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# 600 A CURRENT LEADS WITH DRY AND COMPACT WARM TERMINALS

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**Abstract**

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## ABSTRACT

For the LHC magnet test benches 26 pairs of conventional helium vapour-cooled 600 A current leads are required. The first pair of 600 A current leads has been designed and built by industry and tested at CERN. The main component of the lead is the heat exchanger, which consists of two concentric copper pipes. Special attention was also given to the design of the warm terminal in order to avoid any condensation and to resist at an electrical test of 2 kV. The paper describes construction details and compares calculated and measured values of the main parameters.

## INTRODUCTION

In order to test at CERN about 2000 LHC cryomagnet in superfluid helium at 1.9 K twelve test benches are under construction. Each test bench comprises a cryogenic feed box including four auxiliary current leads to supply auxiliary magnets.
In Table 1 are summarised the designed parameters of helium vapour cooled current leads.

Table 1 Design parameters of the current leads

| | |
|---|---|
| Nominal current | 600 A DC |
| Maximum current (for 10 minutes) | 1 kA DC |
| Leakage current at 2 kV DC at normal working condition | $<0.5\times10^{-6}$ A |
| Design pressure | 2 MPa |
| Working pressure | 0.12 MPa |
| Total pressure drop at maximum current | <10 kPa |
| Heat load at nominal current | <1.2 W/kA |
| Heat load in Stand By (I=0 A) | <0.6 W |
| Insert length | 1470 mm |
| Insert diameter | <50 mm |

In order to ensure stability of the current leads they shall withstand the maximum current with interrupted coolant gas flow for 60 s without any degradation.

Together with design of the main heat exchanger that is important and well known, the warm terminal will be discussed in more detail. An effort was done in order to design the warm terminal compact and dry in any working condition.

## 1. PRINCIPLE OF THE LEAD OPTIMISATION

Current lead performance is evaluated using specially written program code for this purpose considering the temperature dependency of the heat conductivity, resistivity and heat capacity of the conductor material, heat conductivity and viscosity of the cooling gas and local calculation of heat transfer (Johnson 1961 and Leroy and Oberli 1988). Analysis is based on a program code simultaneously solving the conduction/convection problem described by the governing equations for the conductor:

$$\rho_{m,Cu} \cdot c_{p,Cu}(T(x)) \cdot \frac{\partial T}{\partial t}(x) = \frac{\partial}{\partial x}\left[ k(T(x)) \cdot \frac{\partial T(x)}{\partial x} \right] - \frac{\frac{dm}{dt} \cdot c_{p,gas}}{A} \cdot \frac{\partial T_{gas}(x)}{\partial x} + \rho_{e,Cu}(T(x)) \cdot \left(\frac{I}{A}\right)^2$$

and for the cooling gas:

$$\frac{\partial T_{gas}}{\partial x}(x) = \frac{s \cdot h(T_{Boundary}(x))}{\frac{dm}{dt} \cdot c_{p,gas}}$$

The full featured process simulation code allows for parameter investigation and sensitivity analysis for steady state conditions as well as dynamic simulation of the reaction to transient conditions – e.g. loss of cooling media.

## 2. DESCRIPTION OF THE LEAD

Lead consists of the warm terminal, the main heat exchanger, the cold terminal, electrical insulation and instrumentation.

### *2.1 Warm terminal*

Overview of the warm terminal is on Figure 1.

A massive copper (SE-Cu) part (1) equipped with an electrical terminal (3) for warm, water-cooled bus bars is vacuum brazed to both copper pipes of the main heat exchanger (2) and silver plated. Copper part of the terminal is electrically insulated from the cryostat by a glass fibre ground isolator (4). The outlet gas tapping (5) as well as temperature transmitters (6) including electrical connectors (7) for high voltage taps, (8) for thermometers and (9) for heaters are insulated from copper part of the warm terminal by a glass fibre massive insulator (10).

