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Results of the test of a pair of 20 kA HTS currents leads

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Abstract. A new series connected 25 T hybrid magnet system is being set up by the Helmholtz Zentrum Berlin (HZB) for neutron scattering experiments. CRPP has designed and manufactured a pair of 20 kA current leads for the powering of the outer superconducting coils of the hybrid magnet system. In connection with the test of joints for JT60SA, the current leads were tested at ENEA at low voltage up to a current of 18 kA. The mass flow rates required to cool the current leads at different currents measured in the test are in line with the design calculations. For the sum of the resistances of the warm and cold end copper contacts of the HTS module values of 13 (Lead A) and 11 nΩ (Lead B) were measured. In addition, the helium flow through the heat exchanger part was stopped at 10 and 12 kA to study the behaviour of the current leads in case of a loss of flow. The time elapsed between stopping of the helium mass flow and the initiation of a quench was found to be 117 s (Lead A) and 125 s (Lead B) compared to a calculated value of 86 s. The lower value obtained by the calculation can be attributed to the lower initial temperatures in the experiment.

1. Introduction

In the framework of a collaboration of CRPP, ENEA and HZB, CRPP designed and manufactured a pair of 20 kA high temperature superconductor (HTS) current leads [1,2], which are foreseen to power a 25 T hybrid magnet system at HZB. The current leads were used for the test of a JT60SA joint sample at ENEA. The test set-up at ENEA, dedicated for joint testing, was used also to test the 20 kA HTS current leads. The cold ends of the two current leads and the JT60SA joint sample connecting them were immersed in liquid helium. The HTS module composed of 28 AgAuMg/Bi-2223 stacks (8 Bi-2223 tapes per stack) soldered into a grooved stainless steel support tube with bulk copper end pieces is cooled only by heat conduction from the cold end. The copper part is actively cooled by helium gas of ≈44 K inlet temperature. Steady state operation of the HTS current leads at 20 kA would require a mass flow rate of 1.37 g/s. Due to the fact that the maximum achievable 44 K helium mass flow rate was around 1.2 g/s the current leads could be tested only up to 18 kA. In the present article, only the results of the current lead test are presented.

2. Experimental details

In later operation, the cold ends of the current leads will be forced flow cooled, while during the test they were immersed in liquid helium together with the joint sample. The intermediate temperature helium, required to cool the copper parts of the HTS current leads, was supplied from a cryogenic storage dewar, filled with liquid helium. Pressure was built up in the dewar by means of a heater.



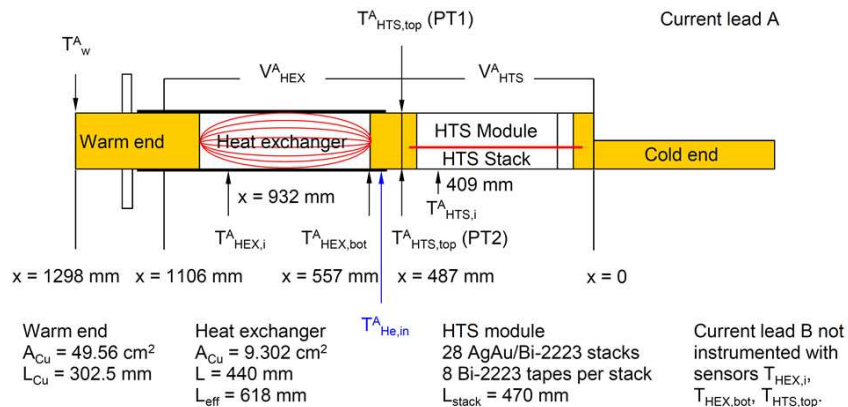


Figure 1. Sketch of the instrumentation of current lead A (x : length from cold end).

The cold helium gas is transferred via a short transfer line to the HTS current leads. A second heater was used to adjust the helium inlet temperature. During the current lead test it proved to be difficult to reach a stable mass flow rate and a constant helium inlet temperature for a time long enough to establish steady state operation of the current leads. In general, it was not possible to fully establish a steady state but for some runs the conditions were close to thermal equilibrium. This situation affects the comparison of the measured results with the design calculations based on operation in fully steady state.

