters.

T A B L E I I

Refrigerator Requirements

Refrigeration at 20°K:		650 watts
Refrigeration at 4.4°K:		
Pump work	120	
A-C heat in magnets	240	
Heat from 20°K environment	20	
Miscellaneous	60	
		440 watts
Liquid helium for leads:		25 l/h

References

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