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Experiment of joints resistance and critical current of Bi2212 conductor

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ABSTRACT

Bi2Sr2CaCu2Ox is a potential material for the superconducting magnets of the next generation of Fusion reactors. A R & D activity based on Bi2212 wire is running at ASIPP for the feasibility demonstration of CICC. One sub-size conductor cabled with 42 wires was designed and manufactured. A test facility was designed and set-up to measure the resistance of joints and the critical current of the Bi2212 CICC in liquid helium. A superconducting transformer, which consisted of two concentric layer-wound superconducting solenoids, was used to provide the current of the conductor sample. Both of the primary and secondary coils were immersed in liquid helium during the experiments. The highest current of the secondary loop was up to around 14 kA. The critical current of the conductor was 13.2 kA with criterion of 1 μV/cm and the joints resistances were lower than 50 nΩ.

1. Introduction

New materials could be used to develop the magnet technology for next generation of Fusion reactors. CFETR, "China Fusion Engineering Test Reactor", is a new tokamak device [1,2]. Its magnet system includes the Toroidal Field (TF), Central Solenoid (CS) and Poloidal Field (PF) coils. The maximum field of CS and TF will reach around 15 T.

For the next generation of fusion reactor, Bi2212 has high feasibility to become the superconducting material of the TF and CS magnets. Considering the high operation temperature (10–15 K), it is economical to use Bi2212 conductor to get rid of cooling with liquid Helium even though the cost of Bi2212 is higher than Nb_3Sn at present. Bi2212 is the only cuprate superconductor that can be made into round-wire (RW). This makes it possible to develop a Bi2212 CICC (cable in conduit conductor) [3–5]. Recent progresses in Bi2212 wires have proved its suitability for round wire developments and high field magnet insert manufacturing.

A R & D activity is running at ASIPP for the feasibility demonstration of CICC based on Bi2212 wire. One sub-size conductor cabled with 42 wires was designed and manufactured. In order to verify the properties of the Bi2212 CICC, a conductor sample with length of 50 cm was prepared for critical current test. A test facility was designed and set-up to measure the resistance of joints and the critical current of the Bi2212 CICC in liquid helium. A superconducting transformer, which consisted of two concentric layer-wound superconducting solenoids, was used to provide the current of the conductor sample. The test method and results are reported in the paper.

2. Bi2212 CICC sample

The construction of Bi2212 CICC is similar to the traditional NbTi CICC and Nb_3Sn CICC, which mainly include jacket and cable. The Bi2212 needs heat treatment in an Oxygen environment. In the process, the wire cannot contact with general stainless steel, e.g. 316L or 316LN, since it could reduce the performance of Bi2212 during heat treatment. In order to avoid the problem, one Ag tube was used as separation layer between cable and stainless steel jacket for the sake of heat treatment, which was so called Ag jacket, as shown in Fig. 1.

The Bi2212 wires used for the CICC were manufactured using the powder in tube (PIT) method by Northwest Institute for Non-ferrous Metal Research (NIN). The layout of Bi2212 cable referred to the ITER CS [6]. The short twist pitch (STP) design was used for ITER CS conductor, which solved the problem of performance degradation due to strain. The cable is with a 3-stage layout (2 × 3 × (6 + 1)), and without central spiral. The total number of wires is 42. The twist pitches of different stages are 20 mm, 50 mm and 87 mm, respectively.

After manufacturing, the conductor was heat treated at 890 °C for 30 min. The temperature reduced to 830 °C with speed of 5 °C/h, and then heat treated at 830 °C for 48 h in an Oxygen environment with pressure of 1 atm. The cross section of Bi2212 conductor is shown in Fig. 2.

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Fig. 1. Photo of manufactured Bi2212 conductor with SS jacket outside and Ag tube in between.

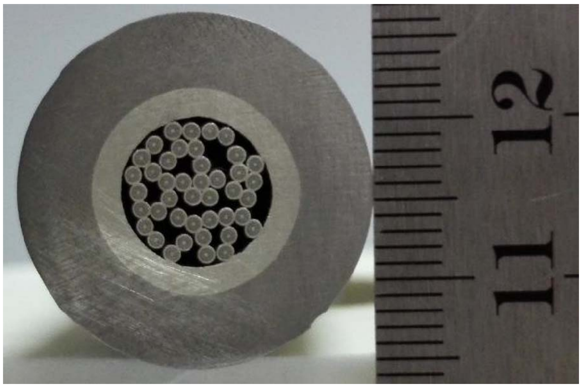

Fig. 2. Cross section of Bi2212 conductor.

In order to verify the performance of the first Bi2212 CICC, a sample with length of 50 cm was prepared for the critical current measurement. The outer jacket which is made of 316L was removed before sample assembly to reduce the joint resistance.

