

Updating and Test on 12kA HTSCL for Russia JINR

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Abstract. The Joint Institute for Nuclear Research (JINR) started manufacture and test of superconducting magnets for the new accelerator complex Nuclotron-based Ion Collider fAcility (NICA). A pair of current leads rated 12 kA was developed for cold testing of the magnets in 2012. The operation of the facility needs ~350 leads rated from 100 A to 12 kA to convey current for the magnets. After the test of the pair of 12 kA leads in JINR a contract of supplying 3 pairs of 12 kA high temperature superconducting current leads (HTSCLs) were signed to ASIPP this year. In this paper the design updating and test of the current leads are introduced.

Index Terms—Current lead; Bi2223; NbTi; Insulation

1. Introduction

Current lead connects the room temperature busbar and cryogenic magnet to convey the large current. The high temperature superconducting (HTS) module is applied on the current lead that will minimize the heat load to the cold end and save 2/3 helium consuming in compare with the conventional copper lead. After the successful producing of Bi 2223 tapes many HTS current leads were developed in the world. The KIT and CRPP developed a 70 kA HTS current lead for ITER^[1]. The current lead was designed with 50 K helium gas cooling of the fin type HEX and 4.5 K SHe cooing of the cold end. It was proved to be safety operation with 80 K helium. In CERN thousands of 6-13 kA leads were commercial produced and used on the Large Hadron Collider LHC^[2]. The HEX was cooled by 20K helium gas and the NbTi low temperature superconducting (LTS) strands were immersed in liquid helium. In ASIPP 15 kA HTS current leads were developed and assembled on EAST tokamak^[3]. The HEX was designed with multi-helix. The cold end of the HEX was direct soldered to the HTS module and cold by LN₂. ASIPP also successfully developed 10 kA, 52 kA and 68 kA trial lead for ITER^[4-6]. The foil type and fin types HEX were developed and compared. The foil type HEX was proved to be with much more cooling efficiency. The stacks soldered from Bi 2223 tapes and NbTi LTS strands were applied. The maximum current capacity of the 68kA trial lead reached 90 kA.

Currently in Russia the new accelerator complex Nuclotron-based Ion Collider fAcility (NICA) are in developing. ~350 leads rated from 100A to 12kA will be supplied for the facility operation. The Joint Institute for Nuclear Research (JINR) needs one pair of current leads to test its superconducting magnet. So in 2012 a pair of 12 kA current leads was developed and tested.

In 2013 ASIPP was awarded a contract of supplying 3 pairs of current leads rated 12 kA before June 2014. In this year the 12kA leads are design updated based on the fabrication experience and test results.



2. Design and test of 12 kA leads

The current leads developed in 2012 were optimized on 12 kA current and current capacity reached 21 kA. The current lead (see Figure 1) is 1.855m length and 40 kg net weight and mainly characterized by^[7] 1) water cooling terminal; 2) foil type heat exchanger (HEX); 3) LN₂ cooling transition; 4) Bi2223 high temperature superconductor (HTS); and 5) NbTi Nuclotron type low temperature superconductor and 6) high voltage (HV) insulation.

