

CRYOSAVER™

CURRENT LEADS

APPLICATION NOTE: HTS110-01

END CAP RESISTANCE AND HEAT SINKING FOR
HTS CURRENT LEADS

End Cap Resistance and Heat Sinking for HTS Current Leads

HTS current leads offer a reliable method for reducing the heat leak into the cold volume of many magnet applications. To gain maximum benefit from the HTS lead, the ends of the HTS lead must be cooled to fix their temperatures. This application note addresses considerations of proper cooling of the HTS leads.

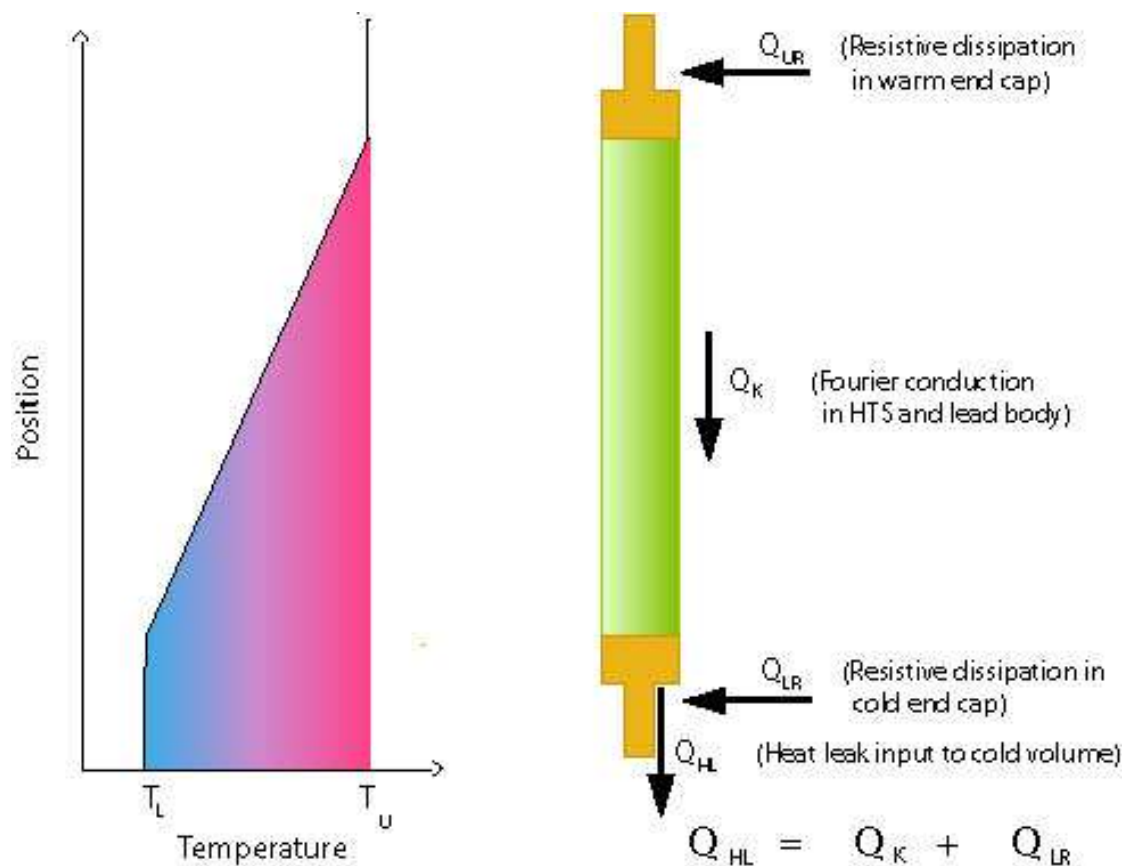


Figure 1. Current lead heat leak description

The HTS lead is shown in Figure 1 spanning the temperature between the cold end temperature (T_L) and an upper temperature (T_U). The cold end cooling may be provided by heat sinking to a cryocooler or by conduction to the cryogen cooling the magnet. The heat introduced to the cold volume by the HTS lead consists of the heat conducted through the lead plus the resistive drop in the lead end cap at the cold end of the lead ($Q_K + Q_{LR}$). The resistance of the cold end cap can generally be designed to be less than $20 \times 10^{-9} \Omega$. This corresponds to a value for Q_{LR} of 0.4 mW for a 100 ampere lead pair. *It should be noted that, in a well designed system, the resistive heating of the warm end cap of the HTS lead is not conducted to the cold end but is instead conducted to the cold head at the upper end.*

