**LHC Luminosity Upgrade: Cryogenic Parametric Studies of a He I Cooling System for a Forward Q0 at ATLAS/CMS**

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For a He I-cooled forward Q0, $Nb_3Sn$ must be used for the coil conductor. Temperature drop across the Kapton wrap brings NbTi above or unacceptably close to its critical temperature. Parametric studies have been carried to estimate coil temperatures and to estimate some of the cryogenic system characteristics.

These studies assume a supply of saturated liquid or slightly two-phase helium. The exact supply conditions depend on the local cryogenic system.

## Pressurized He I Cooling System

A very basic flow schematic for a pressurized He I cooling system is presented in Figure 3. A rough temperature profile is also included.

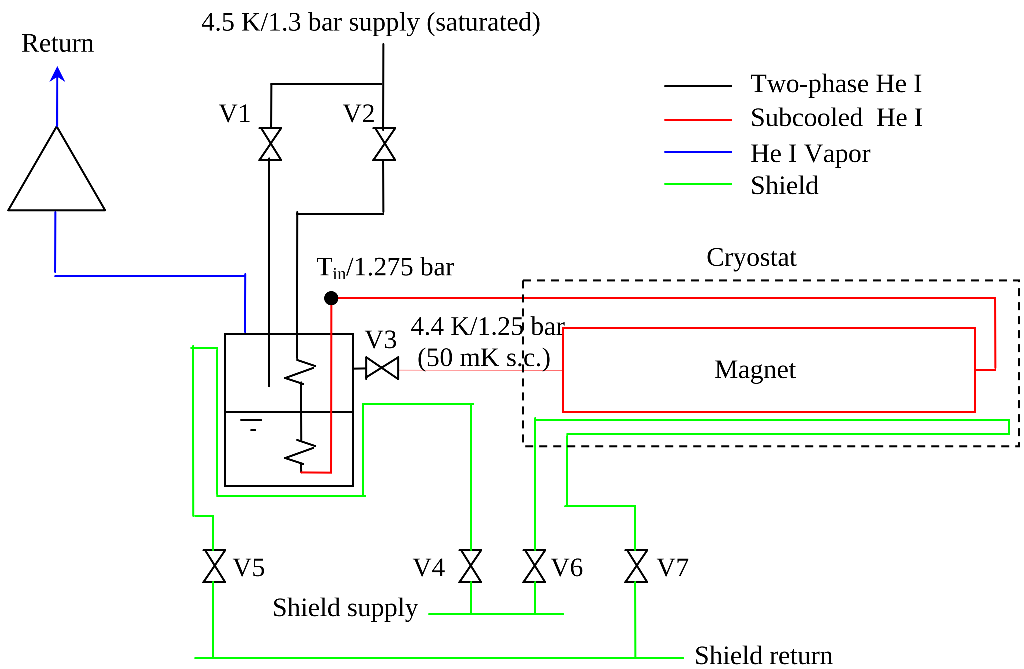



Figure 3 1.9 K static bath cooling system flow schematic.

It is assumed that a thermal shield will be integrated into the cryostat.

**Parametric Studies**

For the purposes of these studies, it is assumed the beam pipe has an outside diameter of 70 mm and the coils have an inside diameter of 100 mm.

Figure 2 plots the required inlet temperature of a magnet as a function of heat load and mass flow rate. It is assumed the exit temperature from the magnet is 4.4 K, 50 mK below the saturation temperature, ensuring subcooled liquid at the outlet of the magnet. Detailed analysis using local heat deposition rates is needed to ensure localized boiling does not occur.

A mass flow rate of 15-25 g/s would allow relatively large heat loads to be removed without requiring excessive subcooling and the associated equipment.

