

First Model Power Cables Made of Russian 2G HTS Wires and their Test Results

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Abstract. Recently launched production of 2G wires by SuperOx Company permitted us to start tests of representative models of power cable made of their wires. In Russian Scientific R&D Cable Institute we have the test facility for extensive testing of heavily instrumented HTS cable models with full size cross-section and length up to 5 m. Our standard test program includes critical current measurements, current distribution measurements among layers, AC loss measurements, etc. In this paper we present details of first power cable models made of 4 mm width 2G wires from SuperOx and their test results. Model cables have two counter-wound layers with 18 tapes in each layer. Critical currents of cables were from 3 kA to ~4.5 kA. We also measured AC losses and compared them with losses in model cables made of 2G wires of other producers. AC losses measured were compared with calculated ones and demonstrated the good coincidence between experiments and calculations. First model cables tests permitted us to conclude that SuperOx wires have good parameters for production of 2G HTS power cables with low AC losses.

1. Introduction

Russian SuperOx company along with its Japanese subsidiary SuperOx Japan LLC entered to worldwide contest in developing of second generation high temperature superconducting tapes (2G HTS) [1]. Recently first IBAD-PLD produced 2G wires with Hastelloy substrate become available in long enough lengths to make some HTS devices, particularly HTS cables [2].

In Russian Scientific R&D Cable Institute (known by Russian abbreviation: VNIIEP) we have the test facility for extensive testing of heavily instrumented HTS cable models with full size cross-section and length up to 5 m [3]. Our standard test program includes (but not exhausted) critical current measurements, current distribution measurements among layers at both: DC and AC conditions, AC loss measurements, etc. [3], [4].

The goal of this work is to make two first models of cable cores and to test them to validate properties of newly produced Russian 2G wires for using in HTS power cables.



2. Experiment and results

2.1. Cable core models design

Several HTS cable cores made of 2G wires were tested in VNIIEP [3]-[5]. Usually, we use a former made of stainless steel tube and two counter-wound layers of HTS tapes. Cable cores were equipped by voltage taps, Rogowski coils and other probes [3]-[5].

Similar two cable core models were made with newly produced SuperOx 2G HTS wires. These tapes were produced by IBAD-PLD technology with GdBCO superconductor. Parameters of wires used for models are listed in the Table 1.

Table 1. Parameters of 2G SuperOx wires used for models.

Marking	Width, mm	GdBCO layer thickness, μm	Minimal I_c guaranteed by supplier, A
First model	4	1.15	~80
Second model	4	1.6	~120

Both models have the same design but used different 2G tapes. SS former with 25 m diameter has been insulated by Kapton™ tape. Two counter-wound layers with 18 tapes per layer were separated by Kapton™ tape as well. On each layer Rogowski coil and two pairs of voltage taps (VT) were installed. Some details of cable models preparation are shown in figures 1 and 2.



Figure 1. First layer of a cable core model with Rogovsky coil installed.

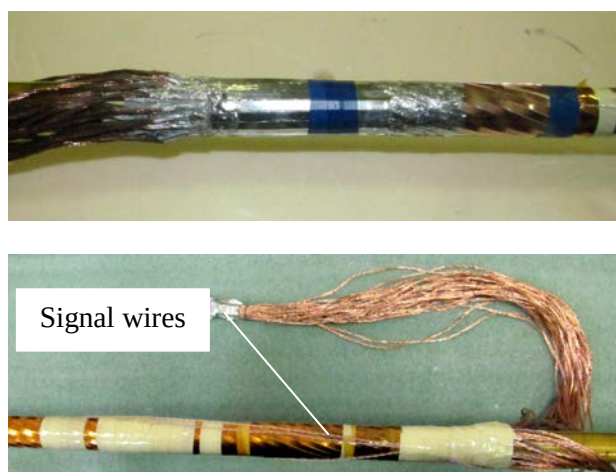


Figure 2. Left (top) and right (bottom) current terminations installed and signal wires.