A sketch of the instrumentation of current lead A is presented in figure 1. The helium temperature was measured at the inlet ($T_{HE,in}^A$) and the outlet ($T_{HE,out}^A$) of the current lead. One temperature sensor was placed at the warm end of the whole current lead (T_w^A) and the two redundant sensors PT1 and PT2 at the warm end of the HTS module ($T_{HTS,top}^A$). Additional sensors $T_{HEX,i}^A$, $T_{HEX,bot}^A$ and $T_{HTS,i}^A$ were applied to current lead A only for the test. The voltages across the heat exchanger (V_{HEX}^A) and the HTS module (V_{HTS}^A) including warm and cold end copper contacts were used to protect the current lead.

3. Results and discussion

The results of a measurement performed at 18 kA, a helium mass flow rate of $\approx 1.19 \text{ g/s}$ and $T_{He,in}^A \approx 28 \text{ K}$ are presented in figure 2. At $t = 4000 \text{ s}$ all temperatures are almost constant and the temperature at the warm end of the current lead reached $\approx 316 \text{ K}$ (figure 2, left). The average of the readings of PT1 and PT2 provides $T_{HTS,top}^A \approx 31.3 \text{ K}$, while $T_{HEX,bot}^A \approx 47 \text{ K}$ and $T_{HTS,i}^A \approx 35 \text{ K}$. The expected sequence would be $T_{HEX,bot}^A > T_{HTS,top}^A > T_{HTS,i}^A$. The readings of the sensors embedded in or attached on the electrical insulation may be affected by cold helium gas in the vicinity of the current leads. The voltage of $\approx 52.3 \text{ mV}$ measured across the heat exchanger seems to be reasonable (figure 2, right).

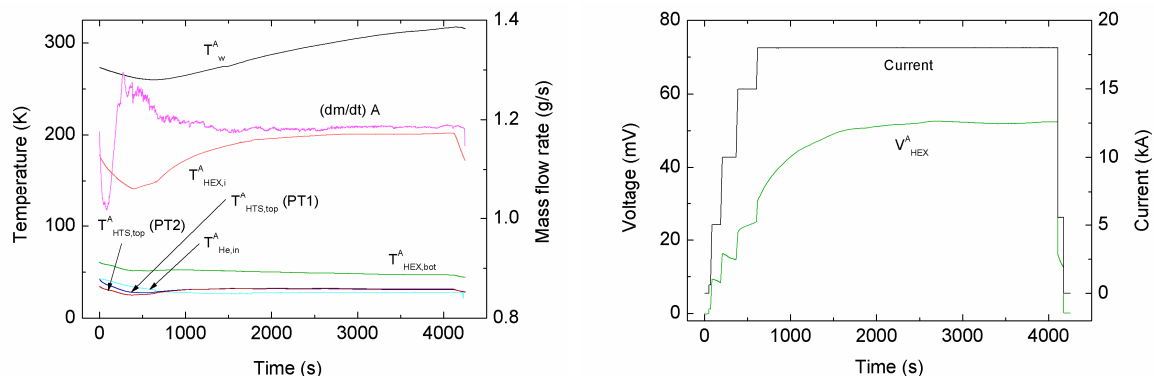


Figure 2. Evolution of temperatures (left) and V_{HEX}^A (right) during longer operation at 18 kA.

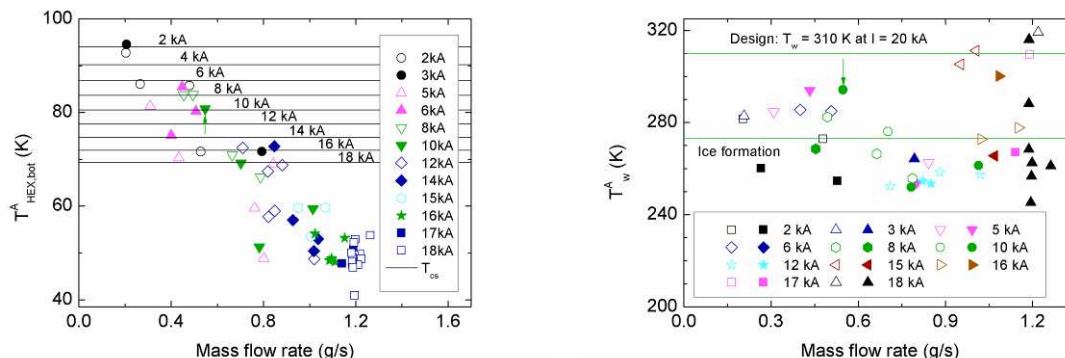


Figure 3. Temperatures at the bottom of the heat exchanger (left) and the warm end of the current lead (right) versus mass flow rate at various currents. Horizontal lines (left) indicate calculated T_{cs} .

