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Bi2212 double pancakes for HTS critical current measurement

Jean-Michel REY, Philippe FAZILLEAU, Jean-Marc GHELLER, Olivier LOUCHARD, Lionel QUETTIER, Daniel TORDERA
CEA-DSM-IRFU-SACM, Gif sur Yvette, France
E-mail: j.m.rey@cea.fr

Abstract. Recent progresses in Bi2212 wires have proved its suitability for high field magnet development. Using the volume of the VAMAS sample CEA Saclay has developed a small double pancake sample for Bi2212 ribbon testing. This sample allows testing up to 6 meters of superconducting ribbon using a react and wind technique, the reaction being done on a provisional reaction mandrel. The manufacturing technique of this sample is presented as well as the results of the critical current measurement. These results are compared with results measured on conventional VAMAS samples and with resistive transition laws previously published.

1. Introduction
Growing interest in research done under high magnetic field especially using NMR techniques are driving conditions to develop new HTS conductors. As energy consumption is in the range of 1 MW/T above 20 T for the high field resistive magnets one can easily imagine the potential benefits of a fully superconducting high field magnet.

Despite a difficult heat treatment cycle to generate the superconducting phase Bi2212 [1]-[3] is a serious candidate to generate high magnetic field. In order to design a high field magnet engineers need a superconducting material[4] that can be processed over long length as well as a good understanding of the resistive transition to design the Magnet Safety System.

In this paper we describe a new type of sample made to test long length of superconducting ribbons in existing test station therefore having almost the same size as usual VAMAS samples. Most of the tape length being indirectly cooled it is expected to ease the quench identification. The critical current measurements are presented for this new type of samples over the 0-15 T and 4.2-30 K range and compared with results obtained on VAMAS samples[5]-[6].

2. Sample description
Samples have been made using existing Bi(2212) superconducting tape. A new compact double pancake design has been developed.

2.1. Superconducting material
The Bi2212 tape has been produced by Nexans. The main parameters of this ribbon are given in Table I. Originally this material has been developed for a SMES working at 20 K. The SMES has been built and successfully tested and an extensive bibliography is available on this subject [7]-[8].
Table 1. Bi2212 superconducting ribbon data.

| unit           |       |
|----------------|-------|
| Width          | mm    | 4    |
| Thickness      | mm    | 0.21 |
| Cross section  | mm²   | 0.84 |
| Number of filaments |     | 76   |
| SC cross section | mm² | 0.21 |
| SC/non SC ratio |      | 25 % |

2.1.1. *Heat treatment.* The heat treatment was done by the Nexans Company[9] using a provisional Inconel mandrel of 25 mm diameter. The wire has been later on transferred on titanium testing mandrels identical to the one used to test Nb₃Sn wires. During the heat treatment the outer shell of the wire sticks locally to the nickel mesh used to prevent diffusion from the inconel mandrel to the superconducting wire. Removing the wire from the mandrel should therefore be done very carefully.

2.1.2. *Electrical insulation.* After heat treatment and before winding to its final double pancake shape the superconducting tape is insulated using 25 mm wide adhesive Kapton tape of 0.14 mm thickness. The extra width of kapton is carefully cut.

2.2. *VAMAS sample*
The usual VAMAS sample developed for NbTi and Nb₃Sn wire testing consist of 9 turns of a round wire on a titanium alloy mandrel. A similar setup has been made for ribbon testing. This has 5.7 turns of ribbon on a 32 mm in diameter and 28.5 mm in length mandrel. The overall ribbon length tested being 570 mm. A picture of a VAMAS is shown on figure 1. Voltage taps are fitted across one and two turns of the sample.

2.3. *Double pancake sample*
A sketch of the cut double pancake it is given in figure 2. It consists in two separate pancakes with a resistive junction (item G) between them. This solution has been chosen to avoid damaging the reacted superconducting material at the midpoint of the double pancake. Each pancake has 24 turns corresponding to a total length of 3300 mm of superconducting tape per pancake. An extra length is used to connect the tape to massive copper parts (items A and E) on both end of the double pancake. The central resistive point (item G) is a copper tube of 24 mm outer diameter on which each pancakes is electrically connected. A voltage tap is taken on this central copper tube to allow the quench detection on each pancake separately. Intermediate insulation is provided by machined G10 washers (items B, C, D). A picture of a double pancake sample is shown on figure 1.
2.3.1. Assembling procedure. A step by step procedure has been developed for the assembling of the double pancake. Once reacted and electrically insulated the tape is tinned on the central copper part and slowly transferred from the reaction mandrel to the spiral pancake winding. The insulating parts (items B and C) are then glued in place. After hardening of the glue the second length of tape is tinned on the central part and winded. The third insulation washer is then glued as well as the end copper connections. The superconducting tape is then tinned to the end connections. The tinning alloys and the glue have to be selected carefully to avoid de-bonding during the progress of the assembling.
3. Test station and testing procedure
The critical current measurements have been made on an existing test station.

