

Heat Leak into Cryostat # 1 through Axial Supports

Robert J. Weggel, Magnet Optimization Research Engineering, LLC

May 18, 2012

This brief report predicts the wall power necessary to cope with heat conducted into Cryostat #1 by the mechanical supports that resist the 46-MN axial force. These supports must have an aggregate cross-section of about 0.1 m² and should be short, in order that they be stiff. Even if of a stainless steel (a material with quite low thermal conductivity) the supports may constitute a major heat leak into the cryostat. The analysis below assumes support members 20 cm long. One candidate geometry is tubular, of wall thickness ~1 cm and diameter ~3.2 m, the mean diameter of the magnets.

The assumed material is Type 304 stainless steel. Its thermal conductivity ranges from 15.3 W/K·m at 300 K to 0.3 W/K·m at 4.2 K [E.D Marquardt, J.P. Le and Ray Radebaugh, "Cryogenic Material Properties Database," 11th International Cryocooler Conference, June 2000]. To predict the thermal conduction along the support I divided it axially into 100 slices and summed the temperature drops across each one, given the assumed heat flow and temperature-dependent thermal conductivity of the slice. Iterating the assumed heat flow matched the predicted temperature of the cold end with its desired value of 4.22 K; the heat flow needed to match cold-end temperatures is ~1.5 kW. If one could achieve 100% Carnot efficiency, the required wall power would be ~110 kW; if the actual refrigeration efficiency were 22%, the required wall power would be half a megawatt.

One can greatly reduce the required wall power by heat sinking the support along its length. For example, if halfway along the length of the support member one clamps its temperature at 77 K (e.g. with liquid nitrogen), the required wall power at 100% Carnot efficiency drops to 31 kW, 3½ times less than without such thermal clamping. The optimum clamping temperature is ~49 K (from, say, helium gas from a cryocooler); the minimum wall power requirement is about 25 kW at 100% Carnot efficiency. With thermal clamping at an additional axial location one can reduce the power somewhat further. For example, the wall power requirement drops below 20 kW if one clamps the temperature not only at 77K but also at 28K (the temperature of liquid neon) at 80% along the length of the support.

Refrigeration kW for 0.1-m² 304-SS Supports 20 cm Long

