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the
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Engineering Specification

120 A CURRENT LEADS FOR THE DFBS

Abstract

The call for tenders (IT-3295/AT/LHC) based on a functional specification for the 120 A conventional self-cooled current leads, of which 196 units are required, grouped as assemblies on flanges in sets of 4 and 8, yielded a single offer at a price far in excess of our estimate. It was therefore decided to look into the possibility of designing these leads at CERN, in order to purchase via build-to-print orders. This report concerns the resulting conceptual design. In order to save time and expense, wherever possible the design is based on the use of previously developed and validated components.

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1. INTRODUCTION

The call for tenders (IT-3295/AT/LHC) based on a functional specification for the 120 A conventional self-cooled current leads, of which 196 units are required, grouped as assemblies on flanges in sets of 4 and 8, yielded a single offer at a price far in excess of our estimate. It was therefore decided to look into the possibility of designing these leads at CERN, in order to purchase via build-to-print orders. This report concerns the resulting conceptual design. In order to save time and expense, wherever possible the design is based on the use of previously developed and validated components.

The test of a prototype assembly with leads operating in nominal conditions is planned to take place in April 2004. The results of the tests will be made available for establishing the precise requirements for the cryogenic valves and control.

2. FUNCTIONAL REQUIREMENTS

Maximum operating current : 120 A d.c.
Operating temperature range : from room temperature to 4.5 K.
Insulating voltage to ground : 1.5 kV d.c., both polarities - 30 seconds.
Leakage current : $\leq |3|$ μA.
Design pressure : 3.5 MPa.
Test pressure : 4.5 MPa.

3. PHYSICAL INTERFACE

The 120 A current lead assemblies are integrated in the DFB chimneys. The chimneys have the same dimensions as those that house the assembly of 600 A High Temperature Superconducting current leads. This interface is taken as a boundary condition. The DFBs concerned and the corresponding number of 120 A current lead assemblies are listed in Table 1. Two types of current lead assemblies are required, consisting respectively of 8 and 4 current leads. The total number of assemblies is 36.

As for conventional self-cooled leads, it is assumed that the 120 A current leads for the DFBs are cooled by the helium vapour generated by the heat conducted by the lead itself into the 4.5 K liquid helium bath.

4. PROPOSED DESIGNED

4.1 BACKGROUND

An optimized vapour-cooled lead brings into the helium bath 1.04 W per kA of current [1]. Particularly for small leads, this theoretical value is difficult to achieve, and a heat in-leak of about 1.5 W/kA is considered to be realistically achievable. An optimised conduction cooled lead, which does not use the helium boil-off to cool it along its length, conducts about 46 W/kA into the liquid helium bath [2]. This would imply about 5.5 W, at 4.5 K, for an optimized 120 A conduction-cooled lead operating at maximum current. Such a heat load would be too penalizing for the LHC cryogenics.

	Group of 4 leads	Group of 8 leads	Location	
DFBAO	1	0	L8	Sector 7-8
DFBAN	0	0	R7	
DFBMA	1	1	L8	
DFBMC	1	1	L8	
DFBMH	0	0	R7	
DFBAP	1	0	R8	Sector 8-1
DFBAA	0	0	L1	
DFBMB	1	1	R8	
DFBMI	1	1	R8	
DFBMJ	0	0	R8	
DFBLA	1	1	L1	
DFBAD	1	0	R2	Sector 2-3
DFBAE	0	0	L3	
DFBMB	1	1	R2	
DFBMC	1	1	R2	
DFBMD	0	0	L3	
DFBAH	1	0	R4	Sector 4-5
DFBAI	0	0	L5	
DFBML	0	0	R4	
DFBMK	0	0	R4	
DFBMG	0	0	R4	
DFBLD	1	1	L5	
DFBAF	0	0	R3	Sector 3-4
DFBLC	0	0	R3	
DFBMD	0	0	R3	
DFBAG	1	0	L4	
DFBME	0	0	L4	
DFBMF	0	0	L4	
DFBMG	0	0	L4	
DFBAJ	0	0	R5	Sector 5-6
DFBLE	1	1	R5	
DFBAK	1	0	L6	
DFBMM	2	0	L6	
DFBAL	1	0	R6	Sector 6-7
DFBMM	2	0	R6	
DFBAM	0	0	L7	
DFBMH	0	0	L7	
DFBAB	0	0	R1	Sector 1-2
DFBLB	1	1	R1	
DFBAC	0	1	L2	
DFBMC	1	1	L2	
DFBMA	1	1	L2	