3. Test facility and sample assembly

3.1. Test facility

Instead of using an expensive power supply and large power consuming current leads, the superconducting transformer [7,8] principle is used to provide testing current for the Bi2212 CICC.

The test system consisted of a 300 mm useful bore diameter cryostat, a superconducting transformer which could generate more than 20 kA secondary loop current, data acquisition, and quench protection system. The transformer would be inserted into the cryostat which is 1600 mm high as shown in Fig. 3.

The transformer consists of two inductively coupled superconducting coils, the high-turn primary and the low-turn secondary. By energizing the primary coil, an amplified current will be induced in the secondary loop.

The primary coil used 0.87 mm diameter multifilamentary NbTi/Cu strands with Cu to non-Cu ratio of 1.38 and residual resistance ratio (RRR) larger than 100. The critical current of the NbTi strands was 550 A at 4.22 K and 5 T. The primary coil had a former made of 316L stainless steel. The inner diameter of the coil was 156 mm and the outer diameter was 170 mm. There were 8 layers and 1032 turns of NbTi strands in the winding. The main parameters of the superconducting transformer are listed in Table 1.

The secondary coil was a one-layer winding consisting of two turns wound on a stainless steel former. The ITER correction coil (CC) conductor was chosen for the high current secondary conductor [9]. The final dimension of the CC conductor was 19.2*19.2 mm^2 and the void fraction was about 35.8%. The critical current of the CC conductor with different magnetic field at 4.23 K is shown in Fig. 4. The critical current of the CC conductor was much larger than the expected critical current of the Bi2212 conductor sample at self-field when immersed in Liquid Helium (LHe). In total about 3 m long CC conductor was used. Polyimide films were wound on the surface of the stainless steel former as insulation.

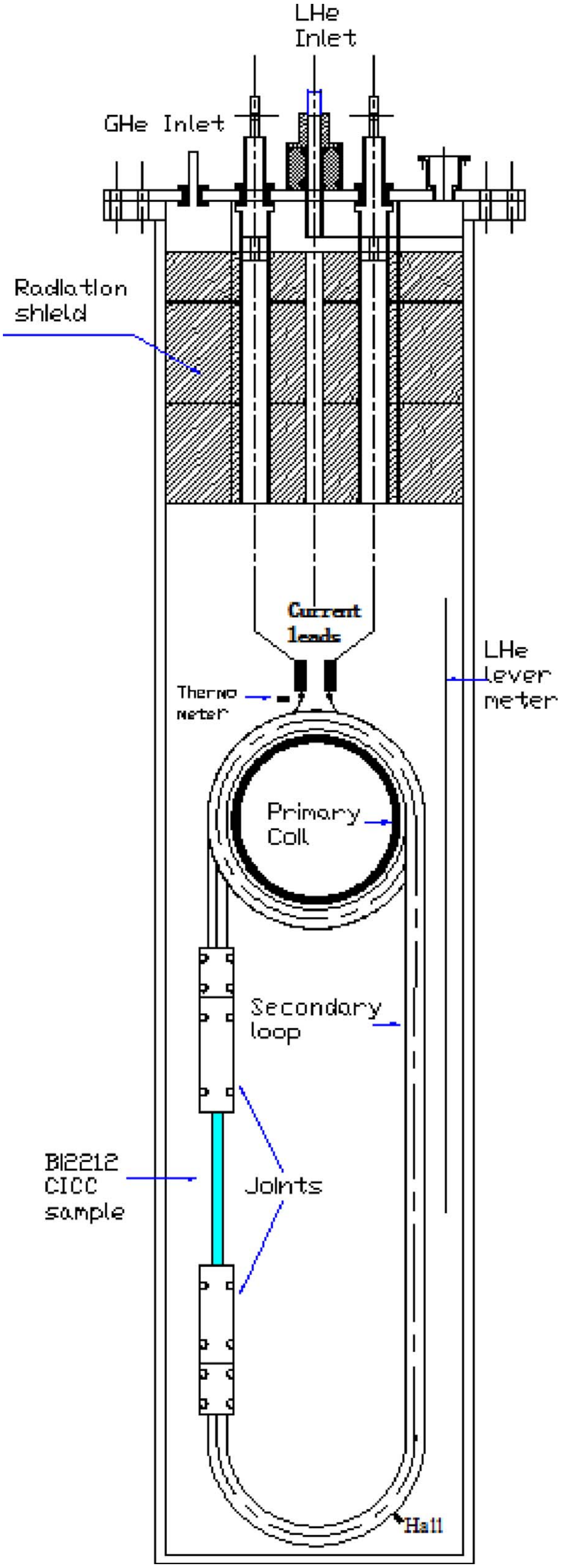

Fig. 3. The scheme of test system for Bi2212 conductor sample.

