Measurement of the Thermal Properties of Prototype Lambda Plates for the LHC

R. Marie, L. Metral, A. Perin, J.M. Rieubland

Abstract

In order to power the LHC superconducting magnets, thousands of busbars will be routed from electrical feedboxes containing saturated helium at 4.5 K to magnets operating in pressurized superfluid helium at 1.9 K. Between those two volumes, the busbars will pass through special feedthroughs also called lambda-plates. This article presents heat flow measurements performed on several configurations of vertical prototype lambda-plates feedthroughs. The results show that the heat flow is strongly influenced by the configuration of the busbar insulation in the saturated helium.

CERN, Accelerator Technology Department, Geneva, Switzerland

Presented at the 20th International Cryogenic Engineering Conference (ICEC20)
11-14 May 2004, Beijing, China

CERN
CH - 1211 Geneva 23
Switzerland

Geneva, 2 September 2004

Measurement of the thermal properties of prototype lambda plates for the LHC

Marie R., Metral L., Perin A., Rieubland J.-M.

CERN Accelerator Technology Division, CH-1211 Geneva 23

In order to power the LHC superconducting magnets, thousands of busbars will be routed from electrical feedboxes containing saturated helium at 4.5 K to magnets operating in pressurized superfluid helium at 1.9 K. Between those two volumes, the busbars will pass through special feedthroughs also called lambda-plates. This article presents heat flow measurements performed on several configurations of vertical prototype lambda-plates feedthroughs. The results show that the heat flow is strongly influenced by the configuration of the busbar insulation in the saturated helium.

INTRODUCTION

The assessment of heat loads and their resulting needs in cooling liquids mass flows are among the important requirements of machines operating in cryogenic conditions such as the Large Hadron Collider (LHC). In the LHC, the electrical currents are supplied to the magnets through electrical feedboxes [1] operating at 4.5 K, 1.3 bar. The lambda-plates ensure the electrical continuity of the circuits while keeping the hydraulic and thermal separation between the normal (4.5 K) and superfluid (1.9 K) helium volumes. The geometrical configuration of the feedboxes does not allow the usage of a stratified helium bath, but requires the usage of vertical lambda plates (and horizontal busbars). In order to limit the heat flow between these two temperature levels, it is therefore necessary to maximize the thermal impedance of the lambda plates. An obvious way to obtain such result is to use long lambda plates (100 mm to 150 mm), but this approach is limited by the mechanical difficulties due to the differential thermal contraction of the busbars and insulating material of the lambda plates.

Another possible way is to act on the heat exchange between the helium and the busbars: busbars are usually electrically insulated with several layers of polyimide tapes that also act as a thermal insulation towards the surrounding helium, effectively increasing the total thermal impedance between the two temperature levels. We investigated the influence of this insulation on the thermal properties of the lambda plates; heat flow measurements were performed with varying numbers of polyimide tape layers on simulated busbars and for two temperatures of the normal liquid helium. The results were then confirmed on prototype lambda plates with real busbars.

EXPERIMENTAL

The configuration of the lambda plate used for our study is shown in Figure 1. It is made of:

- An insulating plug that ensures the hydraulic and thermal separation of the two helium volumes.
- One or several busbars crossing the plug simulated with a round section copper rod with a diameter of 10.8 mm.

Heat flows were measured for the conditions listed in Table 1. The plug is made of polyetherimide (PEI) [2], the busbar is simulated by a copper bar. The RRR of the copper rod is 70 and it is insulated by layers of 50 μm -thick polyimide (PI) tape for cases 3 & 4.

The 20 mm-wide PI tape is wrapped around the bar with a 50% overlap to match the configurations of the LHC bus bars. One layer of PI corresponds to a total thickness of 0.1 mm around the busbar. A

Figure 1 Schematic configuration of the lambda plates

Table 1 List of the test cases

Case	Configuration
C1	Full plug (no cable)
C2	Cu bar not insulated
C3	Cu bar with 1 PI layer
C4	Cu bar with 2 PI layers

thermometer T_e is placed at the He I extremity of the rod (see Figure 2), glued to the copper and under the insulation.

