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1G versus 2G – comparison from the practical standpoint for HTS power cables use

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Abstract. Two types of HTS conductors are currently available or coming to the worldwide market for use to make different HTS devices. They are known as first generation 1G HTS (usually Bi-2223 systems made with "powder-in-tube" methods) and second generation 2G HTS (coated conductors, usually made on the base of YBCO superconductor). HTS transmission and distribution power cables have been under development for several years worldwide and show strong technical and economic value. Several large projects are underway with lengths of HTS cables varying from 30-100 m up to 650 m. Many of these projects are being conducted in real grid conditions. Recently a transition from using 1G to 2G wire has started for these cable applications and future projects are expected to fully transition to the 2G wire. The question is whether 2G wire has all advantages over its predecessor. In this paper we will compare 1G and 2G HTS tapes for their practical use in HTS power cables. Parameters such as critical current anisotropy, mechanical properties, and resistance to the thermo-cycling have been measured. The results will provide valuable data to observe the benefits of each wire type for HTS power cable applications.

1. Introduction

Power cables are the most advanced HTS applications up to now. Several large projects are underway with lengths of HTS cables varying from 30-100 m up to 650 m. Most cables were made from the first generation (1G HTS) high temperature superconducting wires made by the power in tube method. In spite of relatively weak superconducting properties of such wires at liquid nitrogen temperatures, especially in perpendicular magnetic fields, they are quite well fit for use in power cables. The strongest magnetic field in power cables is circumferential, or parallel to the surface of HTS tapes and its magnitude is usually well below 50-100mT. At the same time the radial or perpendicular field is not more than 10% from the circumferential one in the properly designed cable. Critical currents reductions are rather low in parallel magnetic fields for 1G superconductors. That is why they were successfully used for many large HTS power cables projects. Even economically the high cost of silver matrix based 1G wires may be overridden by the advantages of HTS power cables. At very high transmission power, the power cables made from 1G HTS wires could become economically profitable even at the present high cost of the basic wires.

Recently, the transition from using 1G to second generation (2G) HTS wires has begun for these cable applications and future projects are expected to fully transition to the 2G wire. There are many promises that 2G HTS wires will be cheaper than present 1G wires. The question is whether 2G wire has all performance advantages over its predecessor. We decide to compare 1G and 2G HTS tapes for their practical use in HTS power cables. Parameters such as critical current anisotropy, mechanical properties, and resistance to the thermo-cycling have been measured. For comparison we used 1G and 2G superconducting tapes produced by American Superconductor (AMSC), which is one of the world leaders of HTS wires development. Most advanced HTS power cables projects, such as the 200 m Triaxial cable installed in August 2006 at Bixby substation in Ohio or 650 m cable in the LIPA project are made of AMSC wires. Many other HTS cable projects used basic wires from this Company. In our study we tested several standard 1G HTS wires produced by AMSC in the years 2003-2005 and some newly developed samples of 2G wires kindly presented to us by AMSC.

2. Experimental results

In this section we present the results of our measurements of critical current anisotropy, mechanical properties, and resistance to the thermo-cycling for 1G and 2G types of HTS wires from AMSC.

We have to note that we obtained quite similar results for 1G and 2G wires from other well known producers of HTS conductors, both 1G and 2G. The choice of AMSC wires for this paper was determined by our long scientific collaboration and by the fact that this company has great experience in production of both types of HTS wires.

2.1. Critical current anisotropy

We measured the anisotropy of critical currents of several standard 1G AMSC samples, like Hermetic™ or High Strength™ and other types with the self field critical currents varied from 100 to 135A at 77K. We also measured a few newly developed 2G samples from AMSC like 344 superconductors with copper stabilizer, provided in 2006 – 2007 with self field critical currents from 65 to 90A at 77K. In figure 1 the dependencies of relative critical currents (critical current at a certain field divided by the critical current at zero fields) on external magnetic field are shown for two field directions: perpendicular and parallel to the tapes' surfaces.