A LHe lever meter was used to detect the liquid level. A Hall sensor (Lake Shore HGCT-3020 series) was used to measure the current in the secondary loop which was installed on the CC conductor, as shown in

Table 1
The main parameters of the superconducting transformer.

Item	Primary coil	Secondary coil
Winding type	Layer-wound	Layer-wound
Conductor	NbTi strand	ITER CC conductor
Cooling	LHe	LHe
Turn	1032	2
Inner diameter (mm)	156	180
Outer diameter (mm)	170	220
Height (mm)	120	46.4
Inductance (H)	0.14	1E-6
Coefficient of coupling	0.72	

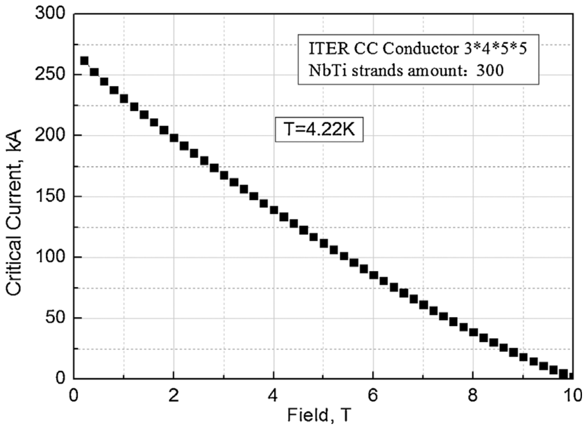

Fig. 4. The critical current of the CC conductor correspond to different magnetic field at 4.22 K.

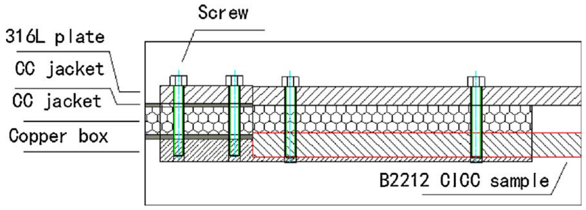

Fig. 5. Joint structure.

Fig. 1. The error of the current measurements caused by temperature and magnetic field sensitivity was estimated to be less than 1%.

3.2. Sample assembly and joints manufacture

The conductor sample will be tested at LHe and the critical current will be confirmed with self field.

A straight section with length of 50 cm was prepared for the sample. A special structure was designed for the two joints of B2212 conductor and CC conductor, as shown in Fig. 5. A copper box with high RRR (> 50) and a 316L plate were used for the joint. The jacket in the end section of CC conductor was removed to solder the CC strands directly to the Bi2212 conductor. The cable was soldered to the Bi2212 conductor with PbSn and the length was more than 1.5 times of the last twist pitch of the Bi2212 sample. Because of the stiffness of Bi-2212 conductor, a 316L plate was used to eliminate the mechanical force applied on the Bi2212 conductor sample during assembly which might affect the sample performance.

Three pairs of voltage taps were attached. One was for the critical current determination with length of 10 cm in the middle part of the conductor sample. The other two were for the two joints. The assembled conductor sample was shown in Fig. 6.

Fig. 6. Assembled conductor sample.

4. Test results and discussion

The assembled conductor sample was put into the cryostat immersed in the liquid nitrogen (LN_2) for pre-cooling. Then the LN_2 was pumped out of the cryostat by pressure. LHe was used to cool the transformer and sample to 4.2 K. And during the test, both the sample and transformer were immersed in the LHe. A lever meter was used to assure that the LHe level is always more than 10 cm above the top of the transformer. In addition, a thermometer was used to monitor the temperature in the top of the transformer.

The current varying rate of the primary coil was 1 A/s in the test. The current varying rate of the secondary loop was about 80 A/s. The highest current in the secondary loop was ramped up to around 14 kA, as shown in Fig. 7. The polarity of the current was changed to charge the primary coil to get both the forward and reversed current for the conductor sample. And from the two voltage-current curves of the test sample, the critical current results were close to each other.

The joint resistances were 16.7 nΩ and 47.5 nΩ, respectively, shown in Fig. 8. So the total resistance for the secondary loop was about 64 nΩ. The difference between the two joints could be caused by the solder content inside the sample ends. After testing, the sample was taken off and solder inside the end with lower joint resistance was found more than the other end.

