Losses measurement in HTc Bi2212 ribbons and round wires.

Jean-Michel Rey, Lionel Quettier, Arnaud Allais, Hervé Cloez, Jean-Luc Duchateau, Jean-Louis Marechal, Louis Zani, Sylvain Girard.

Abstract— **Recent progresses in Bi2212 wires have proved its suitability for round wire developments and high field magnet development. High energy storage magnets can be foreseen leading to cable developments. In order to prepare such work CEA Saclay has developed in collaboration with the Nexans company a Bi 2212 wire having 18 sub-elements. The round wire has been twisted to study losses and twisting degradation. The results are presented here and compared to losses measurements made on already existing ribbons.**

***Index Terms*— AC Losses, Bi2212/Ag superconducting wire and tape, Critical current, High-temperature superconductors.**

I. INTRODUCTION

Recent developments in Bi2212 conductors have proved its suitability for the design of high field devices [1] . Especially round Bi2212 wires [2,3] are interesting candidates for the manufacturing of high current carrying cables [4,5] needed for magnetic systems storing large magnetic energy. The development of devices operating under fast cycling conditions like SMES or accelerator magnets requires the knowledge of the losses appearing in the superconducting material under field variation.

CEA-Saclay and Cadarache started in 2005 with the Nexans company a R&D work to develop a Bi2212 round wire and compare its properties with already existing ribbons. In this paper the losses measured at 4.2 K over the 0.05-0.3 T/min range on Bi2212 ribbons and round wire are presented. In the case of the round wire results are presented as a function of the transposition pitch of the wire.

II. SUPERCONDUCTING MATERIAL

A. Ribbon

Bi2212 received from Nexans came from two production batches, supposedly identical and shown on fig. 1. The main parameters of this ribbon are given in Table 1. Originally this material has been developed for a SMES working at 20 K, so the optimization was not intended for magnetic field production. The SMES has been built and successfully tested and an extensive bibliography is available on this subject [6,7].

In order to be tested the superconducting samples have first been reacted on Inconel mandrel at the nominal radius of the VAMAS testing support. During this heat treatment the Bi2212 ribbon is protected from the diffusion of foreign chemical species coming from the Inconel mandrel by a layer of nickel mesh. The heat treatment has been done by Nexans, and was adjusted to the chemical composition of each batch of superconducting materials.

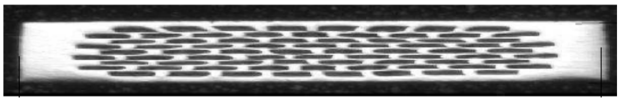

Fig. 1. Bi2212 ribbon cross section.

B. Round wire

The round wire was developed by CEA-IRFU as an internal R&D effort, in collaboration with the Nexans Company. This program started in 2005 was aimed at preparing cabling developments for high intensity variable fields magnets. Twisting the wires to study the influence of transposition pitch on the losses was one of the major objectives. To limit the losses a design with small filaments and numerous sub-elements has been chosen. Parameters on this material can be found on table 1. Complementary critical current values and analysis can be found on ref. [8].

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A cross section of the wire is presented in fig. 2 and its main characteristics in Table 1. The choice has been taken to make a wire with a lot of sub-elements and a low superconducting content to limit the twisting degradation. Mechanically this wire is reinforced by a surrounding shell of silver doped with magnesium. During the heat treatment oxygen reacts with magnesium to form MgO which acts as a reinforcing precipitate.

The superconducting cross section is estimated from picture analysis before heat treatment. As the volume of the

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Manuscript received 19 August 2008. This work, supported by the European Communities under the contract of Association between EURATOM / CEA was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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superconducting phase increases during the heat treatment due to capture of oxygen the superconducting cross section is certainly underestimated.

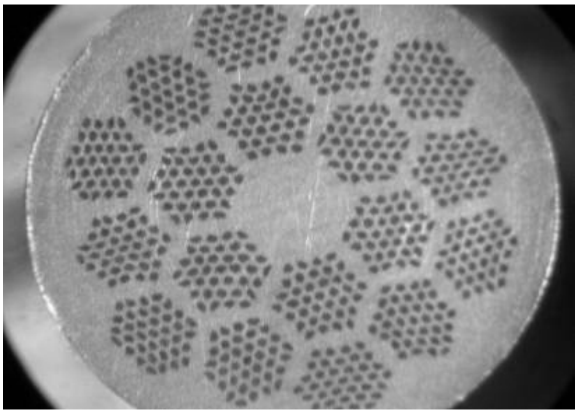

Fig. 2. Cross section of the superconducting wire before heat treatment.