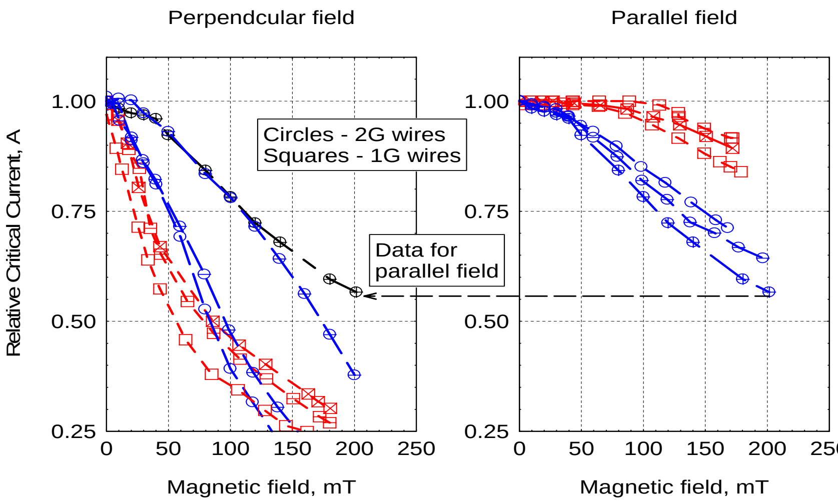


Figure 1. Relative critical currents of 1G and 2G samples vs. magnetic field for two field directions. In the left graph the data of one of 2G samples for the parallel field are shown for the comparison.

One can see some general features which are different in 1G and 2G wires:

- In perpendicular magnetic field 1G wires demonstrate fast decay of the critical current, and generally the relative behavior of 2G wires at perpendicular fields is better;
- At the parallel magnetic field 1G wires demonstrate much slower critical current decay;
- Some 2G samples demonstrate absence of anisotropy at weak magnetic fields (data for the parallel fields are shown in the graph for the perpendicular field for the comparison.)

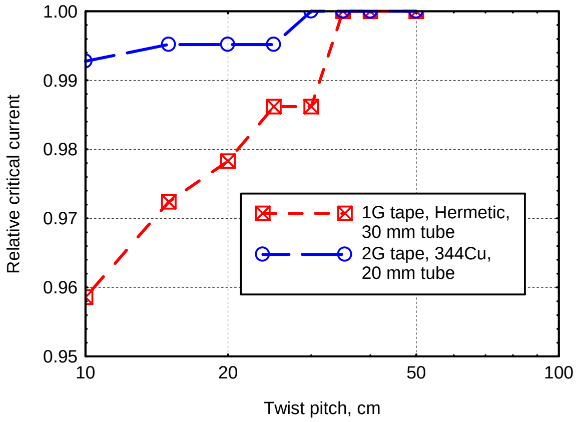
So, in the parallel magnetic fields 1G HTS wires demonstrate in some sense the better behavior than 2G wires. We have to say that we obtained similar data with 1G and 2G samples from other producers of HTS wires. And the higher was the self field critical current of 1G wire the slower was its decay in parallel magnetic field.

It is necessary to note that the overall current density (A per cm^2 of cross – section) of 2G wires already exceeds or is about the same of the overall current density of 1G wires; that is good achievement indeed. But for HTS power cables the linear current density is important (A per cm width); in this respect 2G wires are still less than in advanced 1G wires, although much higher values have been reported [1].

2.2. Mechanical properties

The mechanical properties of HTS tapes we measured by modeling the tapes' working arrangements in a cable. The tested tape has been twisted with the certain twist pitch around support tubes (see inset in figure 2) and its critical current has been measured. Then twist pitch has been reduced until noticeable reduction of the critical current was observed. The results are shown in figure 2.

One can see that 344 superconductors with copper stabilizer (2G HTS wire) undoubtedly demonstrate much better mechanical properties than 1G wires. Being twisted around the tube with lower diameter (20mm for 2G against 30mm for 1G wire tests), they kept their superconducting properties even at very short twist pitch ~10cm. On the other hand the critical current of 1G Hermetic wire degraded to 97%I_c when it was twisted on 30mm tube with less then 15cm pitch.



