HTS CURRENT LEAD OPTIMIZATION*

L. Tkachenko, I. Bogdanov, A. Harchenko, S. Kozub, K. Myznikov, A. Olyunin, V. Sytnik, V. Zubko, Institute for High Energy Physics, Protvino, Moscow region, Russia,
I. Akimov, D. Gusakov, D. Rakov, A. Shikov, Bochvar's Scientific Research Institute of Inorganic Materials, Moscow, Russia

Abstract

600 A current leads based on Bi-2223 HTS tapes for LHC SC magnets are optimised. Three current leads were manufactured for development of current leads and HTS tape design. The economical current leads design satisfying the requirements of the technical specification for prototype 600 A HTS current leads is found.

1 INTRODUCTION

Earlier developed and manufactured current leads #1, based on tape composite conductor Bi2223 in a Ag+10at.%Au matrix [1], have satisfied the CERN technical specification for the fabrication and supply of 600 A current lead prototype [2]. Reduction of Au content in the matrix was studied with the aim to reduce the material cost.

Current leads #2, using of Bi2223 tapes with matrix made of cheaper alloy Ag+1at.%Au, have been fabricated as a next step. However the heat load to liquid helium through the current leads #2 was equal to 130 mW [3] as a result of higher a thermal conductivity of the HTS tape having Ag+1at.%Au matrix in comparison with a thermal conductivity of the HTS tape based on Ag+10at.%Au matrix [4]. This heat leak is about one and half times higher than the acceptable value.

The current leads #3, using of Bi2223 tapes with matrix Ag+1at.%Au, have been made with alternating cross-section along the length of HTS part in order to decrease the heat load to liquid helium and electrical and thermal characteristics of the current leads were studied.

2 CURRENT LEADS DESIGN

The improved current leads #3 have the combined design consisting of resistive end HTS parts. The HTS part of the current leads #3 has a variable cross-section and is made on basis of Bi2223 in a Ag+1at.%Au matrix.

Calculations have been made for current leads #3 and computer simulation defined the optimal geometry of a resistive part, number of HTS tapes and the coordinate of the cross-section alteration along the length of the HTS part. The optimization is based on the numerical solution of the heat balance equation in the leads and in the helium flow, which cooled the resistive part, and takes into account the self cooling effect of the helium HTS part as well as the temperature dependence of the materials and helium properties. This numerical model is used for study of the transition in the normal state in the HTS part current leads as a result of emergence regimes.

For calculation of number of HTS tapes and the coordinate of the cross-section alteration along the length of the HTS part, the voltage-current characteristic was used, which was obtained earlier on the previous current leads with HTS part made of Bi2223 in a Ag+1at.%Au matrix.

The voltage-current characteristic was approximated by the power function for current leads #1 and #2:

$$E = E_c \left(\frac{J}{J_c} \right)^n , \tag{1}$$

where $E_C = 1\ \mu V/cm$, $J_C = J_C(T)$ is the critical current density at E_C, n is the index of power.

Fig. **1** shows the overall view of the current leads.

Fig. 1. Overall view of 600 A HTS current lead.

The HTS part of the current leads #3 were made from 14 tapes, which are placed in two layers. The tapes in the outer layer were cut at 160 mm from the lower end of the leads. The ends of the outer layer tapes are soldered to the inner layer tapes by PbSn solder. The length of the joint is 10 mm. Two NbTi conductors are soldered to the lower end of the HTS part. The HTS part is self cooled by evaporated helium, which flows through the annular gap between the HTS tapes and stainless steel jacket.

The resistive part of the current leads #3 is similar to preceding made current leads. It consists of 2300 copper wires with diameter of 0.13 mm. These wires are enclosed in a stainless steel tube with a length of 500 mm and an inner diameter of 11 mm. The bunch, enclosed in tube of copper wires, is cooled by gaseous helium with the input temperature of 20 K and pressure of 0.13 MPa.

Design features of the current leads #3 in comparison with earlier made leads are reflected in Table 1.

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Table 1 Main design distinctions of current leads.

