The Connection of Refrigeration to a Superconducting Magnet with a Minimum amount of Cryogen

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Abstract: The shortage of helium, particularly liquid helium, has made the use of cryogen free magnets attractive. The attractiveness of cryogen free magnets depends on the operating temperature of the magnet, the distance from the cold head to the magnet being cooled, the thermal conductivity of the connection and the size of the magnet being cooled down. This paper discusses cooling down and cooling a magnet that operates over a temperature range from 4 K to 80 K using coolers. Two approaches are discussed. The first is by conduction through high thermal conductivity metal straps. The second is by using a natural convection thermal-siphon cooling loop. The thermal siphon cooling loop behave like a cryogen free magnet with the fluid stored in the loop.

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The Helium Problem

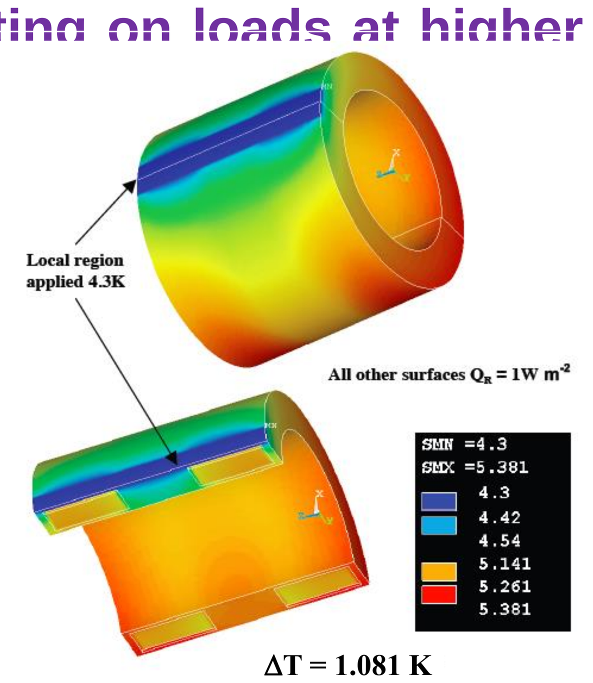
Helium used to be relatively cheap and available in both liquid and gas form. This is no longer true. As a result, universities and laboratories are increasingly using 4 K coolers and helium liquefiers based on coolers

Introduction

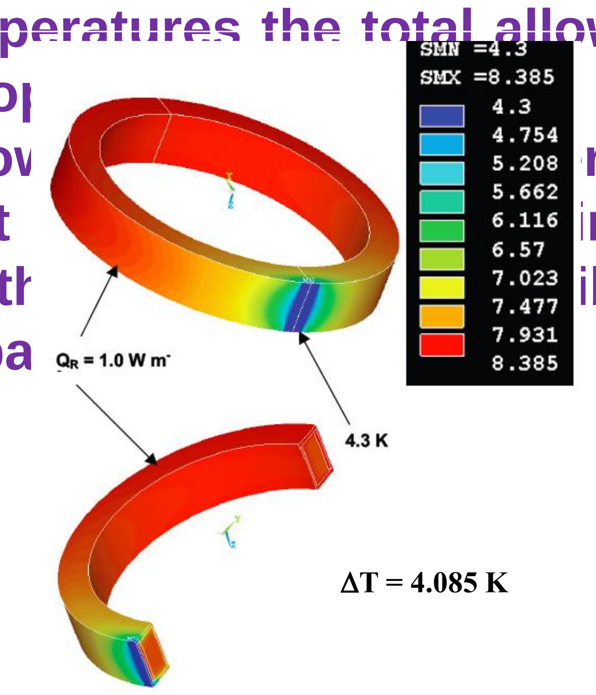
Cooling and cooling-down a magnet with coolers is different from cooling a magnet with a conventional helium refrigerator. When a large helium refrigerator is used, col gas from an expander or J-T valve is delivered to the magnet cryostat at a constant flow and under pressure. When the system is cold enough liquid helium is collected. When the boil-off helium is returned to the cold box cold the machine operates as a refrigerator. When the gas is returned to the system warm it behaves like a liquefier. A cooler delivers refrigeration to the device being cooled by conduction to the cold heads. The connection between the cold head and the magnet can be through a copper strap or some form of a cooling loop or heat pipe. The latter approach requires that there be a connection through gas or combined liquid and gas in the cooling loop