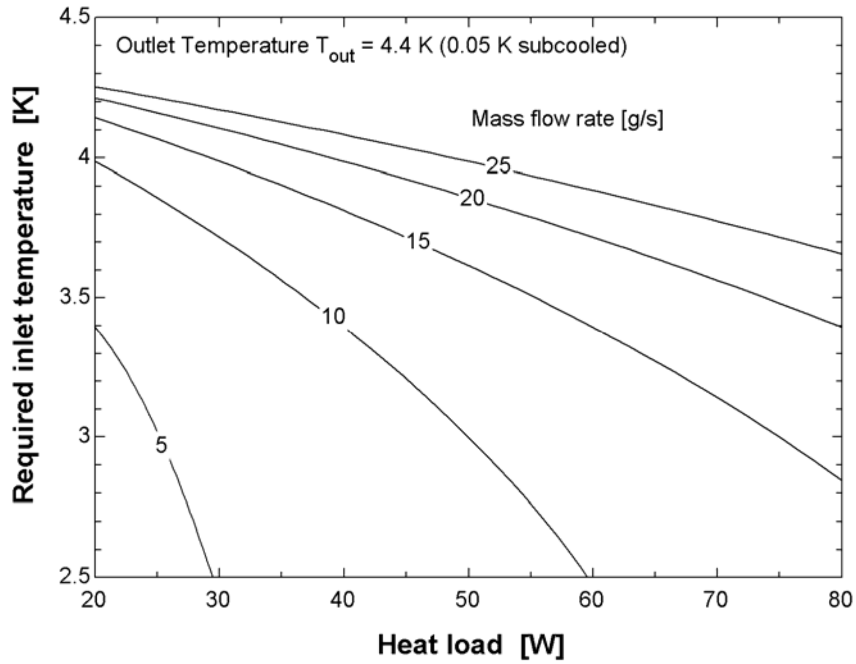
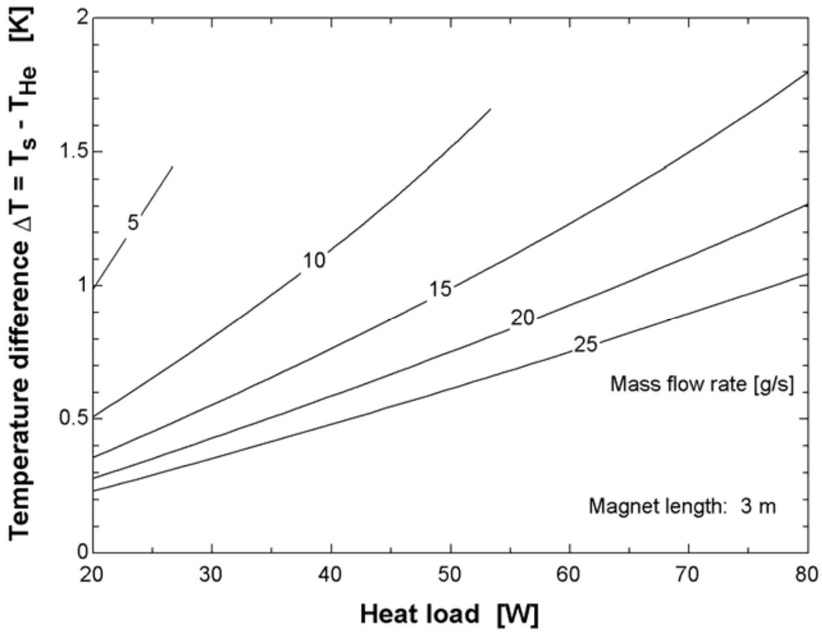


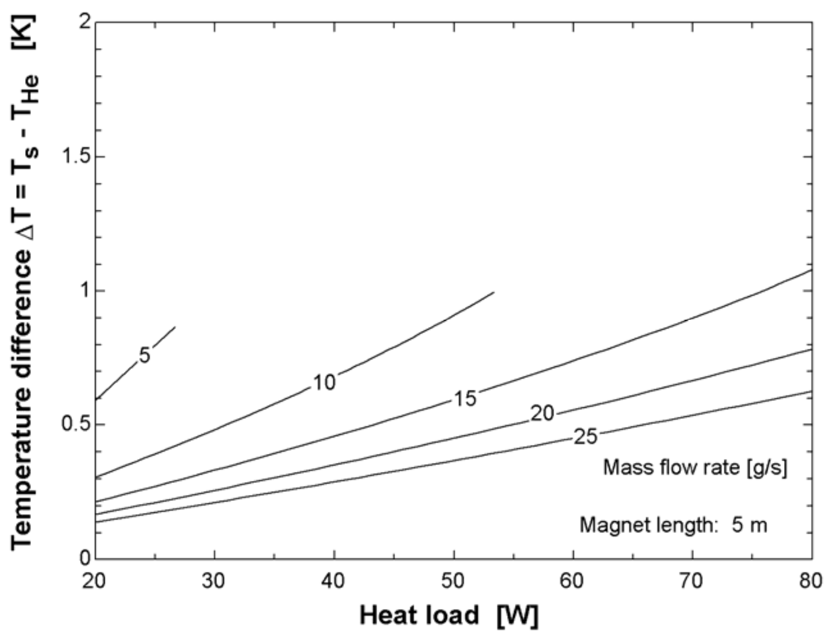

Figure 2 Required mass flow rate vs. heat load for subcooled He I cooling of a forward Q0.