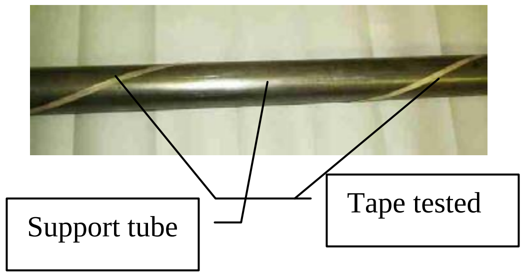


Figure 2. Mechanical properties tests modeling tapes' behavior in a cable.

2.3. Thermo – cycling and bubbling.

The thermo - cycling test has been performed with short 1G and 2G samples in a freely suspended state. The critical current has been measured with the virgin tape; then by use of a special mechanical device thermo – cycles were performed. Tapes were kept in liquid nitrogen for 2-3 min, and then they were warmed at room temperature for 3-5 min and again put to the liquid nitrogen, etc. After ~100 cycles the critical current of a tape was checked again. The results are shown in the Table 1.

Table 1. Results of the thermo – cycling tests of 1G and 2G HTS wires.

Sample	Number of thermo – cycles	% of the initial critical current
1G Hermetic – 2003	120	~98.5
1G Hermetic – 2005	100	~100
344 superconductors – two samples	101	~100

One can see that both types of HTS wires are well resistant to the thermo – cycling in a freely suspended state. More attention should be paid if the samples are soldered to the measuring insert – in this case after 100 cycles critical current could be reduced to ~90-95% of the initial magnitude. Of course this is connected with the difference of the linear thermal expansion coefficients of HTS wires and materials of inserts. Designers of HTS devices should pay attention to possible stresses raised from these differences.

One more important note should be made concerning 1G wires. As is well known they could demonstrate the bubbling phenomenon [2] that may sufficiently reduce critical currents of HTS wires or even destroy them. Different solutions were done to avoid bubbling, for example Hermetic design of 1G HTS wires from AMSC. We have to confirm that the Hermetic design really permits to avoid bubbling as long as its containment is not broken. It is necessary to pay special attention to the soldering procedure of 1G Hermetic wires especially at their ends where liquid nitrogen could penetrate inside a wire.

No bubbling is possible in 2G wires due to their basic design. Another possible issue is that some 2G wires could be spoiled if they are subjected to moisture for a long time, but the architecture of 344 superconductors is designed to also put the HTS material in a hermetic environment.

3. Discussion

The experimental results shown above permit us to make practical comparison of modern 1G and 2G HTS wires from different points of view. Let us consider them.

<u>Resistance to thermo – cycles</u>. This is about the same for both types of wires if for 1G wires measures against bubbling are taken.

<u>Mechanical properties as for power cable.</u> 2G wires have much better mechanical properties undoubtedly.

<u>Critical currents anisotropy.</u> In magnetic fields typical for HTS power cables (magnetic field direction parallel to the tapes' surfaces and magnitude below 50-100 mT) advanced 1G wires are still more preferable because of weak dependence of their critical currents on parallel magnetic field. 2G wires tested have lower critical currents in parallel magnetic fields than 1G wires, which is less desirable for HTS power cables.

Some kinds of 2G wires have almost no anisotropy of critical currents in parallel and perpendicular magnetic fields (see figure 1). Some of them could be adjusted for better behavior in perpendicular field while some could be made better for parallel field [3].

Our point is: producers of new 2G wires have to pay special attention when developing wires for HTS power cables that have special configuration of magnetic fields in operational conditions. <u>For power cables 2G wires should be specially customized for better behavior at parallel magnetic fields.</u>

This point under no circumstances is to discredit 2G wires for use in power cables. They have great prospects for use in any HTS devices, especially if their price will be reduced as is expected. We just would like to call attention to an issue that should be addressed by producers of 2G HTS conductors.

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References

[1] Li X. et al. High Critical Current YBCO Films Prepared by an MOD Process on RABiTS Templates 2007 *IEEE Trans. on Applied Superconductivity* **17**(2) 3553
[2] Masur L. at al. The Status of Commercial and Developmental; HTS Wires; 2002 *Proceedings of International Symposium on Superconductivity. Yokohama. Japan.*
[3] Masur L. *private communication* 2007