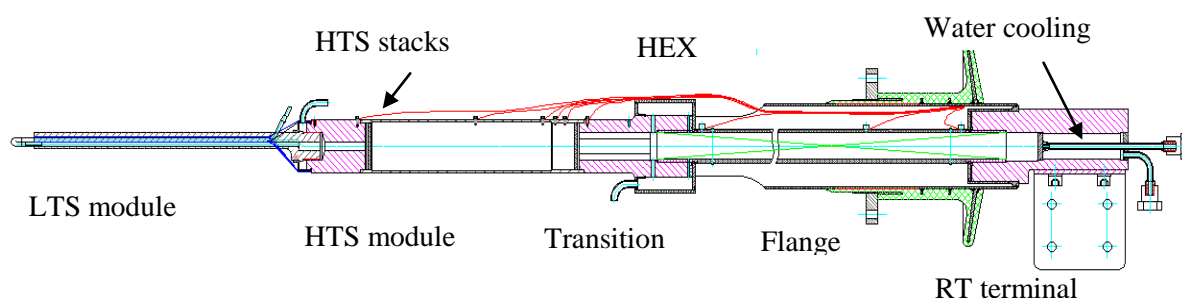


Figure 1. Drawing of the integrated 12kA HTSCL

The pair of 12kA leads was tested in ASIPP after the integration. Heat exchanger was cooled by liquid N₂ (LN₂) which was supplied from an external 500 L LN₂ tank. LTS section of the leads was cooled by liquid He. The pair of leads was soldered with a short length of an original Nuclotron cable as a superconducting jumper.

The current leads were assembled in a cryostat that was developed and fabricated for the test. A thermal shield in the cryostat was cooled with LN₂. The current from direct current (DC) generator was feed into the warm terminal. The current of power supply can be slowly ramped up to maximum 30 kA. The vacuum of the cryostat reached 1×10^{-5} Pa \cdot m³/s level in steady state operation.

Before cooling down of the current leads in the cryostat, the leakage was detected of all coolant circuit and current lead itself. The leakage rate of current lead was less than 10^{-8} Pa \cdot m³/s level. The maximum insulation voltage for flange was test to be more than 3 kV. After 1.5 hours cooling the leads reached a steady operation state. Then the LN₂ supply source was closed to measure the holding time in loss of flow accident until the quench protection was triggered. A maximum 21 kA over-load operation were performed. The test results are list in Table 2 and detail analyzed in [7].

Table 2 Main test results of a pair of 12kA current lead

Contents	1# lead	2# lead
High voltage test of insulation flange	3kV, leakage current < 1 μ A	3kV, leakage current < 1 μ A
5K heat load	3.68 W	3.67 W
Joint resistance of HTS/LTS	0.25 n Ω	1.01 n Ω
Temperature on LTS section	4.83 \pm 0.3K	6.5 \pm 0.4K
Pressure loss in LTS section	<0.02 bar	<0.02 bar
Holding time when loss of flow accident (hotspot < 180 K)	>5 min	>5 min
Over load current	21 kA	21kA

In February 2013 this pair of leads was transported to Russia JINR. However, there was leak between the insulation and the S.S tube. The reasons were analyzed that after the cooling down there were cracks between the tube and insulation because of different thermal shrinkage.

3. Updating on the 12kA leads

Even though the temporary solution stopped the leak to finish the test in Russia a lasting settlement of the troubles is also developing in parallel in ASIPP.

The interface of the current lead and the cryostat is a DN 200 O ring sealed flange (Figure 2). The original insulation flange is the structure of 10mm insulation cured from fiber glass and polymeric those are wrapped on the S.S tube. A S.S ring is welded to the flange and embedded into the insulation. The insulation with minimum 4mm thickness can separate the grounded flange and current lead with potential high voltage. The cap on the top of the insulation can increase the creepage distance.

The bonding between the insulation and S.S tube is the weakness of the insulation flange. The insulation layer is glued to the S.S tube with curing method. The epoxy is a weak contact. After the cooling the cracks happened and were extended.

Two possible solutions were developed and tested in ASIPP. In solution 1 (Figure 3) the S.S cap and reinforce rings welded to the S.S tube is embedded into the insulation. The reinforce rings anchored in the insulation can prevent the thermal shrinkage of the tube. The S.S cap on top of insulation can enlarge the curing surface between the insulation and flange. Because of the room temperature of the top of HTSCL the larger bonding between the insulation and S.S cap will be less thermal shrunk. Additionally the screw on the outer diameter of the tube can also enforce the curing between the insulation and the tube.