TABLE I RIBBON AND ROUND WIRE DATA.

	Unit	Ribbon	Round wire
Width	mm	4	
Thickness	mm	0.21	
Diameter	mm		0.8
Cross section	mm²	0.84	0.5
Number of filaments		76	666
Number of sub elements			18
SC cross section	mm²	0.21	0.053
SC / Non SC ratio	%	25 %	10.5 %

C. *Twisting operation*

Some length of the round wire has been twisted to study the twist pitch influence on superconducting properties. The twisting operation has been subcontracted to the Alstom Company. 3 twist pitches have been used, respectively 15.1 mm 30.7 mm and 45 mm. Corresponding pitch angles are respectively 9.5°, 4.8° and 3.2°. The twisting operation has been realized before heat treatment. Some breakage occurred during this twisting operation as silver alloy is weaker than copper used as matrix for the low Tc superconductors.

D. *Heat treatment.*

In order to be tested the superconducting samples have first been reacted on Inconel mandrel at the nominal radius of the vamas testing support. During this heat treatment the Bi2212 ribbon is protected from the diffusion of foreign chemical species coming from the Inconel mandrel by a layer of nickel mesh. The heat treatment has been done by Nexans, and was adjusted to the chemical composition of each batch of superconducting materials. During the heat treatment the oxygen stoechiometry is established and the superconducting phase expands.

For the ribbon and the round wire the heat treatment was done by the Nexans Company, the wire been later on transferred on titanium testing mandrels identical to the one used to test Nb_3Sn 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 be done very carefully.

III. TESTING DEVICE

Losses have been measured on the “Speedy” test station from CEA Cadarache using the same procedure as for NbTi and Nb_3Sn wires.

The different samples of ribbon and round wires installed on their supports are shown on fig. 3. 2 meters of ribbon and 5 meters of round wires were used for these tests. The sample holder (fig 4) is mounted on an insert, shoved into the bore of a superconducting solenoid (capable of 5 T at 4.2 K in a 25 mm bore) and cooled to 4.2 K. Pick up coils are placed on the sample holder to measure the applied field and the strand magnetization. The losses at a given sweep rate are estimated by numerical computation of the area of the magnetization curve (as the one shown on fig 5).

New mandrels have been defined to allow the winding of ribbons in place of usual wires. For the analysis a shape factor based on the cross section of the samples has been used. The inductance cycle is 0 / +3T /-3T / 0 and this cycle can be done at various field variation from 0.05 T/s to 0.3 T/s. The measured losses are normalized on the total ribbon cross section.

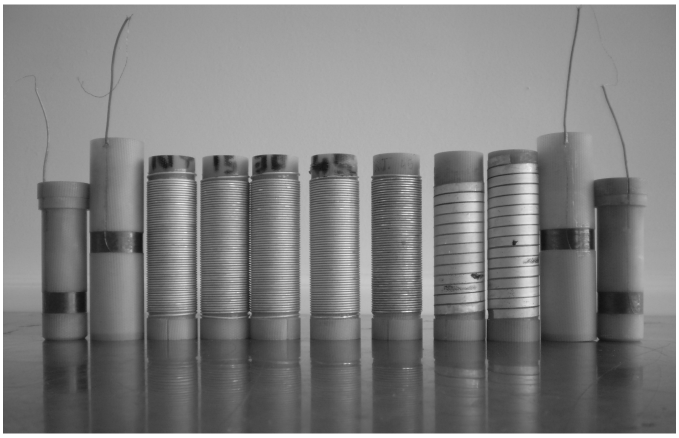

Fig. 3. The “speedy” test samples. On the left the Bi2212 ribbons after transfer on the measurement mandrels. On the right the outer and inner pick up winding used to measure the losses.

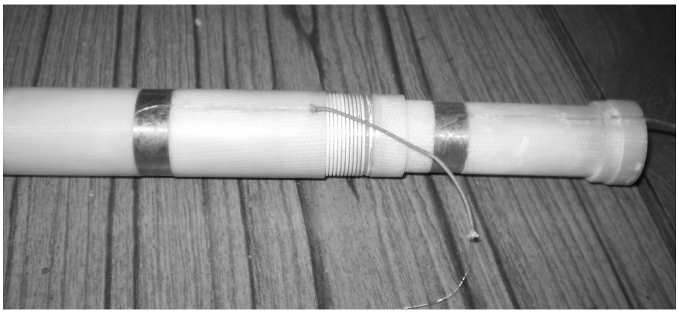

Fig. 4. A “speedy” test samples assembled with its pick up coils.

