MT25
25th International Conference on Magnet Technology
Amsterdam August 27 – September 1, 2017

Optimization of 2G HTS Current Leads Working at External Magnetic Field

Vasily Zubko, Sergey Fetisov, Sergey Zanegin, Alexander Nosov, Vitaly Vysotsky

Russian Scientific R&D Cable Institute, 5, sh. Entuziastov, Moscow, 111024, Russia.

Background

We participate in the project in which where due to space restrictions the limited size of a cryostat demands placing horizontal HTS current leads segments in magnetic field ~2 T. In this paper, we performed the optimization study of HTS current leads segments made of 2G HTS tapes and able to work in the magnetic field up to 2 T. The optimal parameters of the current leads have been determined using numerical simulation. In order to approach the maximum efficiency, it is necessary to have a very good heat exchange between the current leads and evaporating helium gas. The impact of the external magnetic field on the heat leak from current leads into liquid helium has been studied.

Objectives

- HTS segment of current leads with parameters: Number of HTS segments-4; Length of HTS segment 1.1 m; Operating current 2000 A; External magnetic field 2 T; Temperature of warm end 77K; Temperature of cold end 4.5K; Material of HTS tape -2G from SuperOx; Demanded heat leak 0.2 W/kA.

Conclusion

- Four 2000 A current leads based on 2G HTS tapes to work at 2T magnetic field are optimized, designed and produced in Russian Scientific R&D Cable Institute.
- Optimization of the current lead at an external magnetic field is more complicated than without a magnetic field.
- To obtain the minimum heat leak, it is necessary to ensure good heat exchange between HTS current lead and evaporated helium.
- Before use, it is necessary to measure the RRR of the HTS tape.
- If an acceptable heat exchange is ensured then an acceptable heat transfer could be provided by optimization.

Methods

Numerical model

$$\frac{\partial}{\partial z}\left((\lambda S)_i \frac{\partial T_i}{\partial z}\right) = \sum_k (kP)_i^k (T_i - T_k) + (\alpha\Pi)_i (T_i - U) + q_i$$

$$c_p Mg\left(\frac{\partial U}{\partial x}\right) = \sum_i (\alpha\Pi)_i (T_i - U)$$

$$T_i\big|_{z=0} = 4.5K, \qquad T_i\big|_{z=L} = 77K, \qquad U\big|_{z=0} = 4.5K$$

Where for each of the elements (materials) of the current lead (layers of HTS tapes, for example stabilizer etc.): $\lambda = \lambda\ (T_i, B_i)$ is a thermal conductivity; S_i is a cross section; P_i and k_i are a perimeter and heat transfer of contact between contacting elements; q_i is the heat generation; Π_i and α are the perimeter of contact and heat transfer from current lead to the helium. U and c_p are temperature and specific heat capacity of helium, Mg – helium mass flow rate.

$Mg = (Q_c + Q_{add})/C_L = Mg_c + Mg_{add}$, $_{CL}$ is the latent heat of vaporization of the helium, Q_{add} is the heat flux into the cryostat from other sources, Q_c is heat flow at the cold end of the current lead, Mg_c and Mg_{add} are vapor and forced helium mass flow rate.

The heat generation between grid points (j) of the spatial discretization is computed as $Q_{ij}(t,x) = E_{ij} \cdot J_{ij}$. Here J_{ij} is a current density in element of current lead; E_{ij} is voltage over a element. For E in HTS layer of the tape we used usual expression:

$$E = E_c\left(\frac{J}{J_c(B,T)}\right)^n$$

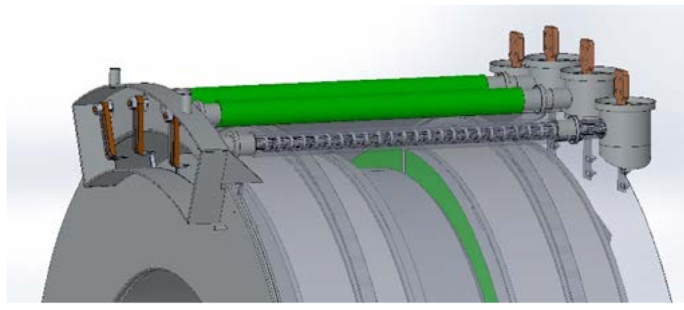
Currents I_{ij} between grids points of the spatial discretization in elements of current lead were calculated from the equation set

$$R_i^j I_i^j - R_{i+1}^j I_{i+1}^j = 0, (i = 1, m-1)$$

$$\sum_{i=1}^{m} I_i^j = I_{total}$$

Samples

Current lead design



Magnet with current lead..

