# Abstract

The use of superconductor in the field winding of an electrical generator increases its efficiency, reduces the weight and cost, but with the added complexity of keeping the field winding at a temperature below 5 K. To minimize the liquid helium requirement for cooling of the field winding, the heat leak to the cold space should be kept as low as possible. Convective heat transfer between the warm structure of the generator and the cold rotor is mostly eliminated by maintaining a high vacuum insulating space around the rotor and radiation heat inleak is reduced substantially by the use of radiation shields. The rotor is isolated from the warm portion of the drive train by a pair of thin hollow cylinders called *Torque Tubes*, which as the name suggests, transmit the drive torque to the rotor. The field winding is energized by a pair of current leads. The torque tubes and the current leads play important role in the operation of the generator. Most of the steady state heat leak into the cold space comes through these two subsystems.

The torque tube should be strong enough to carry the steady state and the fault torques in the machine. This requirement calls for a thick and short tube, in direct conflict with the thermal isolation requirement which asks for a thin and long tube. In addition to the torque, the tubes carry the weight and unbalanced centrifugal force. They also sustain a stiff temperature gradient of 300 to 4 K over a short span. In order to minimize the heat leak into the cold space through the torque tubes, the boil off helium vapour is passed over the tubes in a direction opposite to that of the conduction heat flux. Thus, from thermal analysis point of view, the torque tubes constitute a special class of a counterflow heat exchanger where the heat exchange process takes place between the axially conducting metal tubes and the helium stream flowing opposite to the direction of heat flow. The heat transfer process in this unique class of heat exchangers has been analyzed. The governing equations of the exchanger have been expressed in terms of special dimensionless parameters, which has led to the development of a general design chart. A numerical technique has been developed for simulating torque tubes incorporating tem-

perature dependant fluid and metal properties.

The performance of the current leads is another key element in the satisfactory operation of the field winding. The current flowing in the leads is generally of the order of 1000 amperes. To carry such a high current, a good electrical conductor must be used so that the Joule heating can be kept low. But a good electrical conductor is also a good thermal conductor; it pumps a significant amount of heat to the cold space. Thus the final design of the current lead must be a compromise between these two conflicting requirements. Further, the boil off helium vapour is passed in counterflow through the hollow current leads to intercept some of the heat inleak. The analysis of the current lead is in many ways similar to that of the torque tube heat exchanger except for a source term resulting from Ohmic heating. But unlike the torque tubes, the geometry of the current lead is not predetermined. In fact, the designer has to determine the optimum geometry that leads to the minimum heat leak into the cold space. Four different lead geometries have been analyzed — a cylindrical rod with a concentric longitudinal hole, a cylindrical rod with an external sleeve, a rod with spiral grooves and a rod with radial perforated disk fins. The performance of the leads can be expressed in terms of a parameter $Il/A$ where $I$ = current (A), $l$ = length (m) and A = cross sectional area ($m^2$). The optimum values of this parameter for the different lead geometries have been determined separately. The leads also have been analyzed for the case of complete coolant loss and possible burn out. The time required to attain burn out temperature is determined as a function of design and operating parameters.

The thermodynamic models of the torque tubes and the current leads, as well as those of a host of other minor components is bound together to form a comprehensive program for the thermal and hydrodynamic simulation of the cooling circuit of a superconducting generator. The simulation software can be used to predict the liquid helium requirement and the steady state temperature and pressure profiles in the rotor. The software will find application in the design of the cooling circuits of superconducting generators.