The critical current test result is shown in Fig. 9. The criterion is selected to 1 μV/cm. From the results, the critical current of Bi2212 conductor is 13.1 kA with n index of 12 at self-field and 4.22 K. The self field was 0.0465 T/kA. Compared to the expected critical current which was simply calculated by the critical current of the Bi2212 single strand times the strands number, there was about 15% degradation. This might be caused by wire deformation during manufacture or due to the difficulties in heat treatment for conductor than that for wire.

5. Summary

A test system was set up to measure the critical current of Bi2212 CICC. A superconducting transformer was used to provide the sample current. The NbTi strand was wound in the primary coil. One layer and two turns of CC conductor were wound in secondary coil. And the secondary loop contained the Bi2212 conductor sample and two joints. The primary and secondary coils were immersed in LHe. The highest secondary loop current was ramped up to around 14 kA. The joint resistances were 16.7 nΩ and 47.5 nΩ, respectively. The critical current of the Bi2212 CICC sample is 13.1 kA with n of 12.

At present, the performance of conductor made of Bi2212 wire remains in low level. The high pressure heat treatment with O_2 will be considered for Bi2212 conductor and the performance is expected to be improved largely. The present test system and joint fabrication process also need to be improved to satisfy the potential new test requirements.

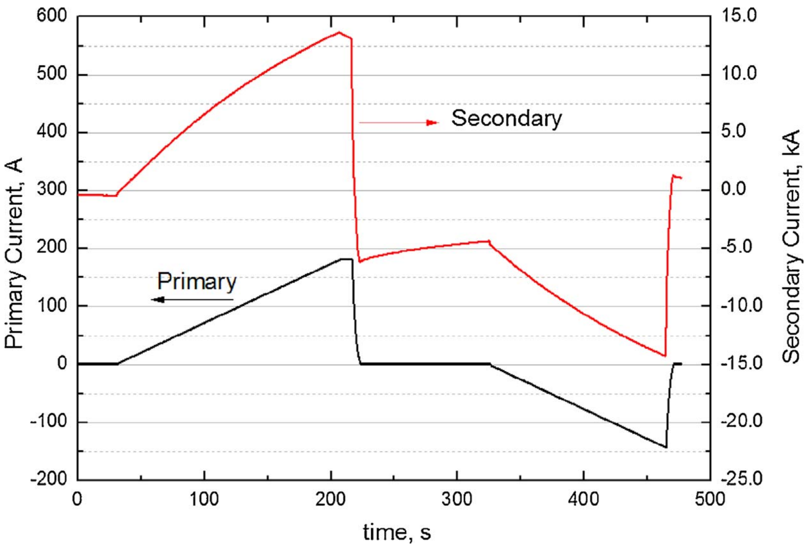

Fig. 7. The current of the primary and the secondary coils in the test. The black line was the primary current and the red one was the secondary current. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

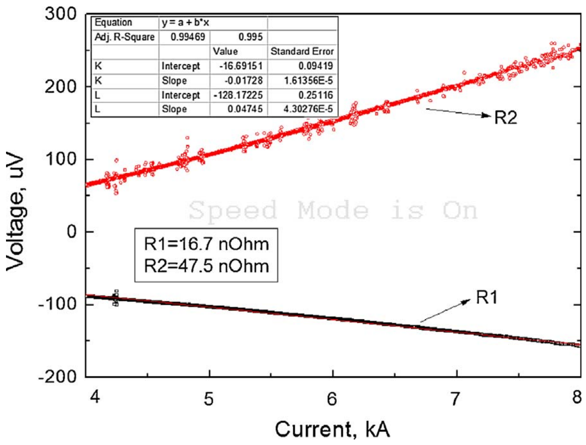

Fig. 8. The joint resistance test results.

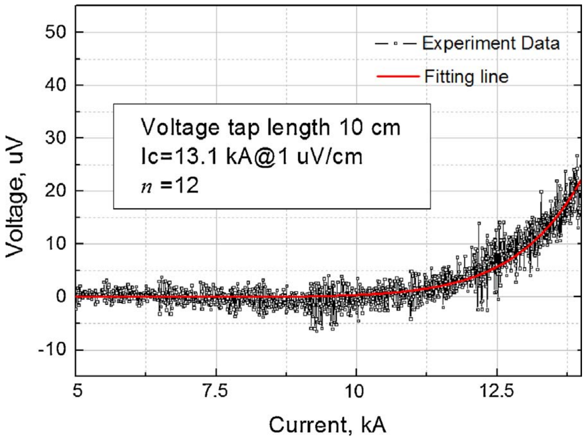

Fig. 9. Testing results of *Ic* for Bi2212 conductor with 42 strands.

Ag jacket removal at the end parts of the Bi2212 CICC sample will be considered to make joints resistance lower. Also a magnet system which can apply more than 5 T will be fabricated for the future Bi2212 CICC or cable sample test.

Acknowledgements

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