Number of assemblies	23	13
Number of leads	92	104
Total number of leads	196	

Table 1. Number and position of 120 A current lead assemblies

The LHC Short Straight Sections incorporate 60 A and 120 A current leads [2]. These leads consist of electrically insulated conductors, which are encapsulated in tight-fitting stainless steel tubes and pass - along a tortuous path - through the cryostat main vacuum insulation. The leads are conduction-cooled but, in order to limit the heat in-leak into the helium bath to some 2.8 W/kA, heat sinking is provided at 4.5 K-20 K (LHC line C') and at 50 K-75 K (LHC line E). The conduction-cooled leads, which are now being produced in industry, were the result of a significant development effort. In order to reduce the development time for 120 A leads of the DFBs and to profit from validated components developed in the past, it is considered an advantage to incorporate as many of the conduction-cooled lead's features as possible into the present design.

4.2 CONCEPTUAL DESIGN

The conceptual design of the proposed 120 A current leads for the DFBs is sketched in Fig.1.

The design uses the same conductors and warm terminal assemblies as in the 120 A conduction-cooled leads. Three heat exchangers (HX1, HX2 and HX3) are clamped to the stainless steel encapsulating tubes, as shown schematically in Fig.1. These heat exchangers are cooled by the boil-off vapour, which is recovered via a single exit tube for each flange. Two heat exchangers (HX2, at about 20 K, and HX3, at about 50 K) reproduce the heat intercepts used in the series of 120 A current leads integrated in the Short Straight Section cryostats. A third heat exchanger (HX1) is incorporated at the lower end of the leads: it uses the gas enthalpy available in the range from 4.5 K to 20 K to further reduce the heat load into the helium bath. The heat exchangers consist of copper blocks, with grooves for the clamping of the conductors as in the conduction cooled leads [2]. In these copper blocks, copper grids are brazed to enhance the heat exchange between the gas and the copper.

The instrumentation wiring inside the cryostat (voltage taps V2 and V3, on each lead, and platinum temperature sensors T1 and T2, both doubled for redundancy reasons) is introduced through a small tube traversing the current leads flange; the terminal of this wiring is insulated from earth. The control of the gas flow used for the High Temperature Superconducting current leads is emulated [3], but in this case using the temperature signal from the second heat exchanger (T1 or T2). An additional voltage tap (V1), accessible from outside, is connected to the warm electrical terminal of each lead. The wires of these voltage taps, up to eight per assembly, are collected in a separate instrumentation connector supported on the current leads' warm flange. The voltage drop across each lead provides the interlock signal (as for all the leads). A small heat exchanger (HX4) is also incorporated at the gas exit; heaters are installed to take the gas to room temperature and prevent icing.

4.3 THERMAL AND ELECTRICAL ANALYSIS

An analysis has been made to verify the thermal and electrical performance of this design. The temperature profile of each current lead has been calculated by numerical integration of the heat balance equation, which considers pure conduction along the lead and conduction/convection at the level of the heat exchangers. The helium mass flow passing through the heat exchangers is produced by the vaporization due to the heat conducted by the leads themselves into the helium bath. Boundary conditions are room temperature, at the level of the warm electrical connection, and 4.5 K where the lead dips into the liquid helium bath. Material properties are considered temperature dependent.