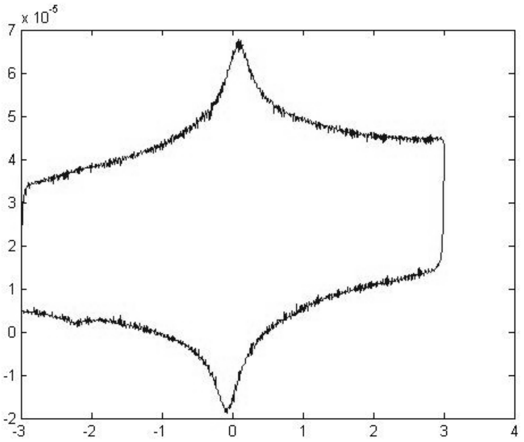

Fig. 5. Magnetization curve in arbitrary unit as a function of induction.

IV. RIBBON MEASUREMENTS

As can be seen on fig. 6 losses on the ribbon are quite small on the 55 – 60 mJ/cm^3 range.

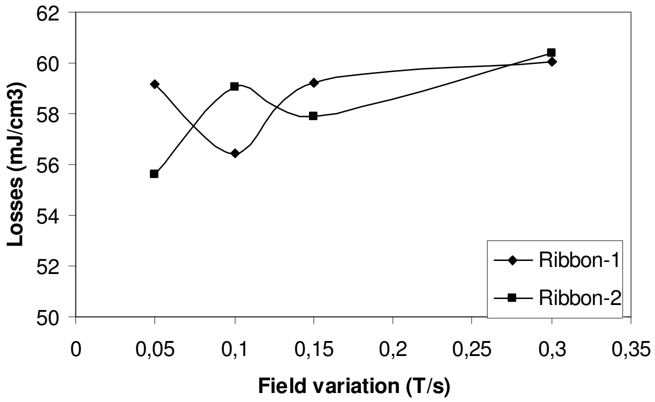

Fig. 6. Losses measured on ribbons expressed as a function of field variation.

Results found in [9] and measured on the same experimental device vary from 107 to 128 mJ/cm^3 for an NbTi strand of 0.81 mm diameter. Using the same test facility for the development of Nb_3Sn dedicated to accelerator development [10] gives values from 432 to 532 mJ/cm^3 for a 0.825 mm diameter wire. One should remember that the conductor section subjected to the field induction is 4 times smaller in the case of the ribbon compared to the round wire. As can be seen on fig. 6 the losses on the ribbon have a very low dependence on field variation of approximately 3% over the 0.05 T/s to 0.3 T/s range. This dependence is so low that it may also come from the measurement scatter.

V. ROUND WIRE MEASUREMENTS

In the case of round wire (fig.7) the losses variation becomes approximately 14% over the 0.05 T/s to 0.3 T/s range. Losses on ribbons are lower than on round wires as could have been expected. This is mostly due to the thickness of the conductor perpendicular to the magnetic field in a 4 to 1 ratio between wire and ribbon.

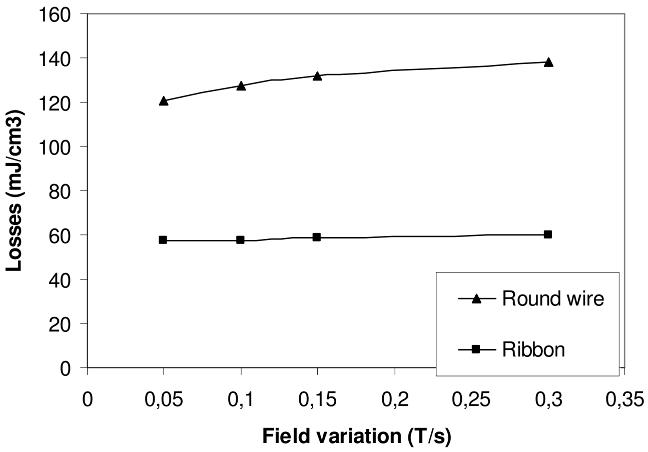

Fig. 7. Comparison of losses measured on ribbon and an untwisted round wire as a function of magnetic field variation.

The speed of field variation has an influence on the level of losses but this effect is lower than the pitch contribution itself (fig. 8).