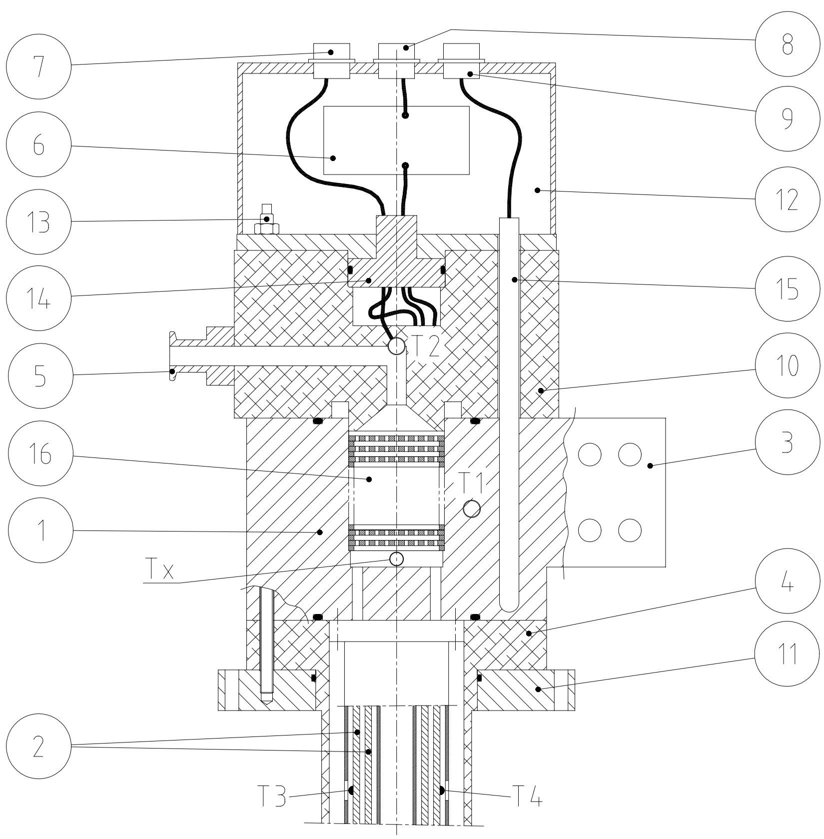

Figure 1 Scheme of the warm terminal

The whole sandwich, including connecting stainless steel flange (11), ground insulator, copper part, massive insulator and electrical box (12) are screwed together with electrically insulated double-end stud bolts (13) and sealed by O-rings in between.

#### *2.1.1 Heating element*

In order to keep the warm terminal at ambient temperature at any working conditions two heating elements (15) of 100 W each are installed directly into the warm terminal. The small gap is filled with a heat conductivity compound to ensure a good heat transfer between the copper block and the heaters.
Ceramic envelopes of the heaters ($Al_2 0_3$) provide excellent electrical insulation while heat transfer is good.

#### *2.1.2 Auxiliary heat exchanger*

As the required leakage current at test voltage of 2 kV is very low, no humidity on the warm terminal is acceptable. For this purpose an auxiliary heat exchanger (16) is integrated in the terminal.
This exchanger is designed as a perforated plate heat exchanger. Thirty perforated disks interlaced by silver plated spacers are vacuum brazed in a compact cylinder pressed-in into the terminal copper part. Diameter of perforation is 1 mm.

### *2.2 Main heat exchanger*

The body of the heat exchanger consists of two concentric copper tubes acting as the conductor. Additionally thin wall stainless steel tubes surround the conductor providing three annular gas passages through which the helium vapour passes for cooling of the conductor. Material for the conductor is copper (SF-Cu) with a residual resistance ratio of 4.

### *2.3 Cold terminal*

The cold terminal of cylindrical shape in copper (OF-Cu) is vacuum brazed to the copper pipes of the main heat exchanger. The terminal is equipped with a groove and silver plated for high quality soft soldering of superconducting cable. In order to ensure the good electrical contact between the terminal and the cable a dedicated soldering device was developed. Surface area of the terminal immersed in LHe avoids film boiling.

### *2.4 Instrumentation*

#### *2.4.1 High voltage taps*

The current lead is equipped with 3 voltage taps. Tap 1 is connected to the warm terminal. Tap 2 is connected to the cold terminal. Tap 3 is prepared to be connected to superconducting cable of the auxiliary magnet. Voltage drop of the current leads is $U_{1-2}$ while resistance of the contact between cold terminal and superconducting cable is done by $U_{2-3}$.

#### *2.4.2 Thermometers*

Four current lead thermometers are located as follows. Thermometer T1 measures temperature of the warm terminal, thermometer T2 measures the temperature of outlet gas and thermometers T3 and T4 (redundancy) measure temperature of main exchanger at 90% of exchanger length from cold side where the burn region is expected. Thermometer T1 is installed from air side. Other three thermometers are located on helium side. All four are connected to the isolated transmitters and further to the connector.

#### *2.4.3 Instrumentation Feedthrough*

Wires for voltage tappings and 3 thermometers pass from the helium side to the air side through a 13 pins feedthrough (14) design specifically for this purpose. Sufficient distances between live and ground parts ensure a minimal leakage current at 2 kV.