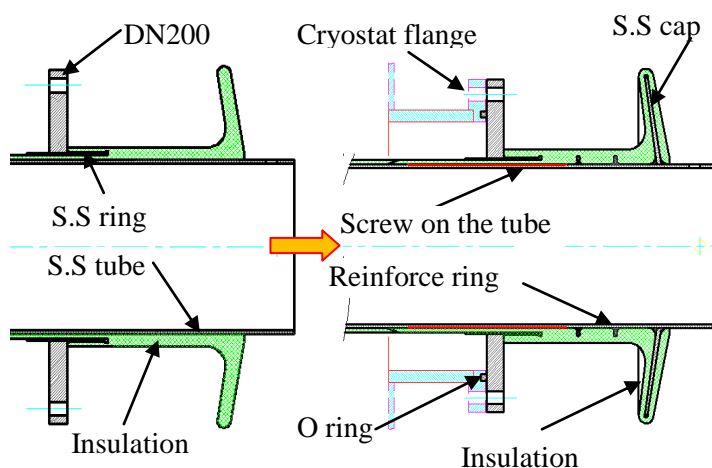


Figure 2. Original design

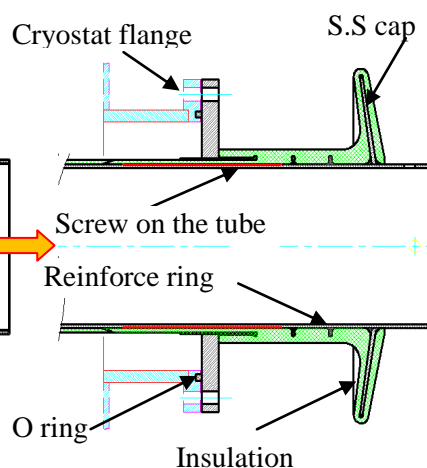


Figure 3. Solution 1

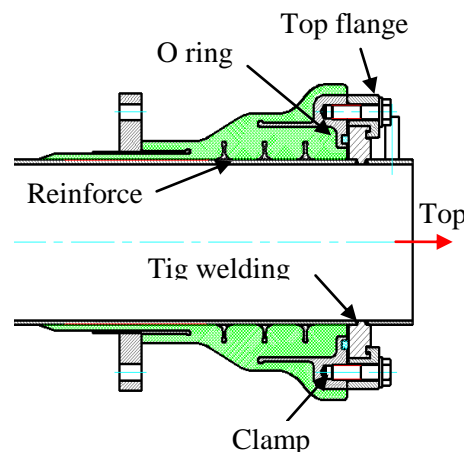


Figure 4. Solution 2

Another solution is more complicated as Figure 4 shows. On the top of the insulation a special flange is embedded. The O ring is sealed before the insulation interface. So the vacuum is totally sealed from the air even in the case of a crack between the insulation and tube.

Both solutions were tested under the real temperature and loads. The LN₂ was supplied to cool the flange down. 200 kg loads were applied by the 4 tighten springs. 3 PT100 sensors were attached on the top, middle and bottom of the insulation component (Figure 5).

The LN₂ was slowly feed into the cryostat. After the T3 temperature was less than -40°C the status was kept for 5 minutes and then warmed it up to room temperature. 5 thermal cycles were tested. The temperatures are recorded in Figure 6. The T1(top) and T2(middle) keep the temperature larger than 0°C during the thermal cycle that is well consistent with the design and the real lead test condition.

The vacuum leak rates were also tested. The leak rates on both solutions were less than 10⁻⁸ Pa • m³/s level.