Cryogen-free Conduction Cooling

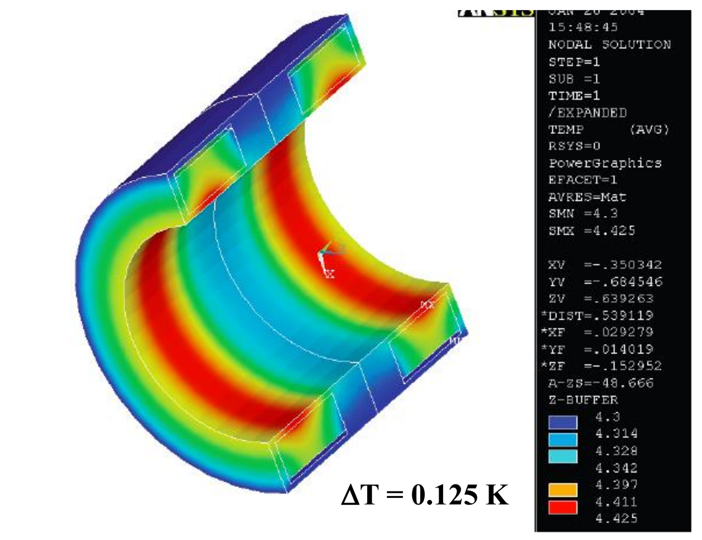
The refrigeration delivered by a cooler is a function of the cooler cold head temperature. That is true for single-stage or two-stage coolers. For heat to flow to the cooler cold heads there is a temperature drop across the strap connected to the load and there is a temperature drop within the load. The total allowable temperature drop at 4 K between the hot spot in a magnet to the cooler cold head should be < 0.5 K. For coolers operating on loads at higher temperatures the total allowable tempe… prop… head tempe… belov… rature distril… gnet… ine on the ou… d with… ibuted on the… oil pa…

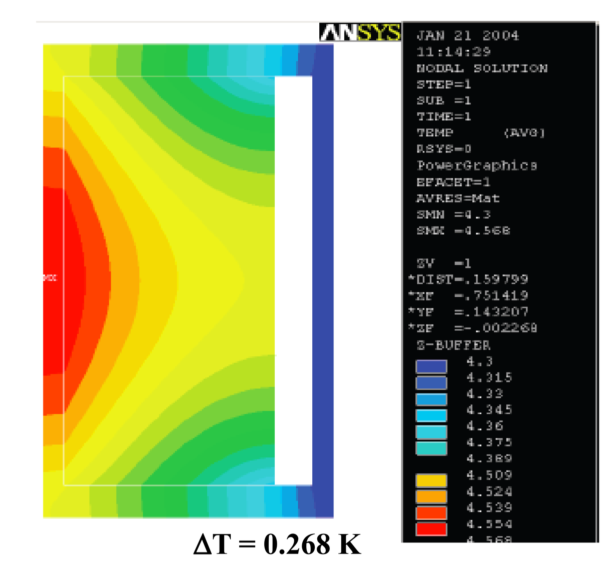


Temperature distribution in the MICE focusing coil with cooling on a single line. The coil area is 3.07 m^2; the coil average diameter is 0.62 m; and the cooling needed is 3.07 W.



Temperature distribution in the MICE coupling coil with cooling on a single line. The coil area is 4.31 m^2; the coil average diameter is 1.66 m; and the cooling needed is 4.31 W.