In figure 3 (left), $T^A_{HEX,bot}$ versus the mass flow rate is shown for currents in the range of 2 to 18 kA. The temperature $T^A_{HEX,bot}$ is expected to provide an upper limit of the temperature at the warm end of the HTS module. The horizontal lines provide the calculated current sharing temperature T_{cs} based on a criterion of $1 \mu\text{V}/\text{cm}$. With the exception of one data point for 3 kA and a mass flow rate of 0.207 g/s , the measured temperatures are lower than the corresponding T_{cs} . In general, the temperature at the bottom of the heat exchanger decreases with increasing mass flow rate at constant current. In figure 3 (right), the temperature T^A_w at the warm end of the whole current lead is shown as a function of mass flow rate. The open symbols represent measurements performed in May 2013, while the solid symbols indicate the results of a second test campaign starting in June 2013. For the second test campaign the total copper cross-section of the cables between the warm end of the current leads and the permanently installed bus bars of the power supplies was enlarged. In the first campaign at a current of 15 kA a warm end temperature of 310 K was reached. In the second test campaign, T^A_w stayed well below 310 K even at a current of 16 kA. The variation of T^A_w for nearly equal mass flow rates and currents can be attributed to the fact that in some of the measurements no steady state was established. The results indicate that the current leads can be operated at 18 kA with a mass flow rate of 1.19 g/s and $T^A_{HE,in} \approx 28 \text{ K}$. However, the comparison with the design is not straight forward because of the higher helium inlet temperature of 44 K. For the 10 kA run indicated by the arrow (see figure 3), the helium mass flow rate and $T_{He,in}$ were $\approx 0.55 \text{ g/s}$ and $\approx 45 \text{ K}$, respectively. The measured values of $T^A_w = 294.2 \text{ K}$, $T^A_{HEX,bot} = 80.8 \text{ K}$ and $V^A_{HEX} = 55.86 \text{ mV}$ are in good agreement with the corresponding design values of 293 K, 74.84 K and 58.42 mV.

The voltages across the HTS module (including HTS-Cu contacts) and the heat exchanger are presented in figure 4. Supposing a uniform current distribution among stacks the data in figure 4 (left) provide $13 \text{ n}\Omega$ (lead A) and $11 \text{ n}\Omega$ (lead B) for the sum of the warm and cold end contact resistances.

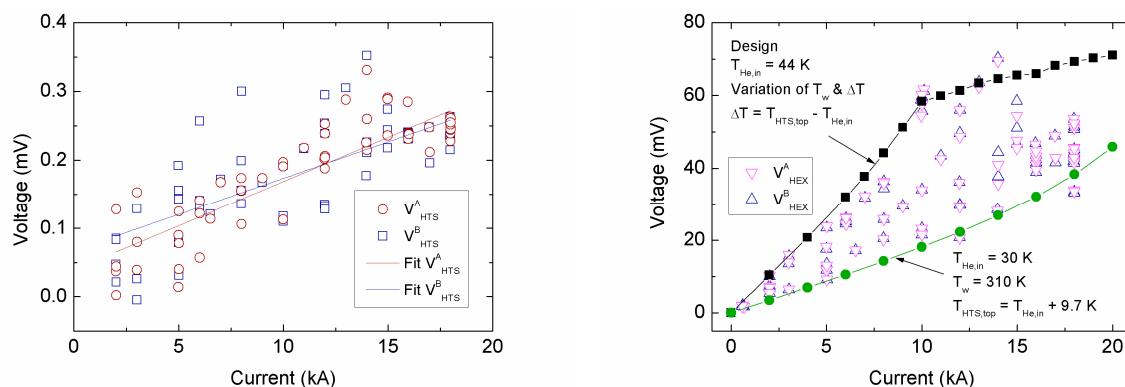


Figure 4. Voltages across the HTS module (left) and the heat exchanger (right) versus current.