Stainless steel former tube with outer diameter 30mm and 1mm thin wall. A both ends of the tube are plugged with machined copper rods with contact surfaces for connection with other current-carrying elements. 198 HTS tapes are stacked by 9 in 22 stacks and every distributed over the outer surface of the stainless steel tube. Copper rods have 9 machined cylindrical surfaces with step-by-step increasing radii. The increment step is 0.1mm (equal to HTS tape thickness) and length of each "step" is 30mm.

Copper end of current lead. Stacked tapes (except one) are "hidden" to show stepped surface of the copper rod. Double start spiral gas guide can be seen also.

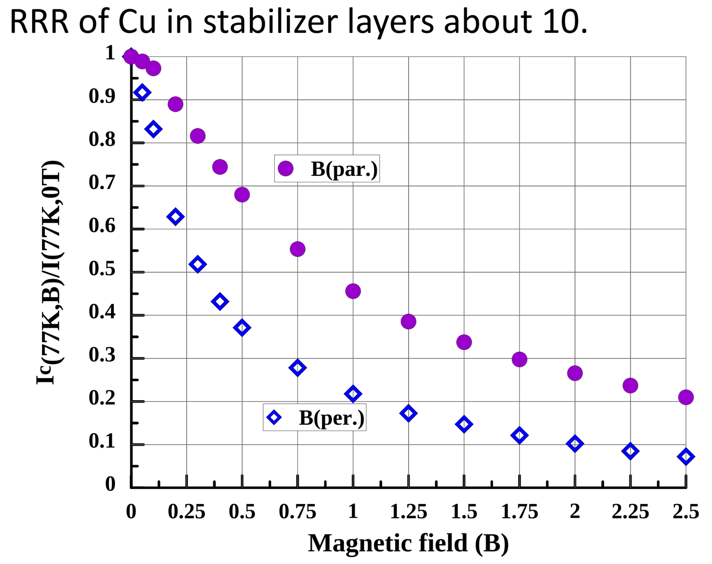
Overall view of four HTS current leads.

Fiber-glass double-threaded spiral guide (to elongate gas trajectory and thus improve cooling conditions by helium gas.

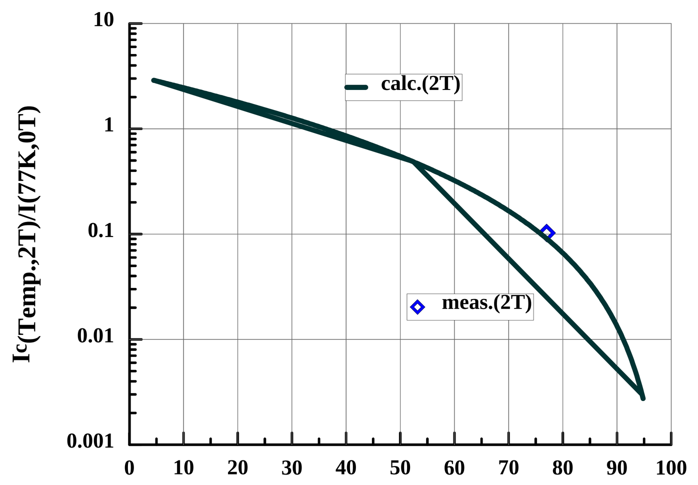
Results

Critical current of HTS tapes

To minimize heat load induced by current leads Second Generation (2G) HTS conductor fabricated by SuperOx [5] was chosen. The 2G HTS conductor consists of HTS layer with thickness of 1 μm, substrate layer with thickness of 50 μm, one of buffer layers is Ag layer with thickness of 5 μm, and Cu stabilizer layers up to total thickness of the tape 0.1 mm. Width of the HTS tape is 4 mm. RRR of Cu in stabilizer layers about 10.



Normalized critical current versus different direction applied magnetics field (temperature 77K).