Leads	#1	#2	#3
HTS conductor:			
Number of filaments	37	61	61
Matrix	Ag+10at.%Au	Ag+1at.%Au	Ag+1at.%Au
Cross section, mm^2	4.3×0.25	4.6×0.25	4.6×0.25
Filling factor, %	30	30	30
HTS part:			
Cross section	constant	constant	variable
Number of HTS tapes	33	16	14
I layer length, mm	350	400	400
II layer length, mm	350	400	240
III layer length, mm	350	-	-
Number of NbTi wires	1	2	2
Resistive part:			
Number of Cu wires	2300	2300	2300
Cu wires diameter, mm	0.13	0.13	0.13
Tube inner diameter, mm	12	11	11
Packaging density, %	29	35	35

The leads were equipped with voltage-taps and thermometers. Four thermometers were attached to the resistive part and five ones to the HTS part in order to determine the heat to liquid helium. The heat load into the liquid helium was calculated in according with the measured temperature profile of the HTS part.

The voltage-current characteristic was approximated by the function (2) for the current leads #3

$$E = E_c \left(\frac{J}{J_c(T)} \right)^n + \rho_j J \,, \qquad (2)$$

where $\rho_j = \rho_j(T)$ is the joint specific resistance between outer layer tapes and inner layer tapes.

3 TEST RESULTS

Measured and calculated temperature profiles along the current leads are found in a good agreement as one can see from Fig. 2 and Fig. 3.

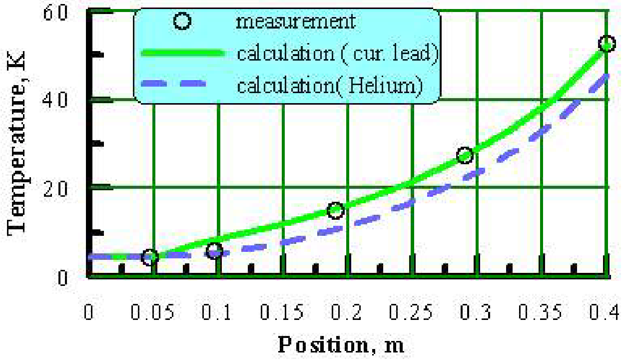

Fig. 2. Temperature profile along the HTS part of the current leads.

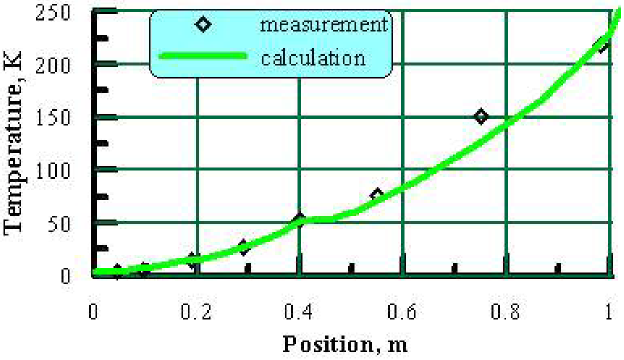

Fig. 3. Temperature profile along the total length of the current leads.

The measurement showed that the stepwise shape of the HTS part allowed one to decrease the heat load down to 80 mW at the nominal current of 600 A. This value is 1.6 times less than the heat load, obtained earlier on the current leads #2, which were made on the base of Bi2223 into the matrix from Ag+1at.%Au alloy with constant cross-section of 16 HTS tapes along overall length of the HTS part.

Measured and calculated voltage-current characteristics of HTS part of the current leads are presented in Fig. 4.

These dependencies were obtained at the temperature about 50 K in the HTS part upper end and at current ramp rate approximately 300 A/s.

The voltage-current dependence has the power of index 6 for current leads #2 and #3, whereas this value is equal to 8 for the current leads #1.

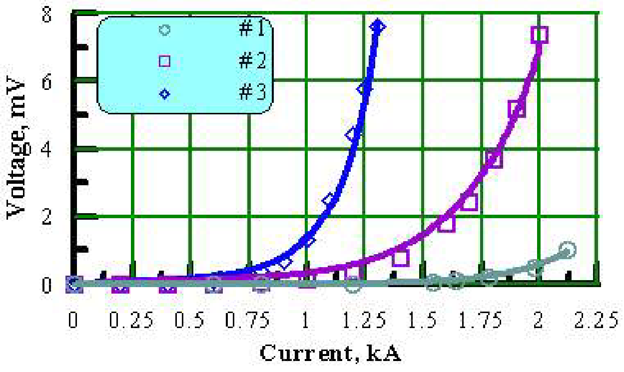

Fig. 4. Measured and calculated volt-ampere characteristics of the HTS part of the current leads.