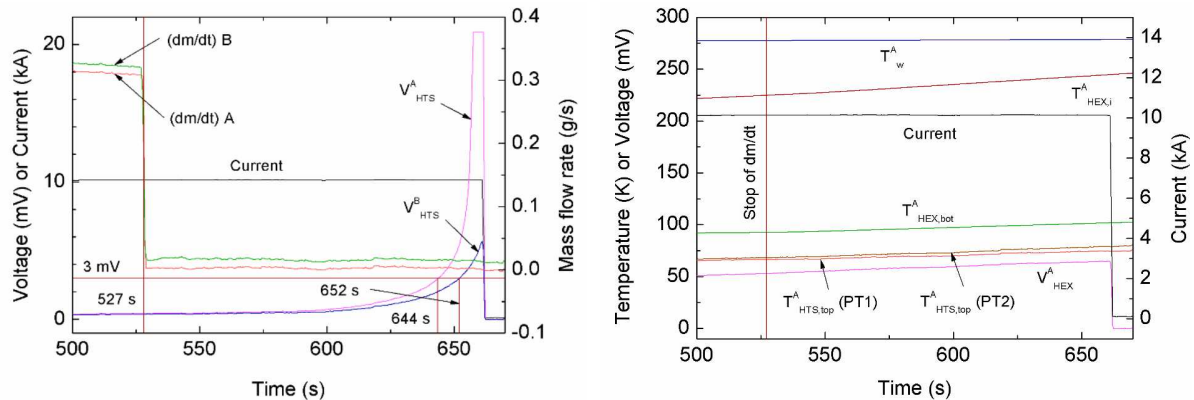


Figure 5. Evolution of V^A_{HTS} , V^B_{HTS} (left), V^A_{HEX} and various temperatures (right) after a stop of mass flow at a current of 10 kA. The time to reach $V_{HTS} = 3\text{ mV}$ is 117 s (lead A) and 125 s (lead B).

The sum of the warm and cold end contact resistances of $13.8\text{ n}\Omega$ found for the 18 kA EDIPO current leads [3] is comparable to the values obtained for the present current leads. In figure 4 (right) the measured values of V_{HEX} are presented. Most of the measured voltages are between the design values ($T_{He,in} = 44\text{ K}$) and that obtained for $T_{He,in} = 30\text{ K}$ and a constant $\Delta T = T_{HTS,top} - T_{He,in} = 9.7\text{ K}$.

The last aspect to be considered is the behavior of the current leads in case of a loss of flow. The evolution of V^A_{HTS} , V^B_{HTS} (left), V^A_{HEX} and the temperatures in lead A (right) after a stop of mass flow at $t = 527\text{ s}$ are presented in figure 5. The initial temperature of the warm end of the HTS module was 66.4 K (lead A, average of PT1 and PT2). Times elapsed to reach a voltage of 3 mV across the HTS modules at $I = 10\text{ kA}$ were 117 s for lead A and 125 s for lead B. In parallel, the temperature $T^A_{HEX,i}$ increased from 225 to 242 K leading to an increase of V^A_{HEX} from 52.9 mV to 63.7 mV . A simulation of the loss of flow behavior for a current of 10 kA provided a time of $\approx 86\text{ s}$ to reach a voltage of 3 mV . The shorter time obtained from the calculation may be attributed to a higher initial temperature of 75 K at the warm end of the HTS module in the calculation.

4. Conclusion

A pair of 20 kA HTS current leads, manufactured at CRPP, to be used to power a 25 T hybrid magnet system at HZB were tested at ENEA at low voltage and currents up to 18 kA . At a helium inlet temperature of $\approx 28\text{ K}$ a mass flow rate of 1.19 g/s was found to be sufficient to operate the current leads in steady state at 18 kA . The design value of the helium inlet temperature is 44 K and therefore a comparison with the design is not straightforward. Measurements at 10 kA with a helium inlet temperature of $\approx 45\text{ K}$ were found to be in reasonable agreement with the design values. The measured sums of cold and warm end Cu-HTS contact resistances were found to be $13\text{ n}\Omega$ (A) and $11\text{ n}\Omega$ (B). The measured time for quench to initiate, following a loss of flow at 10 kA , is larger than the calculated value. Therefore, it can be expected that the design calculations provide a roughly correct value of this time also for the rated current of 20 kA . The calculated design value of 94 s at 20 kA is acceptable and would allow the rapid ramp-down of the magnet system after detection of a loss of flow instead of a safety discharge with a time constant of 2 s starting at $V_{HTS} = 10\text{ mV}$.

References

- [1] Wesche R et al 2012 Design and manufacture of 20 kA HTS current leads for a hybrid magnet system *Physics Procedia* **36** 927-930 doi:10.1016/j.phpro.2012.06.231
- [2] Lewandowska M and Wesche R 2013 Parametric study for the cooling of high temperature superconductor (HTS) current leads *Cryogenics* **53** 31-36 doi:10.1016/j.cryogenics.2012.06.014
- [3] Wesche R et al 2011 Test results of the 18 kA EDIPO HTS current leads *Fusion Engineering and Design* **86** 1414-1417 doi:10.1016/j.fusengdes.2011.01.026