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CRITICAL CURRENT AND JUNCTION BETWEEN PANCAKE STUDIES FOR HTS COIL DESIGN

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Abstract

YBCO Coated Conductor (CC) are very attractive for very high magnetic field coil with lower cryogenics need. We study two major aspects of HTS coil building. First the results of critical current measurements on YBCO tape provided by SuperPower are presented for a large temperature range and in parallel magnetic field configuration. A model is also proposed to extrapolate those measurements at other temperatures and fields. Then we focus on the critical aspect of junctions between pancakes. Junctions in cylindrical configuration are studied using three different soldering materials. The results are promising for further coil building.

Keywords : YBCO, pancakes junction, critical current, model, SuperPower SCS4050

1. Introduction

Many research groups are focused on YBCO tapes because of very high J_e reached by those conductor at high fields or/and low temperatures. In 2009, CEA-Saclay and CNRS Grenoble, with Nexans, started studying different materials in a R&D work to develop an HTS coil. Previously a SMES was built with Bi2212 ribbon and successfully tested [1] by the CNRS team. YBCO tapes show much higher performances (J_e(B,T)) and do not require the very delicate heat treatment of BI-2212. However YBCO still poses issues in terms of protection and high current cables.

Two major aspects of YBCO tape are studied here to develop the YBCO coil technology. First some critical current measurements are presented for long length of YBCO tapes over 0-15T in parallel field and 10-40K ranges. Many measurement data in perpendicular magnetic field and studies of angular I_c

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dependence are available for YBCO tapes [2-9] but no accurate model and data for longitudinal field configuration. An I_c model used in FEM simulation in order to improve the operating condition and protection scheme will be presented. In a second part junctions between pancakes will be studied using different soldering materials to estimate the dissipative joule energy in further prototype coil.

2. Critical current measurement and modeling

2.1. Test Station

The samples have been tested on the CetacéS test station presented in details in a previous publication [2]. Maximal current is limited at about 800A at temperature higher than 4.2K. A Helium gas flow allows a temperature regulation between 10K and 50K. Tests are made under magnetic field parallel to the tape up to 15T. Two pairs of voltage tapes are fixed on the superconducting wire with a length of 120-500mm. Electrical circuit is automatically opened when voltage exceeds 20µV to avoid sample damage. Tests are made between 10K and 50K with a thermal stability better than 0.5K. A 0.1µV/cm criterion has been used to determine the I_c values. Our sensibility allows it and this criterion reduces the risk of sample damage. Few of our measurements were confirmed by measurements made at CRISMAT-ENSICAEN [8].

We estimated that our critical currents are between 8% and 30% underestimated in comparison with classical HTS criterion of 1µV/cm. Higher the resistive transition index (“n value”) is, lower is the difference.

2.2. Sample

Our samples are made from SuperPower SCS4050 conductor. The YBCO fabrication process is the classical MOCVD process used by SuperPower. The tape is surrounded by two 20µm Cu shunt layers. The tape is 0.094mm thick and 4.04mm width. The I_c at self-field and 77K is about 106A.

The tape was tested on VAMAS-like mandrels with a diameter of 31mm. The 1 meter length tape is wound on titanium mandrel and soldered on two copper rings. Copper rings ensure electrical connexion with current leads. The soldering temperature is about 220°C which is lower than the limit temperature of 250°C given by SuperPower. The tensile force is few kg to avoid tape displacement during tests.

2.3. Modeling

Only few models are available in literature to extrapolate the measurements at higher magnetic field or other temperatures in parallel magnetic field configuration [2-9]. The following model is coming from others [3], [4] to obtain better accuracy:

$$I_c(T,B) = I_0(T) * 1/(1 + (B/B_{peak}(T))^{\beta} \qquad (1)$$

Where $I_0(T)$ is the I_c value at 0T; $B_{peak}(T)$ is the magnetic field corresponding to the maximal macroscopic pinning force; the constant parameter β is 1.43 (near to the 1.5 value given by Müller [3]). For practical reasons the reduced critical current $Ic(T,B)/Ic(T,1)$ is used to obtain further results. $I_0(T)$ and $B_{peak}(T)$ are extrapolated by polynomial fit. Results are presented on figure 1. Values at 4.2K were measured by CERN colleagues.

The model presents a good agreement with measurements. J_e corresponds to the critical current divided by the total section of the conductor. There are only little differences below 1T at high temperature and more tests are needed to verify the accuracy at higher magnetic field. This model is actually used in FEM propagation simulations. The engineering current density is very high at low temperature under strong magnetic field. This is why this conductor is promising for application like HTS insert to obtain very strong magnetic fields. However particular attention should be paid to the transverse component of the magnetic field since the J_e dependence is much less favorable.