The transition in the normal state at the current of 600 A was realized in order to simulate emergence regimes. This process was fulfilled by means of interruption of the helium flow, which cooled the resistive part. Experimental and calculated curves of the temperature dependence T against time for the joint between HTS and resistive parts are presented in Fig.5 for given process. Measured and calculated time dependencies of the HTS part voltage U are also shown in this picture. The index of power n was constant at overall temperature range in numerical calculations. The voltage on the HTS part is increased up to 20 mV and the temperature in the upper end of the HTS part reached 115 K during approximately 15 minutes. These results attest the high reliability of the current leads #3.

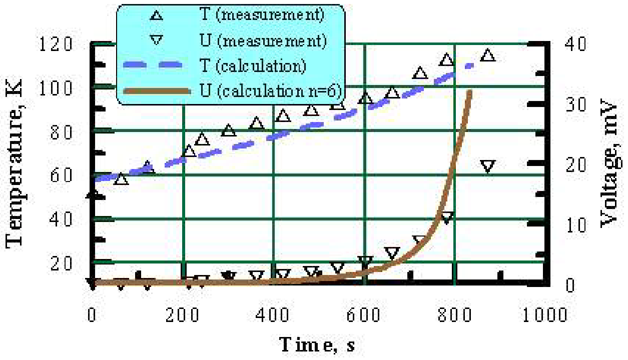

Fig. 5. Measured and calculated dependencies of voltage on HTS part and of the temperature in the upper end of the HTS part versus time after interruption of helium flow in the resistive part.

The main characteristics of three current leads manufactured in IHEP are summarized in Table 2 and obtained results are compared with the requirements for the CERN technical specification.

Table 2. Main characteristics of the three current leads

Parameter	CERN requirements	#1	#2	#3
Mass flow of 20 K He at 600 A, g/s	≤0.03	0.03	0.038	0.04
Pressure drop of 20 K He flow, kPa	≤5	1.0	4.6	5
Heat load at liquid He 600 A, mW	≤80	42	130	80
Heat load at liquid He 0 A, mW	≤70	40	130	67
Joint resistance between HTS and resistive part, mΩ	≤1	0.13	0.22	0.22
Joint resistance between HTS part and NbTi conductors, nΩ	≤30	1.4	2	6

4 CONCLUSION

The current leads #3 showed the high stability in operation and ability to undergo a large short-time current overloads. The current leads operate stably while the temperature of the upper end of the HTS part increases up to 60 K. This fact and the high inertness at the transition into normal state after interruption of cooling gas flow indicate the high reliability of the current leads.

The specific selection of the HTS conductor matrix material as well as the optimization of the HTS part cross-section of the current leads permitted to decrease the cost of the current leads and at the same time to comply with the requirements of the Technical specification for the fabrication of 600 A current leads.

5 REFERENCES

[1] I.V.Bogdanov, S.S.Kozub, K.P.Myznikov et al., “Design and Test of High Temperature superconductor Current Lead”, Proc. of XVI Conf. on Magnet Technology, Tallahassee, USA, 1999, p.1485.
[2] Technical specification for the fabrication and supply of prototype 600 A current leads using high temperature superconductor. IT-17847/LHC/LHC, Geneva, Switherland, July 1998.
[3] I. Bogdanov, S. Kozub, K. Myznikov et al., “Application of HTS Bi-2223 for Current Leads of Superconducting Magnets”, Proc. of EPAC-2000, Vienna, Austria, 2000, p.2178.
[4] I.I. Akimov, N.I.Kozlenkova, P.A.Kuznetsov et al., “Properties of Bi-2223/(Ag+Au) Tapes”, Proc. of XVI Conf. on Magnet Technology, Tallahassee, USA, 1999, p.1493.