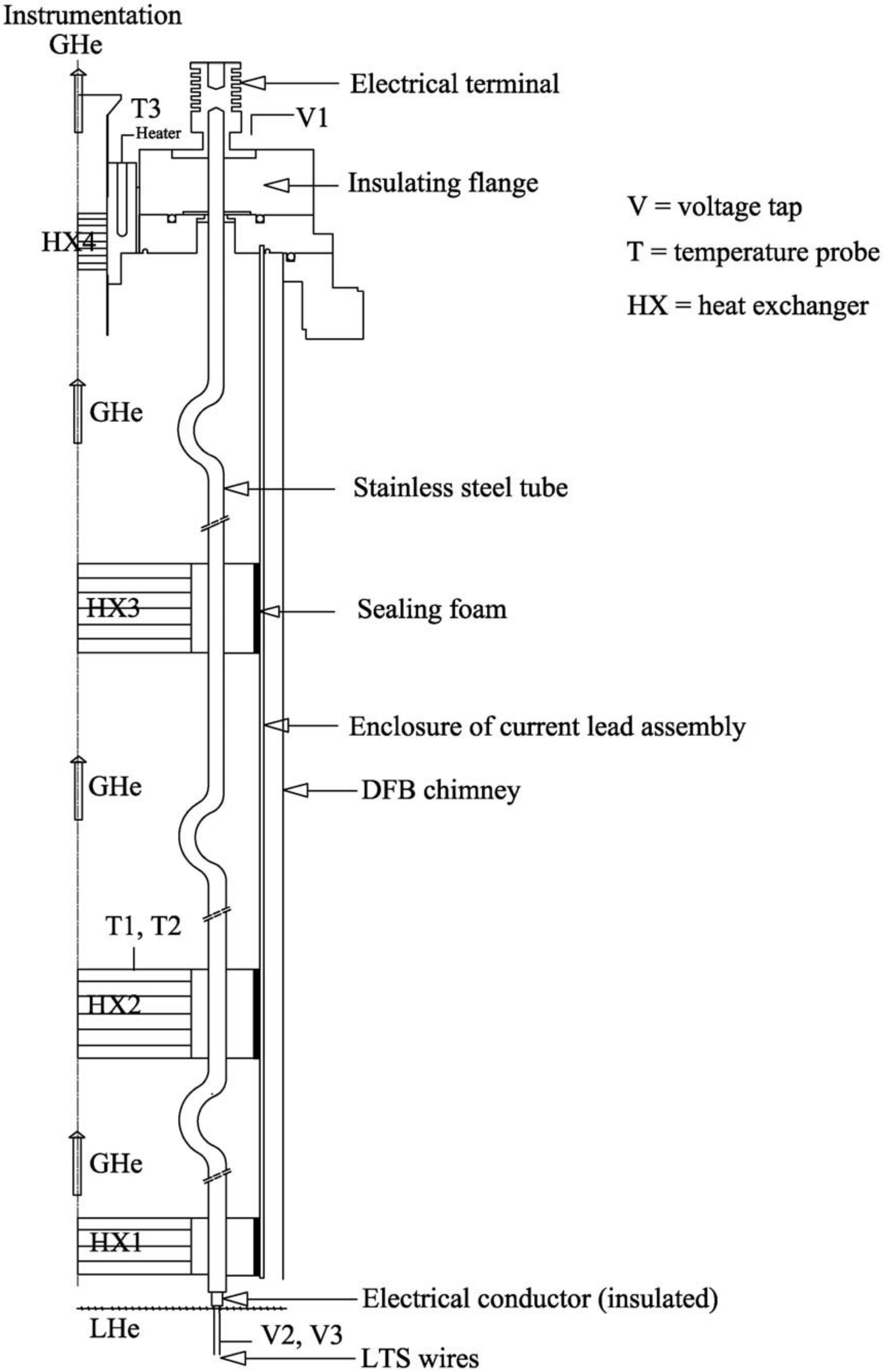


Fig.1. Schematic of 120 A current lead assembly

Fig. 2 shows the calculated temperature profile of the lead when transporting 120 A. The heat load into the helium bath is calculated to be 280 mW per lead at 120 A. In the worst case, when all the eight leads of the same assembly are running at 120 A, the heat adsorbed by the heat exchangers corresponds to: 41 W @ 50 K (HX3), 15 W @ 20 K (HX2) and 3.8 W @ 5 K (HX1). The helium flow rate is 120 mg/s. The total pressure drop of the gas will be maintained to below 30 mbar. The calculated total voltage drop across the leads, at maximum current, is 42 mV. At zero current, with a helium flow rate of 80 mg/s, the heat load into the helium bath is reduced to below 200 mW per lead.

It should be noted that (i) these leads feed correctors that are on average excited to about 20 % of their rating, and (ii) 84 % of these leads feed magnets having a maximum current limited to 80 A.