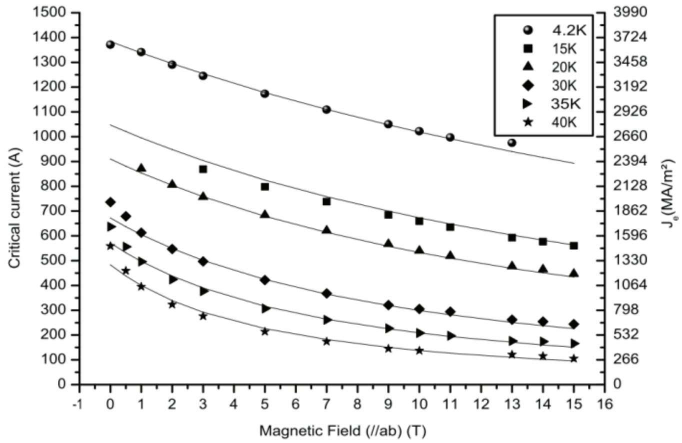

Fig. 1. I_c measurement of SCS4050 and model (solid line).

3. Junction between pancakes

The junctions between pancakes are critical issues to build coil cooled by conduction. Two aspects need to be studied: the soldering materials and the assembling procedure. The soldering material is firstly determined by its melting temperature. For SuperPower coated conductor the soldering temperature must be lower than 250°C which is less restrictive compared to other superconducting material suppliers. Many works have been done to compare materials [10-13] with a lot of resistance values (results about 50 nΩ.cm²). Nevertheless most of the junctions are lap joint because it is a critical issue to have long length of superconducting tape. Nothing was published in cylindrical configuration. Our purpose is to study if low lap joint resistance could be obtained in cylindrical configurations. Our measurements are made in the CétacéS test station in LHe environment and at variable magnetic fields (parallel to the tapes).

3.1. Junction technique

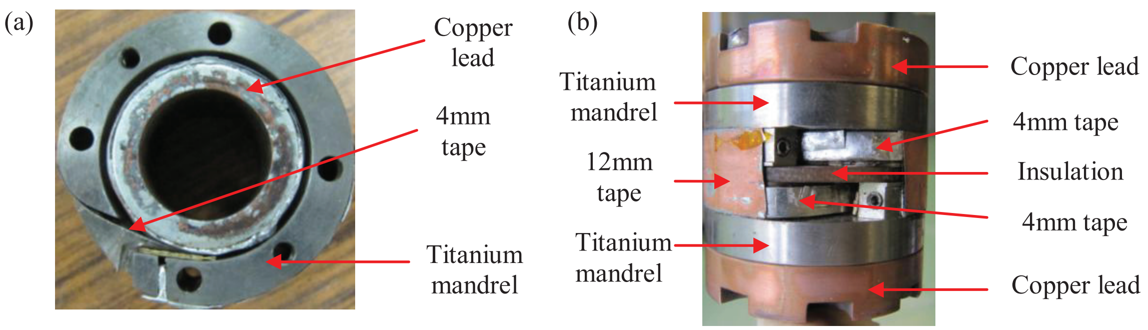

Fig. 2. (a) Detailed picture of one pancake; (b) Global picture of the sample

The sample is composed by three elements : two small pancakes with 4mm width SuperPower SCS4050 tapes (Minimum I_c(77K,self-field)=96A)) and a junction tape with 12 mm width and about 90mm long SuperPower SCS12050 tape (I_c(77K,self-field)=339A)). The two pancakes are separated with a 3.5mm thick G10 Epoxy insulation to be sure that the current flows through the junction.

First the tapes are tined on the superconducting face with different soldering materials (depending on the sample). Then the 12mm width tape is used to join the two parallel 4mm tapes. Junctions are made face to face (HTS face-HTS face) to obtain a resistance as low as possible.

The most critical operation is the making of the two small pancakes. For the most of the samples the resistance of the junction between the 4mm tape and the current lead limits the maximal current before junction overheating.

Photos of the sample with the different parts are presented on fig.2. Two series (Se1 and Se2) of three samples (Sa1, Sa2 and Sa3) were done with three different soldering materials. Details of the samples are presented in Table 1.

For further explanations sample name represents the number of the series (S1 or S2) and the number of the sample in the series (S1, S2 or S3). Example: S1S1 refers to Serie1 Sample1.

Table 1. Sample details and results

Name	Series	Sample	solder	Flux	T_{max} [°C]	Mechanical Results	Electrical results
S1S1	Se1	Sa1	In50 Sn50	Spriflux® 330	150	Bad mechanical resistance	High resistance
S2S1	Se2	Sa1			150	No problem up to 125MPa	middle resistance up to 11T (~330 nΩ.cm²)
S1S2	Se1	Sa2	Sn60 Pb40	MRS7	220	break at 11T	high resistance
S2S2	Se2	Sa2			211	Good mechanical resistance up to 150MPa without break	Low resistance (~135nΩ.cm²)
S1S3	Se1	Sa3	Sn96.5% Ag3.5%	Castolin Eutectic 157 NC	245	Good mechanical resistance up to 420MPa.	Middle resistance growing up to 15T (340 to 600 nΩ.cm²)
S2S3	Se2	Sa3			235	Bad mechanical resistance	Low resistance (~200nΩ.cm²)

3.2. Results

Global results are presented for each sample in table 1. The Se2 presents a very good improvement of the soldering process with better homogeneity of the soldering pressure: resistances of S2S1 and S2S2 were divided by almost 5. To compare to others figures presented for lap joint configuration our values need to be divided by 4. Indeed our junction is equivalent to two lap joint junctions in series with a half contact area (see fig.3).