## 3. PERFORMANCE OF THE LEAD

### *3.1 Test conditions and procedure*

In order to measure parameters of the current lead a dedicated test set up was designed and built at CERN. The pair of current leads was electrically short-circuited by a superconducting cable and connected to a power supply. The helium level was maintained constant, just below a gas inlet of the heat exchanger. Heat inleak at self cooling condition was measured by boil-off method considering that LHe in the cryostat is replaced with cold gas helium, eliminating heat inleak of the cryostat itself and subtracting inleak of restive connection of the cold terminal/superconducting bus bar. Heat inleak of resistive connection was measured by electrical method; self-heat inleak of the cryostat was measured separately. Only for test purpose one extra thermometer Tx is installed in a tapping between both heat exchangers. T3 monitored at this condition is the future set point of the temperature control at normal working condition.

### *3.2 Results of measurement*

In Table 2 are summarised measurement results and the corresponding calculated values.

Table 2 Calculated and measured results

| Parameters | | Calculated value | Measured value |
|---|---|---|---|
| Heat inleak at I=0A | [g/s] | 0.019 | 0.024 |
| Heat inleak at I=600A | [g/s] | 0.036 | 0.037 |
| Heat inleak at I=1 kA | [g/s] | 0.061 | 0.062 |
| Pressure drop at I=1 kA, total (mainHX) | [kPa] | 1.22(1.15) | 1.24 (1.15) |
| Leakage current at 2 kV DC at working condition | [A] | $0.2 \times 10^{-9}$ | $<10^{-9}$ |
| Gas outlet temperature Tx at I=0/600/1000A of the main HX with set point of warm terminal T1=295K | [K] | 294 | 292 |
| Gas outlet temperature at I=0/600/1000A of the Aux. HX with set point of warm terminal T1=295K | [K] | 295 | 294 |
| Required heating power at I=0/600/1000A resp. and T1=295K | [W] | 30/27/13 | 38/34/20 |
| T3 at I=0/600/1000A respectively | [K] | 238/242/259 | 234/240/251 |

Diagram on Figure 2 shows calculated temperature along the main heat exchanger at different current and also at interrupted gas flow. Cooling gas flow stop test (FS) for 120s and running the current leads for 20 minutes confirmed their good stability at 1 kA.

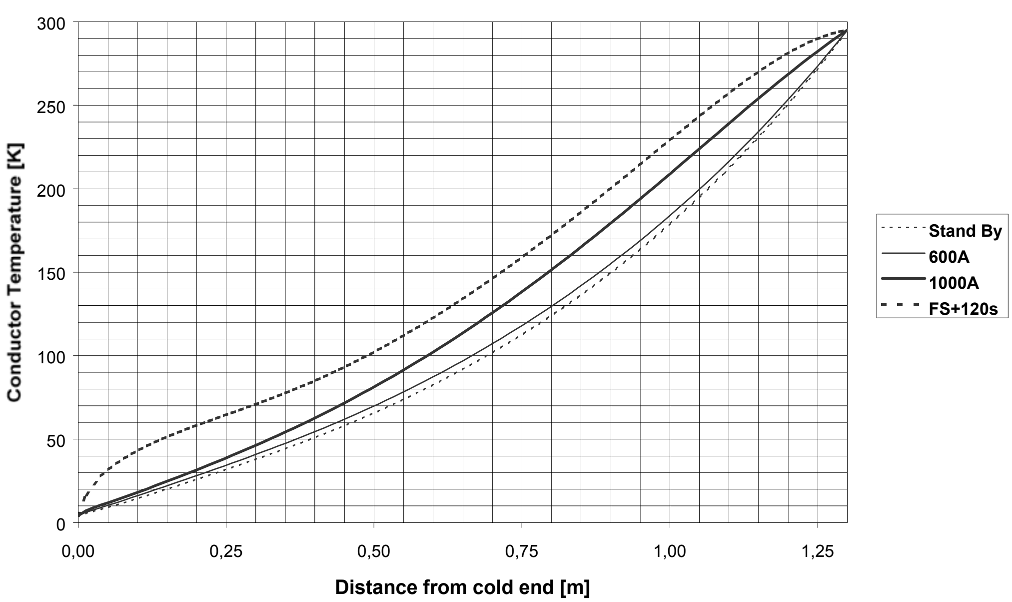


Figure 2 Calculated temperature profiles

## CONCLUSION

Current leads up to 1 kA have been constructed and tested. The measurements of the performance indicate that the design is reliable. The glass fibre insulator is not fragile neither expensive and allows optimisation of its geometry. Enhanced design of the warm terminal avoids any humidity and allows a magnet high voltage test.

## REFERENCES


1. Johnson, Victor J., 1961, *Properties of Materials at Low Temperature* (Phase I). Pergamon Press,
2. Leroy D., Oberli L., 1988, 18 kA Vapour cooled current leads, *ICEC 12* Southamton, England