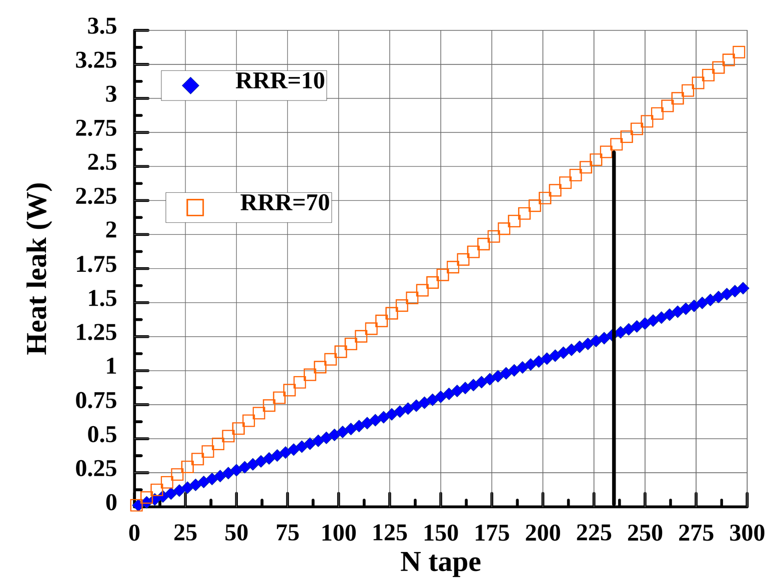


Normalized critical current versus temperature (magnetic field 2T).

Measured average critical current I_c(77K, 0T) is 85A.

$$J_{c\perp}(B,T) = 0.9\frac{B_0(T)^{1.61}}{B}\left(\frac{B}{B_0(T)}\right)^{0.54}\left(1-\frac{B}{B_0(T)}\right)^{2.82} \qquad B_0(T) = B_0\left(1-\frac{T}{T_0}\right)^{3.48}$$