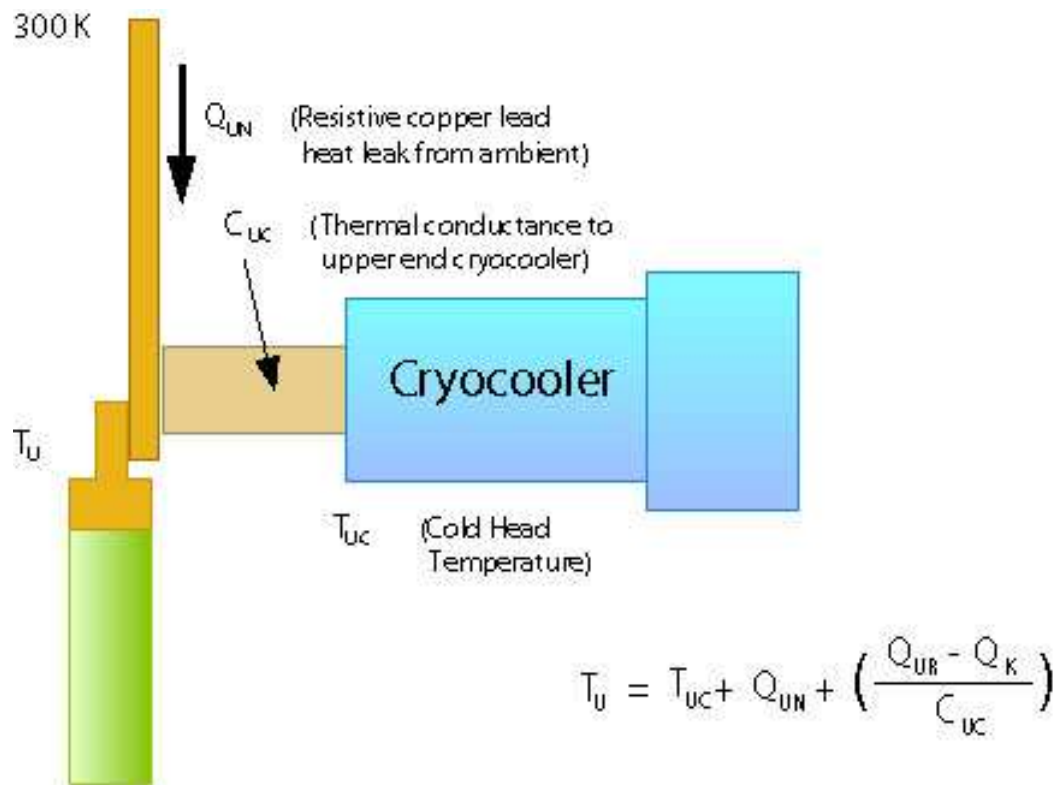


Figure 2. Heat sinking at warm end

The upper end heat sink for the HTS lead is generally provided by a cryocooler. The cryocooler must accept the heat load from the upper (normally-conducting) current lead spanning the temperature between T_U and ambient (300 K) less the net heat conducted into the HTS lead. The thermal conductance to the cooler at the upper end of the HTS lead and the heat load from the upper lead spanning T_U to 300 K determines T_U as shown in Figure 2.

As shown in Figure 2, the conductance to the cold head must be maximized to limit the temperature rise with respect to the cold head. In almost all cases the heat leak through the resistive lead connecting the to ambient temperature (Q_{UN}) is more than 20 times higher than the heat conducted into the HTS lead (ie $Q_{UR} - Q_K$ is negligible compared to Q_{UN}). The performance of the HTS lead is generally quoted for a specific warm end temperature (T_U). If the thermal conductance to the cold head (C_{UC}) is too low, the performance of the lead will be degraded as a significant temperature gradient will develop between the cryocooler and the upper lead. The system designer must ensure that the heat leak from the upper lead is properly heat sunk to the cold head, or the HTS lead temperature will be too high to achieve quoted performance.

In general an optimally designed non-vapour cooled lead pair will have a heat input which is approximately 9 watt/100 amp¹. To limit the temperature rise to the cold head to less than 2 K, the thermal conductance (C_U) to each lead must be greater than 4.5 W/K for a 100-amp lead. This assumes a well designed upper lead.