Figures 3a-c plot the difference between the surface temperature of the epoxy insulating the Nb3Sn coil and the bulk He flow as a function of heat load for three different magnet lengths and mass flow rates of 5-25 g/s. Again using 15-25 g/s as a reasonable flow range, the temperature difference between the surface and the helium is 1-2 K. Up to an additional 0.3 K can be expected across the epoxy insulating the coil surface.

Temperatures within the coils are governed by the volumetric heat deposition and the thermal conductivities of the coil materials. Detailed analyses of conduction-cooled coils are required to determine the limiting operating temperature margin.




<u>Figure 3a</u> Surface temperature difference vs. heat load for a 3 m He I cooled magnet with mass flow rates of 5-25 g/s.




<u>Figure 3b</u> Surface temperature difference vs. heat load for a 5 m He I cooled magnet with mass flow rates of 5-25 g/s.

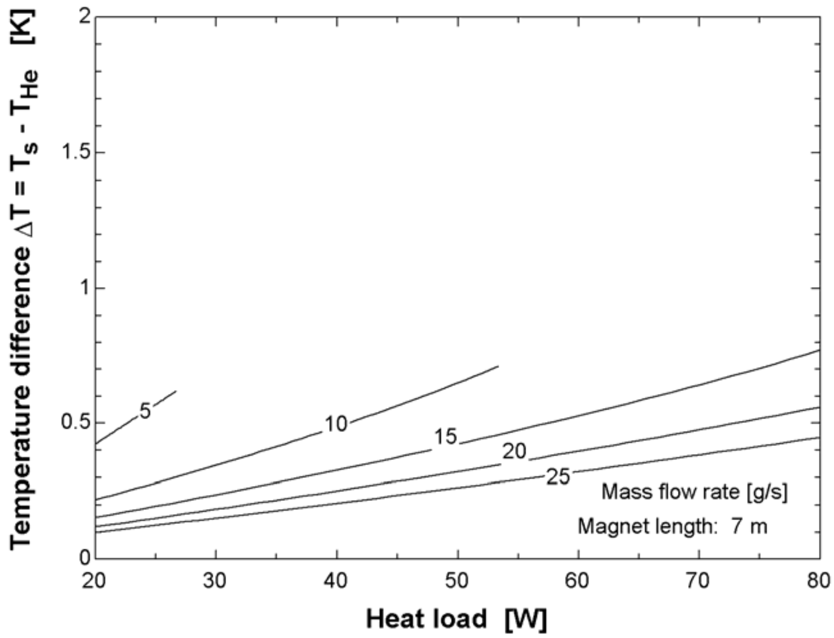



Figure 3c Surface temperature difference vs. heat load for a 7 m He I cooled magnet with mass flow rates of 5-25 g/s.

The preceding three figures can be consolidated into Figure 4, showing the temperature difference between the surface and the bulk helium as a function of heat flux for mass flow rates of 5-25 g/s.

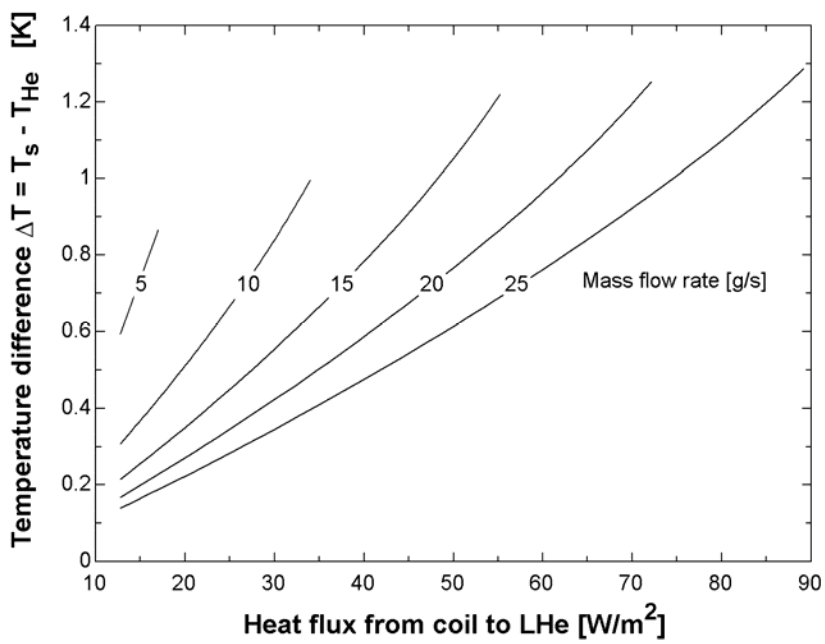



Figure 4 Surface temperature difference vs. heat flux for a He I cooled magnet with mass flow rates of 5-25 g/s.