2.2. DC test

The standard test program for cable core in VNIIEP includes (but not exhausted):

- DC test to determine critical currents and current distribution among layers caused by non-uniformity in termination resistance;
- AC test to determine current distribution among layers at AC conditions and AC loss measurements by electrical method [3], [5].

The test facility for testing of HTS cables models up to 5 m length has been described in details in [3]. The results of DC tests are shown in figures 3-5.

In figure 3 current distributions among layers are shown for two cases. In figure 3a terminations were soldered to 2G tapes via bunches of thin copper wires. One can see that due to asymmetry of 2G wires when superconducting layer is located from one side of a tape – current

distribution is strongly non-uniform. We developed special connection method for 2G wires [6] that permits to achieve uniform current distribution at DC mode as it is shown in figure 3 b.

Voltage – current characteristics of models tested are shown in figure 4. In figure 4a VCC are shown for two layers of a cable model made of the first batch of 2G wires delivered.

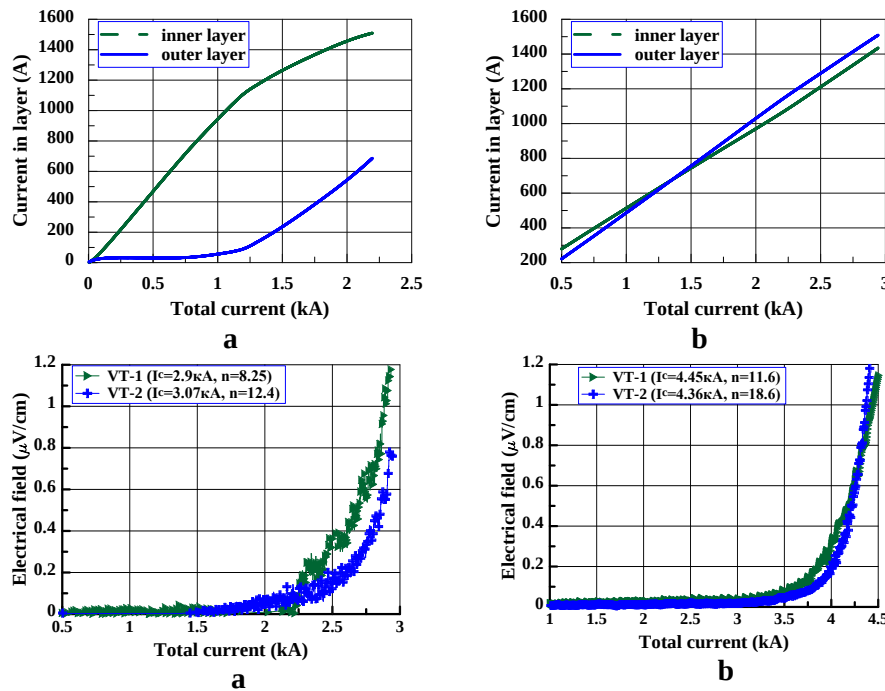


Figure 3. Current distribution among layers in DC mode for the first cable model. a – standard termination joint technique, b – using special joint uniforming technique [6].

Figure 4. VCC of cable models tested, a – first cable model, b – second cable mode.

In figure 4a one can see the critical current measurements of the first cable model. I_c measured by voltage taps (VT) on inner layer is about 2903 A (or 83 A per tape) and 3065 A (85 A per tape) for VT on outer layer. Index value was ~ 8 -12. This result is quite good for the very first production.

In figure 4b one can see that critical current of the second cable model is about 4360 A (or 121 A per tape) for inner layer and 4450 A (124 A per tape) for outer layer. Index value was ~ 11 -18.5. Up to now it is the best result in critical current so far obtained in our measurements of 2G cable models.

2.3. AC test

During AC test current distribution among layers was quite uniform like in our previous tests [3]-[5]. In figure 5 AC losses measured are shown. In figure 5 a – total losses measured, in figure 5 b – normalized losses (I_c^2 of tape) compared with losses measured for 2G similar cable models made of Super Power 2G wires [3]. One can see that AC losses are typical for 2G HTS wires with non-magnetic substrate. The value of AC loss $\sim 1 \text{ W/m}$ was achieved at current $\sim 0.9 I_c$ while for cables made of 1G HTS wires with same I_c such value of losses was achieved at $\sim 0.3 I_c$ [3].