The design is such that the leads are stable in the event of an interruption of the gas flow. In this case, at the expense of an increased heat load into the helium bath, the lead would be able to transport up to 60 A, in steady state conditions, without overheating. At 80 A, the lead would reach, in steady state conditions, a peak of temperature of 480 K.

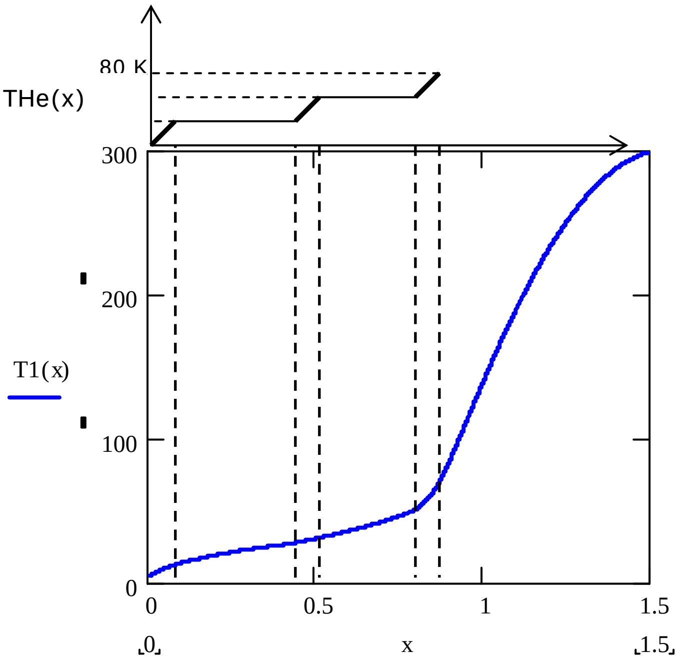


Fig.2. Temperature profile, at 120 A, of the lead (T1(x)) and of the gas (THe(x))

5. PLANNING

Sufficiently detailed sketches have already been made for making a current lead assembly in collaboration with the Main Workshop. This was done to validate the design, and simultaneously the detailed drawings are being made in the drawing office. Raw and semi-finished material with long delivery are being ordered, so that when the prototype assembly has been made, sub-components have been tested and the detailed drawings are ready (by the end of the year, if the work is given appropriate priority), rapid delivery orders for the final series can be placed. Risk and cost will be minimized by judicious fractioning of the orders. It is considered realistic to have the first series components ready by middle 2005.

6. COST

The design should enable us to stay within the originally foreseen budget for the supply of this set of current leads.

Additional savings should also be possible:

1. The flow control is simplified. Whereas for conventional self-cooled leads, such as the ones integrated in the DFBX, one warm valve per current lead is needed for the control of the helium flow rate, in this case the requirement is reduced by 80 % (the need is of one warm valve per assembly). In addition, the connection of the gas recovery piping to the leads (to be made in tunnel) is simplified in the interest of the integration issues.
2. It is proposed to test at nominal, cryogenic, conditions the prototype assembly and the first assembly of the series production. Additional cryogenic tests should not be necessary.

7. CONCLUSION

- A build-to-print design for the 120 A vapour-cooled current lead assemblies is proposed.
- In order to accelerate the detailed design process, the design incorporates components previously developed at CERN, and it is expected that the total cost will be brought back to within the original estimate.
- The gas recovery and cryogenic control is simplified with respect to the system based on the standard vapour-cooled leads in that there is one circuit per flange (containing 4 or 8 leads) instead of one circuit per lead. This should also lead to cost savings.
- Provided appropriate priority is given to this work, the first serial components could be available by mid 2005, in harmony with the present LHC installation schedule.

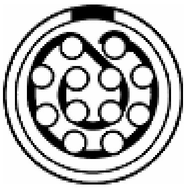
8. REFERENCES

1. Superconducting Magnets, M. Wilson, Clarendon press, Oxford, 1983, pp 256-276
2. Conduction-Cooled 60 A Resistive Current Leads for the LHC Dipole Correctors, A. Ballarino, LHC Project Report 601
3. LHC HTS Current Leads, A. Ballarino, Functional Specification, LHC Project Document No. LHC-DFL-ES-0001, EDMS Document No.350602