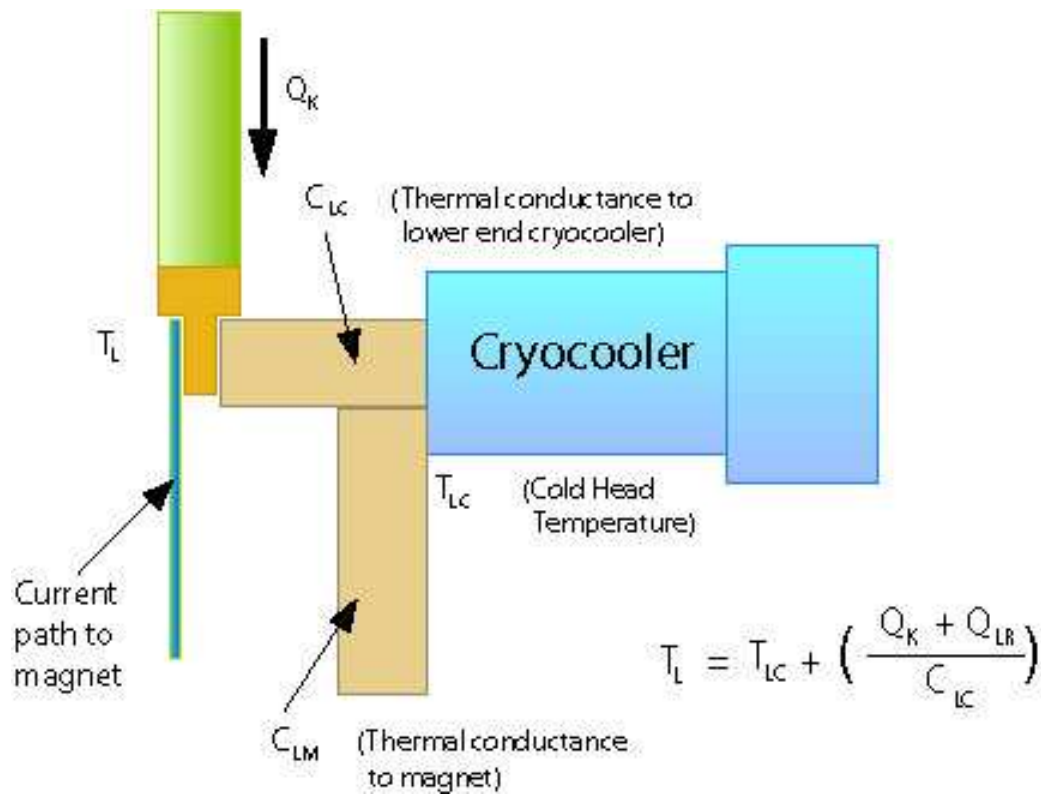


Figure 3. Heat sinking at cold end

The cold end of the HTS lead is shown in Figure 3 assuming cryocooled operation. A dedicated thermal connection to the cold end of the HTS lead is generally preferred. It is generally not good practice to heat sink the HTS lead to the magnet in a conduction cooled application. In many applications the HTS lead is exposed to significantly higher fields at the cold end relative to the warm end. The HTS lead is quoted for a specific cold end temperature (T_L) and if the thermal conductance to the cryocooler is too low, the performance of the lead or the magnet may be adversely impacted. In general a thermal conductance (C_L) of 0.05 W/K for a 100 amp lead will be more than adequate at the cold end.

Nomenclature

T_L	Temperature of cold end cap.
T_{LC}	Temperature of low-temperature heat sink.
C_{LC}	Thermal conductance of link between cold end cap and low-temperature heat sink.
C_{LM}	Thermal conductance of link between magnet and low-temperature heat sink.
Q_{LR}	Resistive dissipation at cold end cap.
T_U	Temperature of warm end cap.
T_{UC}	Temperature of high-temperature heat sink.
C_{UC}	Thermal conductance of link between warm end cap and high-temperature heat sink.
Q_{UR}	Resistive dissipation at warm end cap.
Q_{UN}	Heat leak from resistive lead between T_U and ambient.
Q_K	Fourier conduction down HTS and lead body.
Q_{HL}	Heat leak from cold end cap into cold volume.