3.1. The Cetacé test station
The samples have been tested on the Cetacé test station, upgraded to allow critical current measurement at various temperatures ranging from 4.2 K to 30 K. Fig. 3 shows a view of this test station.

The variable temperature device uses a two stage gas regulation concept. A first stage of thermal regulation is done outside the magnet using a dedicated helium evaporator. At that stage the helium gas is put at a temperature of 1 K lower than the test temperature. The second stage is done directly above the sample and the final gas temperature is adjusted with a precision better than 0.1 K. In order to reduce the heat losses near the sample the lower half of the current feed through are composed of copper and 4 ribbons of Bi2212 superconductor. This allows a current up to approximately 600 A at 4.2 K to be put in the sample. The main cryostat contains a superconducting solenoid manufactured by Oxford Instrument. It produces 15 T at 4.2 K using a 100 A current. The field variation is 1T/min up to 15 T. The useful cold bore in the cryostat is 49 mm. Critical current measurement is made at 4.2 K; 10 K, 20 K and 30 K. The thermal stability during the tests is better than 0.5 K.

Figure 3: The Cétacé test station

3.2. Testing procedure
Voltage on the samples has been measured over the whole length of each pancake 3300 mm. The voltage taps are located on the central copper part between the pancakes and at the other end connection of each pancake. The critical current $I_c$ is defined as the current in the sample corresponding to a resistance of $1\mu V/cm$ the same value as the one used for low Tc superconductors.

The voltage/current curve is recorded for each double pancake to identify the critical current.
Critical current measurement is made at 4.2 K; 10 K, 20 K and 30 K. The thermal stability during the tests is better than 0.5 K.

3.3. Numerical post treatment
The bare data are post treated after the tests to remove eventual resistive offset due to poor tinning of the voltage taps, and possible resistive contribution before the transition due to local defects within the superconducting material.

4. Experimental results and discussion
Two different set of double pancake have been tested, labeled DPA and DPB in the figures. Figure 4 shows the transition of both double pancakes compared to a usual VAMAS sample made of the same superconducting tape. A 0.1 V offset is added to the voltage measured on the VAMAS to ease comparison between the two sample geometry. The graph shows one double pancake (DPB) having a resistive contribution before the transition. The resistive transition of the double pancakes is faster than the one of the VAMAS sample.

![Graph showing resistive transition on double pancakes compared with VAMAS results.]

Figure 4: Resistive transition on double pancakes compared with VAMAS results.

4.1. Self field correction
Due to the double pancake winding a magnetic field is generated by the sample itself during tests. A correction is therefore needed to determine the real magnetic field at the quench. This is particularly significant when the current in the sample is high when no surrounding field is produced by the test
station. In some cases the quench may be influenced by the transverse field component, especially in the case of defects in the superconducting material.

A self field correction factor of 0.233 T/100 A in the superconducting ribbon has been applied on all the magnetic values in the next paragraphs.

4.2. Critical current values
The critical current measured on double pancake A as a function of magnetic field is given on figure 5 and compared with the critical current values of a good VAMAS sample. The shape of the curves for magnetic field greater than 2T is the same for both types of samples but the values are systematically greater in the case of the double pancake sample. At low magnetic field this effect is not observed and the shapes of the curves are different. This is probably a consequence of the self field effect, the magnetic field around the conductor being very different between the double pancake and the VAMAS.

![Figure 5: Critical current measured on double pancake and VAMAS samples.](image)

4.3. Transition index
Transition index of usual VAMAS samples using this superconducting tape is very low as shown on figure 6 (dotted lines, experimental data’s previously published [5]). The double pancake geometry gives much higher transition index as shown on figure 6.
4.4. Discussion on the stated differences
Some hypothesis can be made about the differences stated between results obtained on double pancake and VAMAS samples.

The self field contribution generates differences on the behaviour at low field.

There is one significant difference between VAMAS and double pancake samples. In the case of the VAMAS the current in the samples is directed in such a way that the forces act to press the conductor on its mandrel. The winding helix is on the right on these samples. For the double pancake winding the helix on the heat treatment mandrel was on the left having for consequence that the magnetic field produced by the sample sums up with the external field produced by the test station. Therefore the forces on the conductor are always keeping tension on the conductor. Nevertheless this argument cannot explain the critical current at high field observed higher on the double pancake sample as on the VAMAS sample.

The higher transition index may is attributed to the different cooling mode between both samples. In the case of the VAMAS the coolant, being directly in contact with the external surface of the superconducting tape, is very effective. In the double pancake the high field part of the winding, where the quench is most likely to occur, is indirectly cooled, thus allowing faster quench propagation and a greater transition index.

5. Conclusion
A new sample design has been realized to test long length of superconducting tapes and measure resistive transition under reduced cooling conditions. The results have been compared with results of VAMAS samples [5]-[6].

The tape being indirectly cooled the quench identification is easier and its evolution is faster the transition index being 3 to 4 time greater than on a conventional VAMAS. The critical current values obtained using the double pancake geometry is significantly higher than the one measured on VAMAS samples. Further work is needed to understand the reasons of this difference.
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