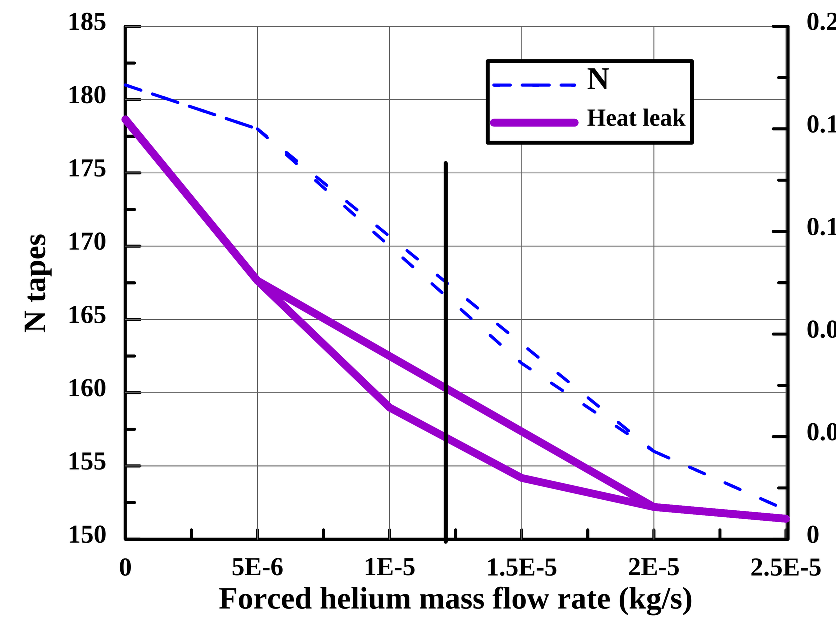
Conduction cooled HTS tapes



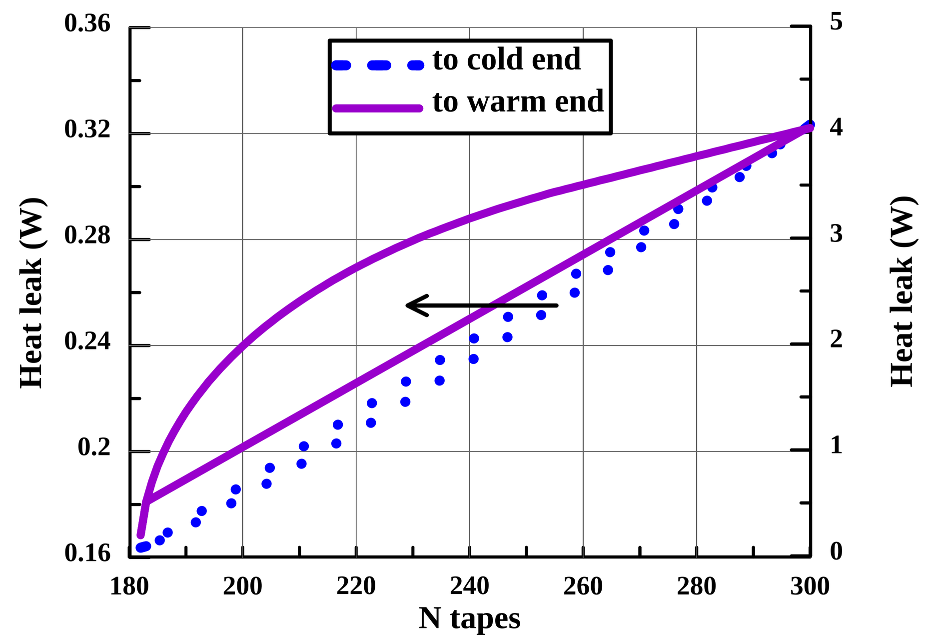
Heat leak through the HTS tapes versus number of the HTS tapes

The minimum possible number of tapes were $I_{op} > I_c$(77K,2T) $N_{min} = I_{op}/I_c$(77K, 2T) = 236. Hence, the heat leak through the current leads will be about 1.5 W, which is more than can be obtained. For case RRR=70 heat leak through the current leads will be about 2.6 W.

Vapor and Forced-flow cooled current lead

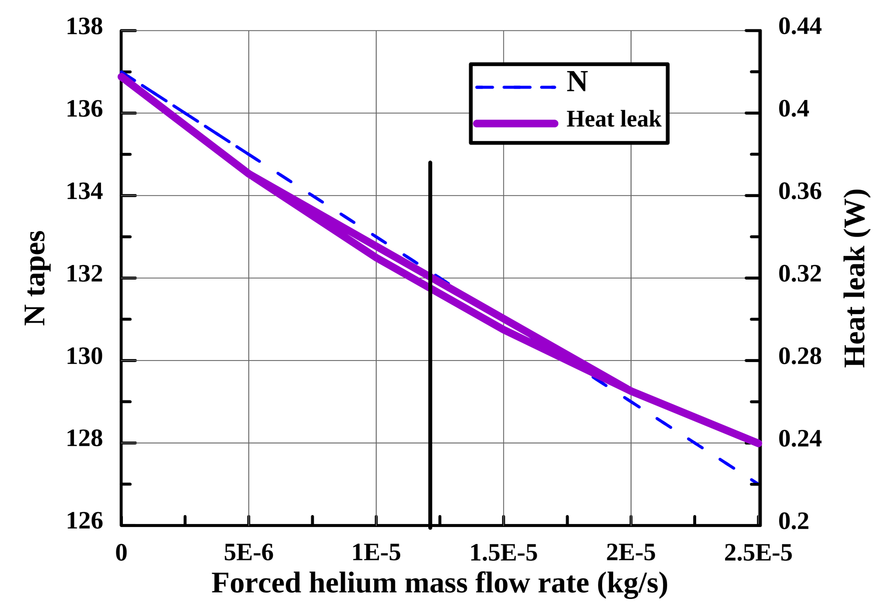


Minimum possible number of tapes and heat leak to cold end versus forced helium mass flow rate(RRR stabilizer layers = 10). one can see that in case of using forced helium mass flow rate 1.21·10-5 kg/s we can get a heat leak to cold end about 0.05 W and N_{min} can be about 170.



Heat leak to cold and warm end versus number of the HTS tapes.

There is a heat inflow into the cryostat ~1W via suspensions, supports and vacuum insulation that is independent of our current leads. This provides an additional helium mass flow rate (Mg_{add}) that can be used to cool HTS segments, or per each segment Mg_{add} = 1.21·10-5 kg/s.



Minimum possible number of tapes and heat leak to cold end versus forced helium mass flow rate (RRR stabilizer layers = 70). Using forced helium mass flow rate 1.21·10-5 kg/s the heat leak to cold end is about 0.32 W and N_{min} can be about 132 respectively.

Presented at Magnet Technology Conference , 2017, August 27 – September 1 , Amsterdam; the Netherlands; Poster: MT25-Mon-Af-Po1.09-19