The test system, shown in Figure 2, was designed to reproduce the thermohydraulic operating conditions of the lambda plates in the LHC. The whole system is installed in a vacuum vessel insulated by a 20 K thermal screen. It is composed of:

- A volume of saturated helium at 1.9 K which acts as the cold source and cools the pressurized He bath through a copper heat exchanger acting as a Kapitza resistance heatmeter [3]
- A pressurized bath of superfluid helium at 1.9 K
- The lambda-plate, shown in Figures 1 and 2, separating pressurized 1.9 K helium II and helium I
- A volume of helium I at 1 bar. The temperature of this volume is controlled with a heater.

Each volume is equipped with thermometers to ensure an accurate temperature control. Heat flows are determined by measuring the temperature difference across the Kapitza resistance heatmeter. The system was calibrated by performing a measurement on a lambda plate without busbar (test case 1). This configuration was then used as a reference, in order to discriminate between the heat flow due the plug and the conduction along the copper bars. Measurements were performed for 2 temperatures of the 1 bar helium I, T_{HeI} . The temperature of the pressurized helium II was always 1.9 K.

RESULTS AND DISCUSSION

The heat flow through the lambda-plate $Q_\lambda(T)$ can be separated into:

- The heat flow through the full plug without any copper bar $Q_{plug}(T)$: it includes the heat flow due to helium leaks and the heat flow through the plug material and stainless steel piping.
- The heat flow through the copper bar(s) $Q_{Cu}(T)$

In order to distinguish the two contributions to the total heat flow, a measurement was performed without any copper rod (test case C1 in Table 1, $Q_{plug}(T)$ in table 2). For the other measurements the contribution

Figure 2 Schematic view of the test system

Table 2 Heat flows in mW for several configurations.

T_{HeI} [K]	$Q_{\text{plug}}(T)$	$Q_{\text{Cu}}^{\text{C2}}(T)$	$Q_{\text{Cu}}^{\text{th}}(T)$	$Q_{\text{Cu}}^{\text{C3}}(T)$	$Q_{\text{Cu}}^{\text{C4}}(T)$
		no PI	no PI	1 layer PI	2 layers PI
4.1	163	867	1007	327	205
3.1	100	300	403	125	-

of the copper rod $Q_{\text{Cu}}(T)$ was calculated by subtracting $Q_{\text{plug}}(T)$ from the total heat flow. The results obtained for 0 ($Q_{\text{Cu}}^{\text{C2}}(T)$), 1 ($Q_{\text{Cu}}^{\text{C3}}(T)$) and 2 ($Q_{\text{Cu}}^{\text{C4}}(T)$) layers of PI insulation are shown in Table 2 for $T_{\text{HeI}} = 4.1$ K and $T_{\text{HeI}} = 3.1$ K ($Q_{\text{Cu}}^{\text{C4}}(3.1$ K) is missing due to an experimental problem). The results are also shown graphically on Figure 3. For comparison, the theoretical value $Q_{\text{Cu}}^{\text{th}}(T)$, estimated assuming perfect heat exchange between the copper rod and the surrounding helium is also shown in Table 2. For this calculation the temperature T_0 of the copper rod at the warmer end of the plug (see Figure 2) is thus assumed to be equal to T_{HeI} .

In the experimental configuration, $T_{\text{HeI}} - T_e$ (see Figure 2) decreases with increasing distance from the plug and for an infinitely long rod $T_e = T_{\text{HeI}}$. For a given T_{HeI} , the distance required to transfer a defined part of the heat flow is proportional to the heat impedance between the helium I and the rod surface. The effect of the experimentally limited rod length (250 mm) is to underestimate the heat flow with respect to an infinitely long rod. A qualitative evaluation of this effect can be obtained by comparing T_e with T_{HeI} .

Without insulation, the heat flow for $T_{\text{HeI}} = 4.1$ K is very similar to $Q_{\text{Cu}}^{\text{th}}(4.1$ K), confirming a good convective heat exchange between the helium and the copper at 4.1 K. For $T_{\text{HeI}} = 3.1$ K, the heat exchange does not appear to be as good: this is most probably due to a reduced natural convection resulting from the smaller temperature difference.