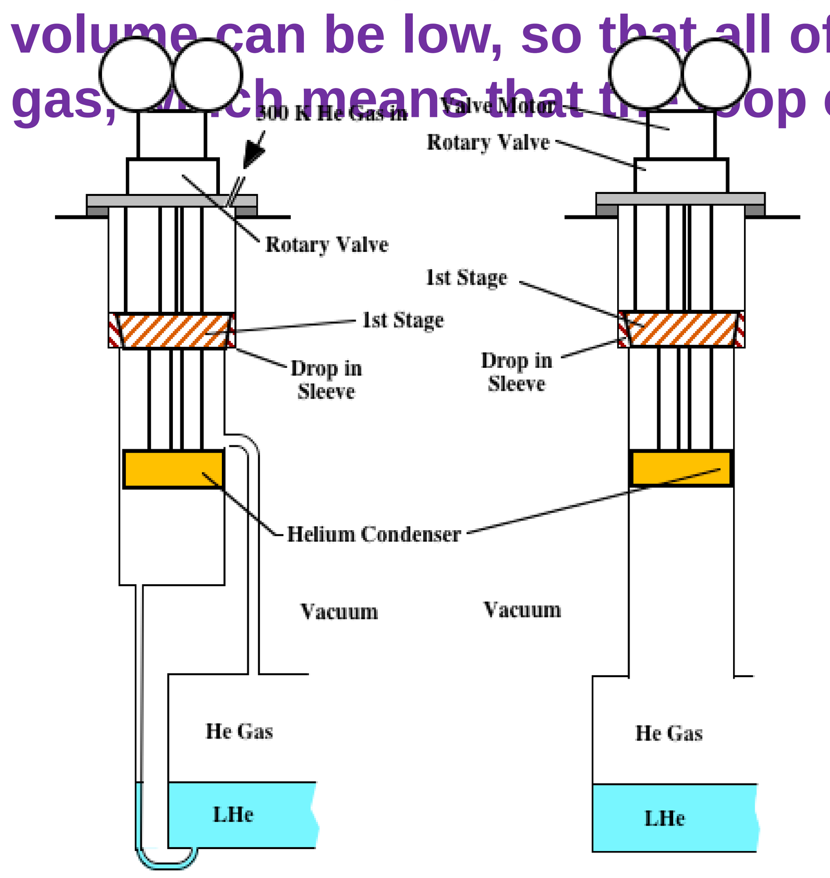


Temperature distribution in the MICE focusing coil with cooling on the outer surface.

Temperature distribution in the MICE coupling coil with cooling on the outer surface.

Thermal-siphon Cooling Loop

The reduced temperature drops shown above can be achieved using a two-phase thermal-siphon cooling loop to connect the cooler cold head to the load. The advantages of the loop are: 1) Low ΔT (~0.1 K for helium) can be achieved between the load and the cooler cold heads, 2) The coolers can be far from the load as long as they are located above the load. The ΔT is independent of the distance between the load and coolers. 3) More heat can be transferred per unit area through the pipes than a copper strap. 4) Drop-in coolers can be used for maintenance and ease of shipping. 5) Several coolers can share the same loop. 6) The loop can cool-down the load and liquefy the cooling system cryogen. 7) The liquid volume can be low, so that all of the cryogen can be stored as gas, which means that the loop can be a closed cycle loop.



Drop-in cooler systems using PT415 coolers. The system on the left permits a magnet to be cooled-down using a thermal siphon cooling loop. This system will liquefy helium gas at room temperature. The system on the right is a standard re-condenser. This system will re-condense helium and other gases and thus provide cooling to the load. The re-condenser on the right will cool-down a magnet, but the cool-down is not very efficient. The system on the right won't liquefy helium gas at room temperature

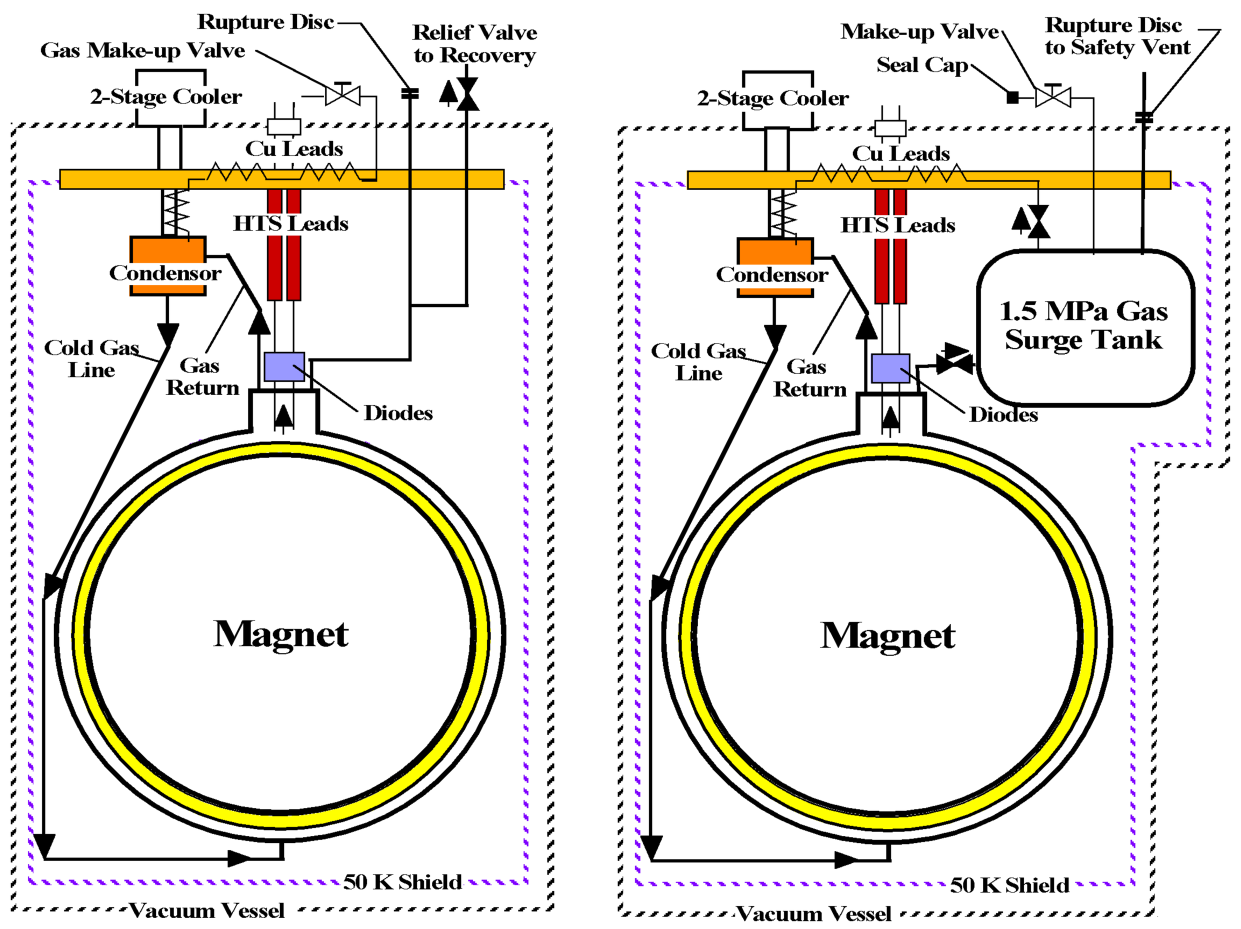
Cooling Loops can use other Cryogens besides He