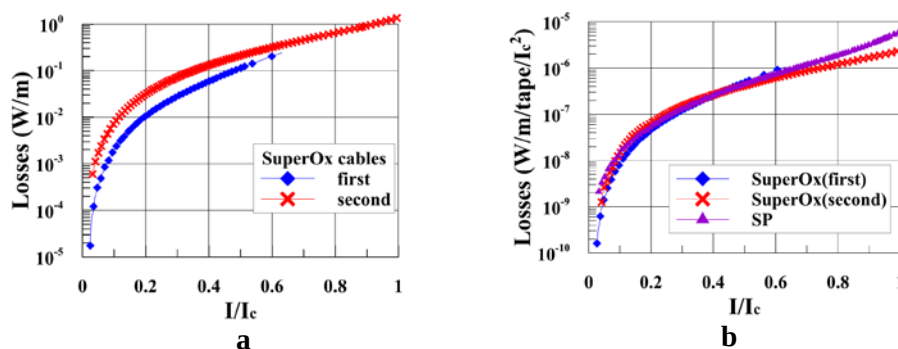


Figure 5. Measured AC losses in the cables, a – total, b – normalized.

3. Discussion

We analyzed AC losses in two-layers cable core with non-magnetic substrate. Calculations were done by Norris models (strip and ellipse) and developed 2D FEM model. In calculation with FEM model we took into account the non-uniformity density of critical current across of 2G tapes [7] in cable layers. Numerical calculation was made for two 2D cross-section in the cable: tape-on-tape cross-section and tape-on-gap cross-section [4].

Comparison calculated and measured AC losses (first model) are shown in figure 6. One can see good coincidence of numerical calculated and measured AC losses. That means that our model can be used for calculation of AC losses in thin superconducting layer.

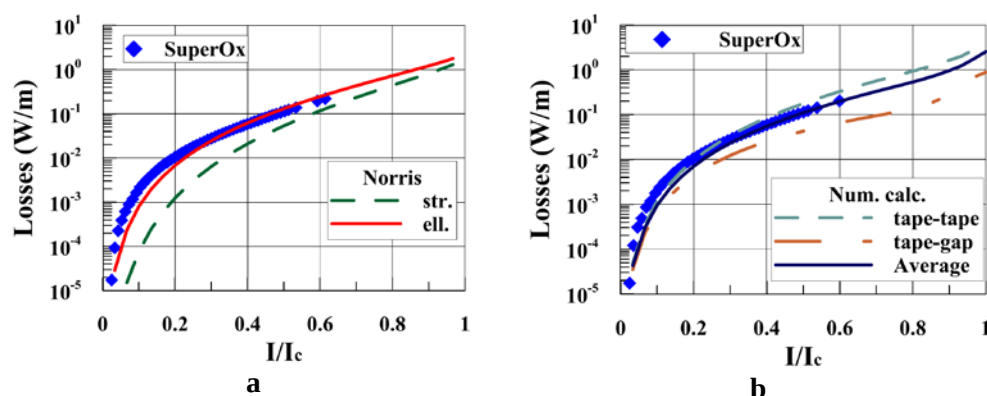


Figure 6. Measured AC losses, and calculated AC losses, a – Norris models, b – numerical model.

4. Conclusion

Two cable core models were made and tested made of 2G HTS IBAD-PLD wires produced by Russian SuperOx Company. Both models demonstrated good results. While the first cable demonstrated critical currents usual for other producers, the second model demonstrated quite high critical current along with good VCC index. Normalized AC losses are typical for cables made of 2G HTS wires with non-magnetic substrate and can be calculated by the numerical model developed. AC losses in our 2G cables are much less than those in cables made of 1G HTS wires. This allow for 2G cables to work close to I_c level with low losses.

IBAD-PLD wires produced by SuperOx can be used for HTS power cables with low AC losses and high current density.

5. References

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