At 4.1 K, the first layer of PI insulation reduces the heat flow by a factor close to 3 and a second layer divides the heat flow by a factor greater than 4. At 3.1 K the effect of the insulating layers is somewhat smaller. For insulated rods, the heat exchange between the helium and the copper rod depends on essentially two mechanisms: natural convection at the PI / helium interface and conduction across the PI layers. The measurements show that even one PI layer is already very effective in decreasing the total heat flow by insulating the copper rod and therefore also decreasing the convection heat exchange thanks to reduced temperature gradients at the interface between the PI and the helium I. This effect is most apparent for $T_{\text{HeI}} = 4.1$ K where the convection heat exchange is stronger than at 3.1 K where the temperature gradients are smaller. We can estimate that even with only one layer of PI the temperature T_0 (see figure 2) of the copper rod is significantly lower than 3.1 K ($Q_{\text{Cu}}^{\text{C2}}(3.1$ K) > $Q_{\text{Cu}}^{\text{C3}}(4.1$ K)).

However, the results of $T_{\text{HeI}} - T_e$ (0.6 K for $T_{\text{HeI}} = 4.1$ K, and 0.5 K for $T_{\text{HeI}} = 3.1$ K) show also that the rod is not long enough to be representative of very long busbars for which a smaller gain due the insulation is expected.

Figure 3 Heat flows through the Cu rod as a function of the number of PI layers

Table 3 Heat flows for the prototype lambda plate in mW

He I temp. [K]	$Q_{Cu}^{th}(T)$ Proto	Proto	Proto corrected
4.1	880	362	215
3.1	366	140	93

Figure 4 Lambda plate prototype with 22 superconducting wires

In order to confirm the validity of the results for the LHC busbars, we measured the properties of a prototype lambda plate with the same plug configuration (see Figure 1) but with 22 superconducting LHC busbars of a cross section of 2 mm^2 (Cu stabilization $RRR=100$) insulated with 2 layers of $50 \text{ }\mu\text{m}$ PI (see Figure 4). This configuration is the original insulation of the busbars, determined by electrical requirements. Table 3 presents the heat flows for $T_{HeI} = 4.1 \text{ K}$ and $T_{HeI} = 3.1 \text{ K}$. For practical reasons the extremities of the busbars were not insulated, but for having a comparison with the test rod, we also present a roughly corrected value for which the estimated contribution of the conduction from the extremities has been subtracted from the measured heat flows (value estimated from heat exchange of the copper rod without insulation). Table 3 also shows the estimated value for a theoretical configuration without insulation and perfect heat exchange between the helium and the busbars $Q_{Cu}^{th}(T)$. As the extremities are not insulated $T_e = T_{HeI}$, the measured values are higher than the expected values for long ($>250\text{mm}$) busbars. The corrected values represent an “insulated extremities” situation and are therefore smaller than the expected values for long busbars. The relative estimated magnitude of the heat flow through the extremities emphasizes the importance of extending the insulation as far as possible from the lambda plate.

CONCLUSIONS

Our measurements show that the electrical insulation around the busbar is very effective in reducing the heat flow between the superfluid helium and the normal helium volumes in vertical lambda plates. These results, confirmed on a multi-busbars lambda plate, demonstrate that it is possible to optimize the thermal properties of a lambda plate by improving the thermal insulation of the busbars on the He I side, without increasing the length of the lambda plate itself.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the team of the Cryolab at CERN and especially S. Prunet and L. Dufay for their support.

REFERENCES

1. Goiffon, T., Lyngaa, J., Metral, L., Perin, A., Trilhe, P., van Weelden, R., paper presented at this conference (ICE20)
2. Perin, A., Macias, R., Study of materials and adhesives for superconducting cable feedthroughs, *Adv. Cryo. Eng.*, vol.47, p. 551
3. Kuchnir, M., Gonczy, J. D. and Teague, J. L., *Adv. Cryo. Eng.*, vol. 31, Plenum Press, New York (1985), 1285.