Any fluid can be used to transfer heat to a cooler when there is two-phase cooling. We looked at hydrogen and neon along with helium. While cooling-down a load, hydrogen is a little better than helium. A cool-down with neon in the loop takes

Cryomech PT415 Drop in Cooler 1[st]-Stage with a Condenser attached to 2[nd]-Stage

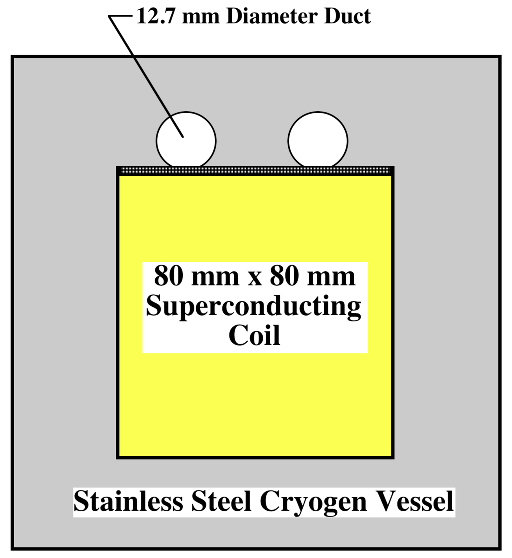
MSU Gas-stopper Magnet

Gas-stopper Magnet Condenser Boxes

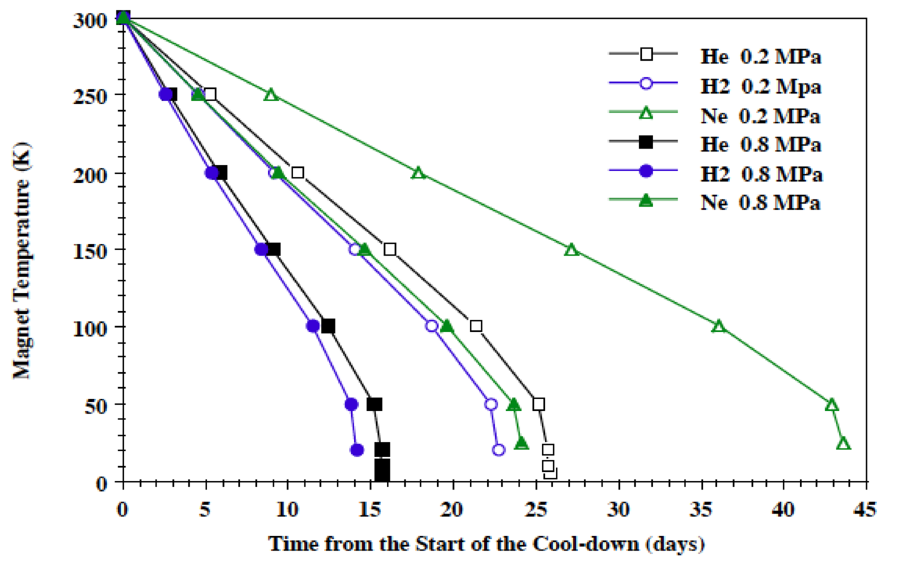


a) Open System for He *b) Closed System for He, H_2, and Ne*

Open and Closed Magnet Cooling Loops



The cross-section of a 1250 kg coil with two 12.7-mm diameter cooling tubes



Calculated temperature versus time for the coo-down of a 1250 kg coil using a PT415 cooler. The loop gases are He, H_2 and Ne at loop starting pressure of 0.2 and 0.8 Mpa.