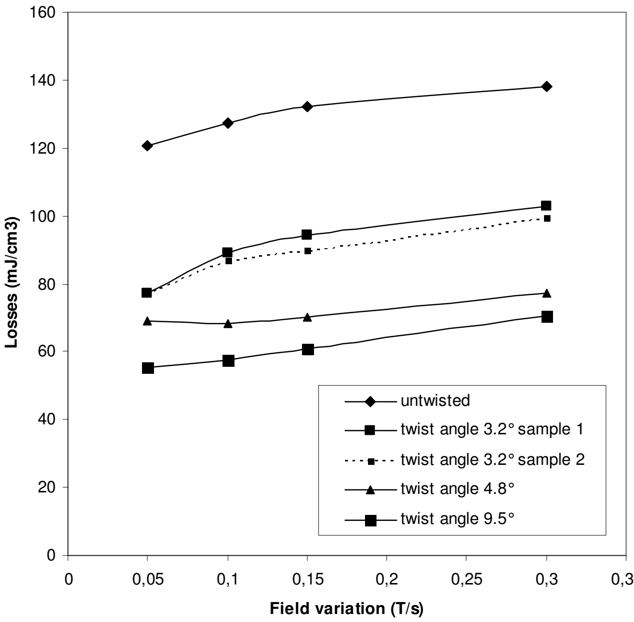

Fig. 8. Losses measured on the round wires having different twist pitches expressed a function of the field variation.

Twisting of the wire has a very significant impact on the losses as can be seen on Fig. 9. Pitch angle of about 3.2 degree (corresponding to 45 mm pitch) already give 30% losses reduction without reduction of the critical current. Greater pitch angles are of reduced interest as the benefits in term of losses is slow compared to the reduction of critical current (fig. 10.).

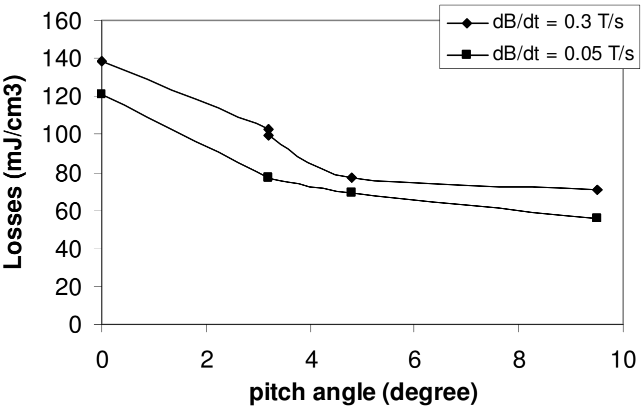

Fig. 9. Losses as a function of pitch angle for the slowest and fastest induction cycle tested.

Fig. 10 gives the critical current result for 4.2 K, 10 K, 20 K and 30 K. As can be stated there is no degradation seen for the 45 mm twisting pitch. Some degradation is seen for shorter twist pitches. The critical current values from twisted and untwisted samples have the same general shape. The degradation can be attributed to a lack of connectivity between the grains in the superconducting material. As the heat treatment has been performed after twisting this lack of connectivity probably comes from elongation effects in the outer sub elements of the superconducting wire.

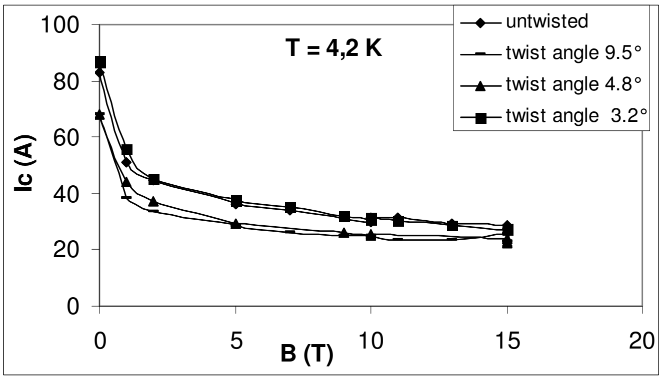

Fig. 10. Critical current at 4.2 K on a round wire as a function of twist pitch.

VI. CONCLUSION

Losses have been measured on Bi2212 ribbon and a newly developed round wire. Results have been compared to losses of low Tc superconductors. Losses on the round wire are of the same level as NbTi wire. The Bi2212 ribbon showing lower losses despite large untransposed filaments.

Twisting effect of the Bi2212 round wire reduces the losses but a degradation of the critical current appears also for short twist pitches. From this last statement cabling degradation have to be expected.

ACKNOWLEDGMENT

Thanks are due to Laurence Vilards, Christophe Verwaerde and their team of technician from the Alstom Company for the help and care taken during the critical twisting operation.

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