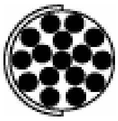
9. ANNEX 1

Electrical connectors and pin-out of instrumentation wires

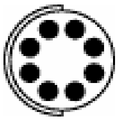
Three electrical connectors are integrated on the warm electrical insulating flange of each lead assembly. They collect the instrumentation wires consisting of: 3 voltage taps (V1, V2 and V3 in Fig.1) per lead and three platinum resistance temperature sensors (T1, T2 and T3 in Fig. 1) per assembly. The voltage taps connected to the cold end of the lead (V1 and V2, doubled for redundancy reasons) are wired in the 16 pins Fischer connector. The warm voltage taps (V3) and the wire of the temperature probe T3, all accessible from outside, are wired in the 12 pins LEMO connector. The 8 pins Fischer connector collects the wires of the two temperature probes T1 and T2, doubled for redundancy reasons.



LEMO connector, PKG 2B 312 CLLD 62, 12 pins



Hermetic Fischer connector, DBEE 104A086, 16 pins



Hermetic Fischer connector, DBEE 104A066, 8 pins

In analogy with the High Temperature Superconducting current leads for the LHC machine, the following denomination will be used for the instrumentation signals:

for the temperature probes:

T8JK, J=1 for gas exit and 2 for heat exchanger; K=temperature probe number;

for the warm voltage taps:

EEXY, X=number of lead, Y=1 for top;

for the cold voltage taps:

EEXYZ, X=number of lead, Y=2 for bottom, Z=voltage tap number.

Pin-out of the LEMO connector, PKG 2B 312 CLLD 62, 12 pins

Pin	Signal	
1	EE11	
2	EE21	
3	EE31	
4	EE41	
5	EE51	
6	EE61	
7	EE71	
8	EE81	
9	TT811	U+
10	TT811	U-
11	TT811	I+
12	TT811	I-

Pin-out of the hermetic Fischer connector, DBEE 104A086, 16 pins

Pin	Signal
1	EE121
2	EE122
3	EE221
4	EE222
5	EE321
6	EE322
7	EE421
8	EE422
9	EE521
10	EE522
11	EE621
12	EE622
13	EE721
14	EE722
15	EE821
16	EE822

Pin-out of the hermetic Fischer connector, DBEE 104A066, 8 pins

Pin	Signal	
1	TT821	U+
2	TT821	U-
3	TT821	I+
4	TT821	I-
5	TT822	U+
6	TT822	U-
7	TT822	I+
8	TT822	I-

10. ANNEX 2

Protection

As the 120 A conduction cooled leads integrated in the LHC SSS, each current lead integrated in the DFBs shall be individually protected to prevent the burn-out of the conductor in case of loss of the thermalization in correspondence of the heat exchangers. As mentioned in paragraph 4.3, in this case the leads are still able to operate at currents lower than the maximum one at the expense of an increased heat load in the liquid helium bath.

The protection signal is the voltage drop measured across the lead (V1-V2 or V1-V3 in Fig.1) via the voltage tap signals integrated in the lead. The nominal voltage drop at maximum current is of the order of 50 mV. The protection voltage is 100 mV. Thanks to the stability of the component, integration times of several seconds are allowed.

11. ANNEX 3

Electrical insulation

Each current lead is electrically insulated at 1.5 kV d.c. in nominal operating conditions (see paragraph 2). This applies between the non-insulated part of the lead (electrical connection to the power cables) and the ground (cryostat flange).

The electrical connectors are mounted on the current lead insulating flange (see Fig.1), which assures the 1.5 kV d.c. insulating voltage with respect to ground. In nominal operating conditions, the guaranteed insulation voltage between the electrical contacts in the same connector is 100 V d.c. The maximum differential voltage reached across the 120 A power converter is 60 V. During the high voltage insulation tests, when the power cables are disconnected, the instrumentation plugs must also be removed.

12. ANNEX 4

Leak tightness

The 120 A current lead assembly operates in the helium gas environment of the DFBs chimney (at 1.3 bars absolute pressure). The leak tightness of the 4.5 K circuit of each assembly will be measured. As for the High Temperature Superconducting current leads integrated in the DFBs, the integral of leaks detected between the lead assembly and the external environment is specified to be $\leq 10^{-7}$ Pa $m^3 s^{-1}$ (10^{-9} bar l s^{-1}).