Figure 5 plots the maximum length of piping for the subcooled He I vs. pipe diameter. The allowable pressure drop is 0.025 bar. An inner diameter of 15-20 mm appears to be the minimum, allowing piping lengths of up to a few tens of meters.

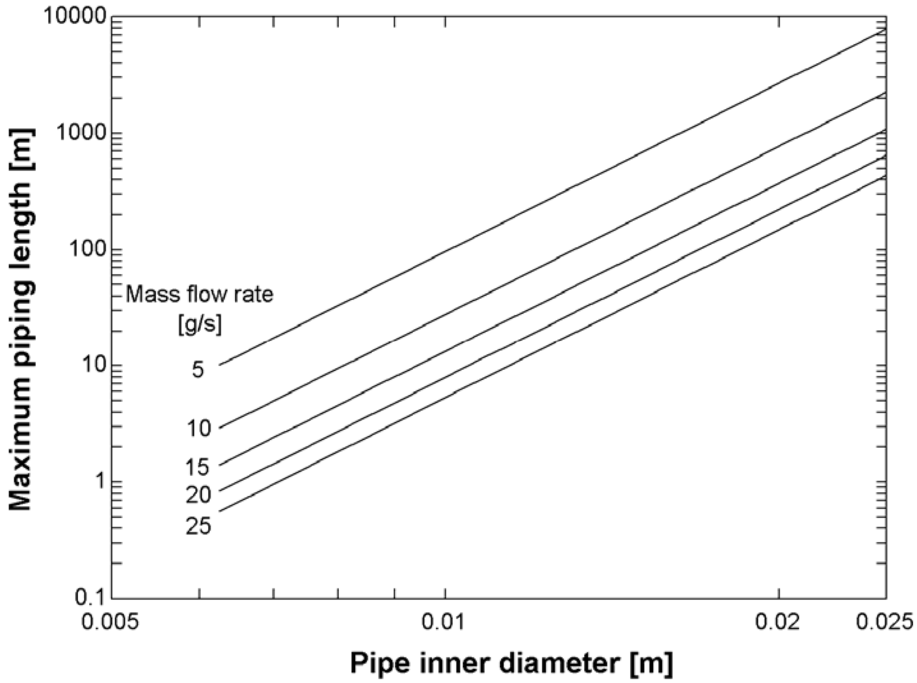



Figure 5 Maximum piping length vs. pipe inner diameter for subcooled He I flows of 5-25 g/s.

**Physical Installation**

In addition to the magnet itself, space must be allocated for several additional items:

- 4.4 K supply pipe. This line is used both during cooldown of the magnet from 300 K to 4.5 K and during normal operations, when there is a continuous flow of subcooled He I. An estimated size for this vacuum-jacketed line is 25 mm inner line and 88 mm outer line.
- 4.4 K return pipe. This line takes the flow from the magnet exit to the subcooler bath. An estimated size for this vacuum-jacketed line is 25 mm inner line and 88 mm outer line.
- Thermal shield supply and return. An estimated size for these vacuum-jacketed lines is 25 mm inner line and 50 mm outer line.
- Cryogenic operation of the subcooler and the magnet are performed by valves V1, V2, and V3. V1 is a control valve to regulate the subcooler liquid level. V2 is an isolation valve for the He I flow to the magnet. V3 is a J-T valve to expand the subcooled He I returning from the magnet into the subcooler bath.

- Subcooler and cold compressor, either centrifugal-type or reciprocating-type. Heat loads and system volume are not as critical in a forced flow He I system as they are in a He II system, so there is more freedom as to where the equipment can be placed.

It is preferable to thermally shield the 4.4 K supply and return pipes because these lines will be filled with liquid helium.

Shielding can be integrated into flexible lines by companies such as Nexans Deutschland Industries GmbH & Co [1]. Another option is to use thermally-shielded hard piping sections with bellows, indium seals, etc. Using hard piping sections is more complicated, but these connections will need to be assembled/disassembled infrequently, only when the detector is opened or closed.

## References

1. K. Schippl, “Flexible transfer lines,” Symposium for the Inauguration of the LHC Cryogenics, CERN, May 31-June 1, 2007.