EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 216

Current Feedthroughs for Superconducting Magnets Operating Below 2 K

V. Benda [1], O. Zilbert [2]

Abstract

For superconducting magnets working in superfluid helium, a thermal and pressure barrier between liquid helium baths at different temperatures, so called “lambda plate”, is required. Bus bars connected to current leads of magnets to be powered, pass through current feedthroughs. These feedthroughs have to stand high pressure, thermal shock, high voltage, and mechanical stresses, must be leak tight and introduce minimum heat inleak. This article describes a possible solution. Three prototypes were built and measured. Design of this feedthrough and preliminary results are presented.

[1] LHC Division - CERN, Geneva, Switzerland
[2] Metaceram, Villejuif, France

Presented at ICEC 17, 14-17 July 1998, Bournemouth, UK

Administrative Secretariat
LHC Division
CERN
CH - 1211 Geneva 23
Switzerland

Geneva, 31 July 1998

Current Feedthroughs for Superconducting Magnets Operating Below 2 K

V. Benda [1], O. Zilbert [2]

[1] LHC Division - CERN, Geneva, Switzerland
[2] Metaceram, Villejuif, France

For superconducting magnets working in superfluid helium, a thermal and pressure barrier between liquid helium baths at different temperatures, so called “lambda plate”, is required. Bus bars connected to current leads of magnets to be powered, pass through current feedthroughs. These feedthroughs have to stand high pressure, thermal shock, high voltage, and mechanical stresses, must be leak tight and introduce minimum heat inleak. This article describes a possible solution. Three prototypes were built and measured. Design of this feedthrough and preliminary results are presented.

1 INTRODUCTION

CERN is preparing to build a new particle accelerator, the Large Hadron Collider (LHC). About 2000 superconducting magnets, which are essential components of this accelerator, will operate with their magnet coils at a temperature of 1.9 K [1]. Magnet coils are powered via current leads, which are connected to coils by bus bars. As the cold termination of current leads is immersed in saturated liquid helium at 4.5 K and magnet coils operate in subcooled liquid helium at 1 bar and 1.9 K, the connecting bus bar must pass through the lambda plate separating these two baths.

For some applications when an absolute tightness of the lambda plate is not required, one can use a glass-fibre plug glued into a pipe, while the bus bars passing through are glued into the plug itself. The main disadvantage of this solution is the high probability of leak and later degradation. It is extremely difficult to ensure long-term stable and tight gluing in the above mentioned conditions. If the lambda plate is not tight, there is a heat exchange between two baths at different temperatures by helium mass transfer through the leak. As experience from an existing magnet test bench [2] confirmed the above-mentioned problem, a long-term tight lambda plate was studied. On the basis of preliminary tests a stainless steel lambda plate with ceramic feedthrough as bus bar passage plug is proposed as an industrial solution. The feedthrough, which is considered as the most delicate part of lambda plate, is described in this article.

2 TECHNICAL SPECIFICATION OF THE LAMBDA PLATE FEEDTHROUGH

Required working temperature of the feedthrough is from 1 to 400 K at pressure from 0 to 20 bar on any of the two sides including pressure transients, in an integrated radiation dose of up to 10^{14} neutron cm^{-2}.

Its tightness should be better than 10^{-10} Pa m^3 s^{-1} in any working conditions. The feedthrough must withstand a thermal shock even under non-uniform temperature distribution and mechanical forces applied by bus bar. Its leakage current must be smaller than 10^{-6} A in 1 bar gaseous helium at 300 K with 2 kV between pin and ground. The heat inleak of the feedthrough must be minimized. The heat inleak of the complete lambda plate, with two feedthroughs including one bus bar of 13 kA in each, should be smaller than 2 W from 4.2 K to 1.9 K. The life time of the feedthrough must be at least 10 years and capable of standing 1000 thermal cycles to ambient.

3 PRINCIPLE

The design of the feedthrough is based on that of standard electrical insulators made of alumina. A single-wall ceramic insulator can comply with all points of the above-mentioned technical specification, except the requirement for small heat inleak, because of the high thermal conductivity of the ceramic. A fully welded double-wall ceramic insulator was therefore developed (Figure 1). The space between two ceramic cylinders is filled with 1 bar dry gaseous nitrogen at 300 K. This is preferable to evacuation of the internal space, in order to comply with the high-voltage insulation, as residual gas at low pressure is more prone to dielectric breakdown than in 1 bar of nitrogen. Two single-wall ceramic insulators of the future feedthrough are on one end tightly connected by a flexible element to withstand differential contractions between internal and external ceramic. In case of a leak between the external volume of the feedthrough and its internal volume filled with nitrogen, the external ceramic cylinder is designed to rupture as a relief device gauged. In any case, the main function of the leaky feedthrough is not altered, only the heat inleak will be higher.