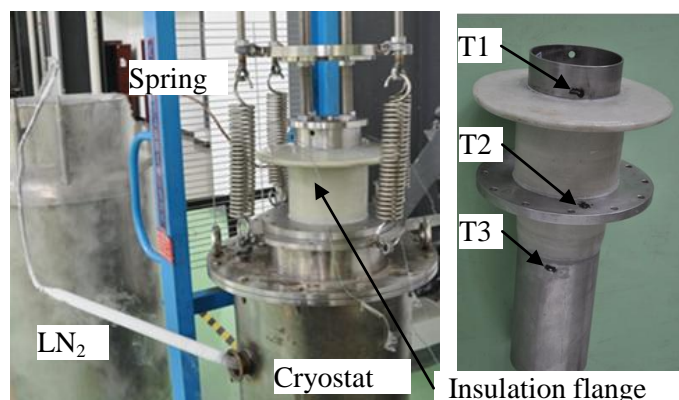


Figure 5. Test of the updated insulation flanges

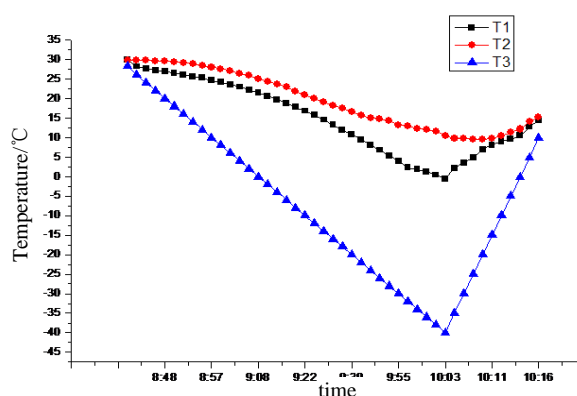


Figure 6. Temperature profiles during one thermal shock

After thermal shock the insulations were tested under high voltage to maximum 10kV. Under 2kV the leakage currents for both solutions were less than $8\mu\text{ A}$ (Figure 7 and Figure 8). On the 10kV voltage the leakage currents were less than $20\mu\text{ A}$. Given $40\mu\text{ A}$ leakage current criteria the insulation of both solutions are safe enough and larger margins are given.

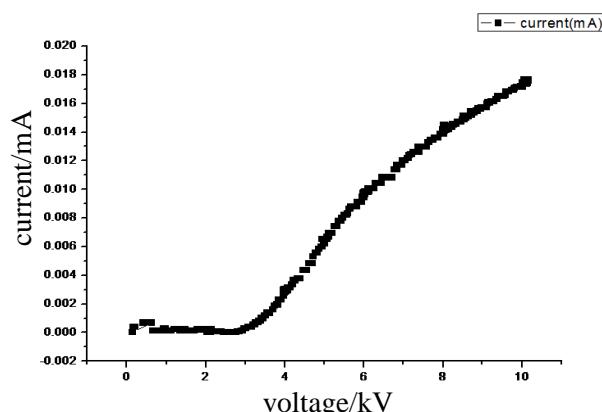


Figure 7. HV test on solution 1

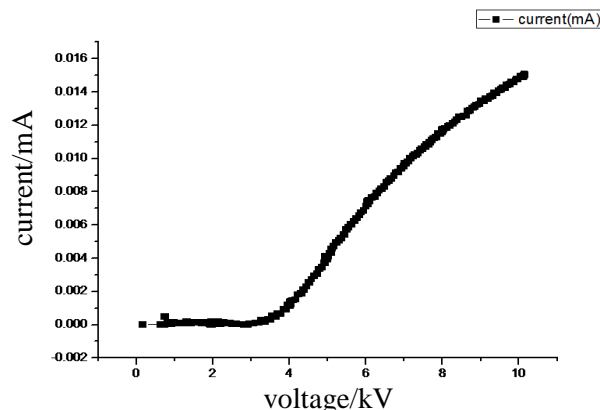


Figure 8. HV test on solution 2

The test results approve that both solutions can satisfy the design requirements. No obvious performance differences between two solutions. Solution 1 is chosen because of easy fabrication.

4. Conclusion

A pair of 12 kA HTS current leads was manufactured and tested in ASIPP. The insulation flange is updated after the cracks during the test and passes the vacuum leakage and HV test. Another 3 pairs of 12 kA leads will be prepared in ASIPP for JINR.

5. References

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