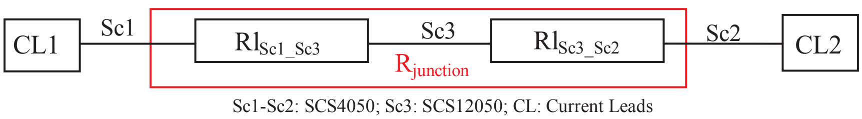

Fig. 3. Equivalent electrical circuit

Our best results are equivalent to about 35 nΩ.cm² which is in good agreement with the values obtained by research groups using less complicated configurations [10-13]. The superconducting state of soldering material of Sa1 and Sa2 explains the very low resistance at 0 T (60Sn40Pb is superconductor below 7.05K and 832 Gauss and 50Sn50In below 7.45K and 6408 Gauss).

A soldering process at 235°C (S2S3) was tested to avoid sample damage (two Sa3 type samples were damaged during soldering at 245°C) but the temperature is too low to assure a good mechanical junction: the resistance for Sa3 was only divided by about 1.5 and the sample S2S3 was damaged at 4T at about 50A. All junctions are made in about 40 min (about 10 min up to soldering temperature, a step of 2 min at soldering temperature and then a natural cooling without thermal shock).

Abruptly rising of resistivity (visible on Fig. 3(a)) corresponds to a mechanical damage of the junctions (for S1S1 at 1T, S1S2 at 11T and S2S1 at 10T).

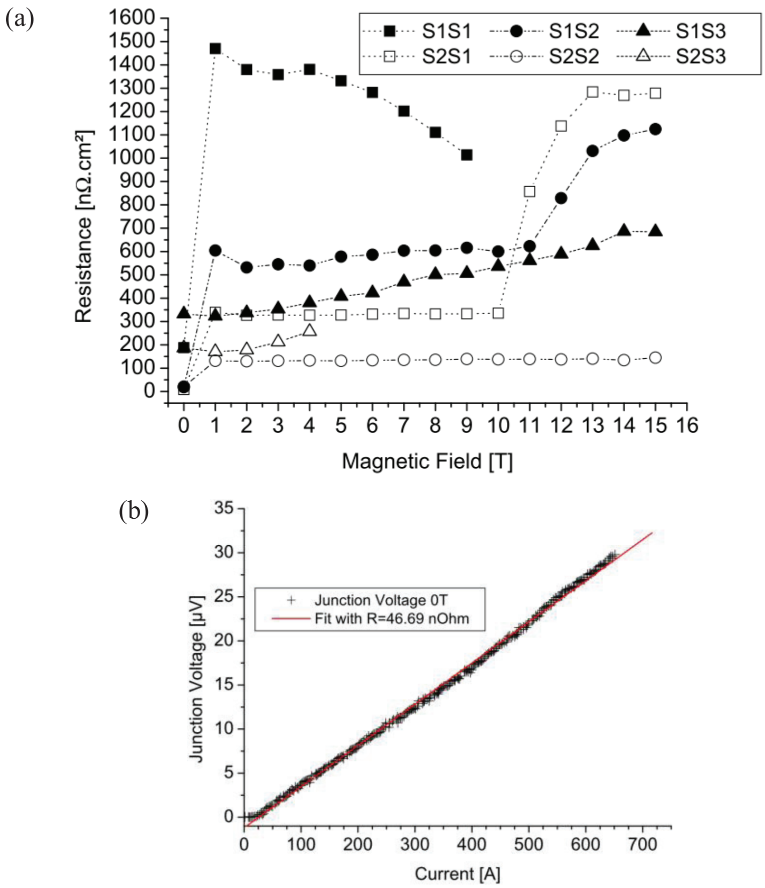

Fig. 3. (a) Resistance of the six tested samples (b) typical (V-I) curve (example of S1S1 at 4.2K, 0T)

Conclusion

Experimental values of critical current of YBCO SCS4050 in parallel field configuration up to 15T and for 4.2K-40K temperature ranges for long length sample are now available.

A model to extrapolate those measurements is also proposed and shows a good accuracy with the measurements.

Our study of the junction between pancakes offers new soldering process in cylindrical configuration. It gives very interesting results and shows that low resistance could be obtained using a 12mm width tape to make a junction between two 4mm width parallel tapes.
Our critical current measurements and model was already use to estimate margin for coil design [14] and will be used for the same purpose in other project. Indeed we will build an HTS prototype coil in pancakes configuration and all our results will be used for it. FEM simulations using our critical current model are also made to predict the behavior of our further prototype coil. That must be done to limit potential coil damaging.

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