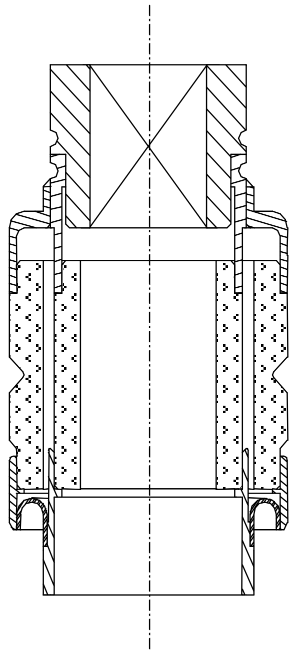

Figure 1 Double-wall ceramic feedthrough

4 TECHNOLOGY AND CONTROL PROCEDURES

As a ceramic/metal junction is considered to be delicate, a connection alumina/Kovar®is basically used because of the matching thermal expansion coefficient. Two machined ceramic cylinders are locally metallised. Kovar® terminations are brazed to both ends of external and internal ceramic cylinders in a vacuum furnace. These two pieces are thermally shocked 5 times in liquid nitrogen and leak tested. To ensure a better quality of the soldered connection between bus-bar and feedthrough, the rectangular hole in the stainless steel flange of the feedthrough is silver-plated. After all required tests, the metallic parts of the feedthrough and the alumina/Kovar® subcomponents are welded together by laser. The feedthrough is afterwards heated up in a vacuum furnace and purged in order to remove water vapour. At this stage the internal space of the feedthrough is not tight, as one Kovar® fitting is perforated. In the end the feedthrough is filled with pure dry nitrogen at 1 bar and 300 K and the hole creating the last communication between internal and external space is plugged by laser welding. To avoid any leak, a lot of care was taken in the selection of materials and technological procedures and the quality control at each step of manufacturing. This also applied to the design and test of the external ceramic cylinder acting as relief device. The rupture pressure was checked on 5 samples at ambient and liquid nitrogen temperature. On this basis a rupture region was realized reproducibly. The rupture pressure at room temperature is 200 bar. The complete feedthrough is thermally shocked and high voltage tested at 5 kV DC in air at ambient pressure and temperature.

5 COMPLETE LAMBDA PLATE

The feedthrough is only one element of the lambda plate, which consists of:

feedthroughs
body of the lambda plate
bus-bars
electrical insulation
mechanical support of bus-bars

Proposed solution of the lambda plate assembly using the described feedthrough:

The body of the lambda plate could be a stainless steel plate 90 mm in diameter and 25 mm thick, in order to reduce the heat inleak by conduction, in which the feedthrough is welded. The complete set should comply with the requirement of high voltage test between pin and pin, and between pin and ground. To minimize radial forces on feedthoughs stressed by bus bars, it is recommended to support them on both sides of the lambda plate. Pressure and leak tests of the complete lambda plate including bus bars should be done after 3 thermal shocks.

6 RESULTS

6.1 Calculations

The main source of heat inleak through the lambda plate from 4.2 K to 1.9 K is conduction along the bus bar. In our case the bus bar is composed by two superconducting cables soldered together with no additional copper stabilizer. The copper cross section of this double superconducting cable is 25 mm^2. The soldered length of this bus bar in the flange of the feedthrough is 20 mm. The thermal conductivity of the copper cable between 4 K and 2 K is about 200 W m^{-1} K^{-1}.

The heat inleak of the feedthrough through its double wall due to radiation and residual gas conduction is negligible. Heat inleak through a simple Kovar® wall depends on its heat conductivity, considered the same as for stainless steel. The last source of heat inleak is conduction through the stainless steel body of the lambda plate. For above mentioned assumptions and maximum temperature difference Δ=2.3 K, calculated heat inleaks are presented in the table below. In reality stratification in liquid helium should reduce the maximum temperature difference across the lambda plate.

Number of elements	Element of the lambda plate	Heat inleak calcul. (W)
2	13 kA bus bar (double superconducting cable)	1.25
2	Simple metallic wall of the feedthrough	0.6
	Double wall of the feedthrough	0
1	Body of the lambda plate	0.15
1	Complete lambda plate in total	2

6.2 Measurement

To confirm this calculated value a few measurements of the feedthrough heat inleak were done. The bus-bar hole in the feedthrough was plugged by a stainless steel block. The feedthrough was filled with liquid helium from both sides independently. The heat flux from the warmer helium bath through the feedthrough to the colder helium bath was measured by boil-off. The helium mass flow, absolute temperature and temperature difference were monitored.

The measured heat inleak across the feedthrough in Watt per Kelvin was: Q=0.2 ±0.1 W K^{-1}

7 CONCLUSION

As for some cryogenic application a glued lambda plate cannot be used, the tight stainless steel lambda plate with double-wall ceramic feedthrough as bus-bar passage is proposed. The prototype of this feedthrough was designed in collaboration between CERN and Metaceram. Three prototypes were built and factory tested by Metaceram and finally qualified at CERN's central cryogenic laboratory. Four new feedthroughs will be used for the lambda plates of new LHC magnet test benches. For other application in the LHC two types of ceramic feedthroughs can be considered:

double wall ceramic feedthrough as a barrier between liquid helium at 4.5 K and 1.9 K
simple wall ceramic feedthrough as a barrier between two baths of liquid helium, both at 4,5 K

8 ACKNOWLEDGMENTS

The authors wish to acknowledge the help and support of Ph. Lebrun, J.-M. Rieubland and B. Vullierme during development and tests.

9 REFERENCES

1 The LHC Study Group, The Large Hadron Collider Conceptual Design, CERN Report AC/95-05 (LHC) (1995)
2 Benda V., Granier M., Lebrun Ph., Novellini G,. Sergo V., Tavian L., Vullierme B,. Cryogenic Benches for Superfluid Helium Testing of Full-Scale Prototype Superconducting Magnets for the CERN LHC Project Cryogenics (1994) 34 ICEC Supplement 733-736