Voltage-current characteristics of two soldered 2G HTS tapes

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Abstract. Most prospective 2G HTS are asymmetric in cross section due to technology feature. Superconducting layer is located more close to one side of a tape, while from the other side highly resistive substrate is located. Thus, it is possible to combine two 2G HTS tapes with different mutual orientations of superconducting layers. In this work we studied voltage current characteristics (VCC) of eight samples made of two soldered HTS tapes (copper coated SCS4050 tapes from Super Power Inc.). Connection of samples to terminations varied as well. VCC measured were different depending on tapes’ combining method, joint to terminations and external magnetic fields. Peculiarities on VCC were indicated a current transfer between tapes. Possible explanation of the phenomenon is discussed also.

1. Introduction
To increase current carrying capacity of HTS conductors it is necessary to combine two or more HTS tapes by soldering or packaging. Recently we studied soldering of two 1G Bi-based HTS tapes [1] which are symmetrical in cross-section. It was shown that there is complicated current transfer between tapes during energizing. During characterization of CCE the proper location of potential taps is important [1].

On the other hand most prospective 2G HTS are asymmetric in cross-section due to technology features. Superconducting layer is located more close to one side of a tape, while from the other side there is highly resistive substrate. Thus, it is possible to combine two 2G HTS tapes with different mutual orientations of superconducting layers. Generally speaking – four possible combinations of non-symmetric HTS tapes are possible as it is shown below. Two methods of tapes joints with terminations are possible as well [1].

In this work we study current carrying elements made of two 2G tapes from Super Power Inc. We measured voltage – current curves (VCC) at self field for all four possible orientations of HTS tapes and for two types of joints: “step-like” and “equal length” in self field and in background magnetic field. Some preliminary data are presented. Possible explanations of VCC peculiarities are discussed.

2. Experimental arrangement and results.
We studied eight current carrying elements samples made of two 2G copper coated wires SCS4050 type from Super Power Inc. These tapes have approximate critical currents $I_c \approx 90\text{A}$ (at self field, 77K). Four different orientations of 2G tapes tested with two types of joints are shown in figure 1. Position
of YBCO layers is shown in red. All tapes first were soldered to each other and then together soldered to terminations as shown in figure 1. In the step like samples lower tapes were 2.5 cm shorter from each side. Total length of terminations was 6 cm.

We tested samples with lengths 22 cm, 47 cm and 60 cm. Two pairs of voltage taps were attached to each sample – one pair to the lower tape and one pair to the upper tape. Positions of voltage taps were exactly on the opposite sides of a sample and in the centre of a sample. Distances between voltage taps were 2 cm and 5 cm to exclude edge effects.

Samples were tested by standard four probe method and VCC for each pair of voltage taps were recorded in self field and in external perpendicular magnetic field. For all samples’ lengths and voltage taps distances VCC were similar. Experimental arrangement is same as those described in [1].

"Step like" joints are shown in red. All tapes first were soldered to each other and then together soldered to terminations as shown in figure 1. In the step like samples lower tapes were 2.5 cm shorter from each side. Total length of terminations was 6 cm.

Figure 1. Four 2G tapes orientations and two types of joints tested. Currents in terminations are shown. Shaded region is a solder; red line - YBCO.

Examples of VCC measured at self field are shown in figure 2 for each of eight samples listed in figure 1. We show VCC in arbitrary units just to demonstrate the data qualitatively. One can see the difference between VCC depending on YBCO layers orientation and joints type.

For example in configuration #1- UD -“step-like” and “equal length” VCC for both tapes are equal that means uniform current transfer between tapes. Same we can say about configuration #3-UD for “step like” joints while same configuration for “equal length” has difference between VCC. In #3 “equal length” current first transfers to a bottom tape until its reach its critical value for this tape and then transfer to a top tape.

Similar differences we observed in other tapes configurations: current first transfer to one tape than to another one. For “equal length” joint in most cases current first transfers to bottom tape than to the top one. For “step like” joint for two configurations #1 and #3 we observed practically uniform current distribution. On the other hand in samples #2 and #4 current first transfers to the top tape.

We also would like to note the difference between configuration #4-UU with different joints method. For “step like” joint current first transfers to a top tape while for “equal length” joint current first flows to bottom tape. For “equal length” joint in configurations ##2-4 current transfers to bottom tape first.

Critical current of current carrying element made of two tapes (1 µV/cm criteria) is slightly less than sum of $I_c$ of each tapes due to self field influence like we showed in [1].
We checked how the VCC are changing at magnetic field. In figure 3 VCC for four samples with “step like” joints are shown. One can see that for all configurations, but #1-UD, current transfers first to top tape and then to the bottom one. Only for configuration #1-UD uniform current distribution is kept.

Figure 2. VCC measured for eight samples. Upper black curves are for top tapes, lower red curves are for bottom tapes shown in figure 1.

Figure 3. VCC measured for four samples with “step-like” joints at perpendicular magnetic field 50mT. Upper black curve is for top tape, lower red curve is for bottom tape shown in figure 1.

From data shown in figures 2-3 we can conclude that configuration #1-UD and “step like” joint
lead to uniform current transfer between tapes for all cases. This configuration and joint type looks optimal for joining non-symmetrical 2G tapes to terminations.

3. Discussion.
We analysed the reason of difference in VCC for two tapes. It is obvious that non-uniformity in currents in parallel superconductors at DC mode is due to difference in effective resistances between terminations and superconducting tapes in two layer current carrying element. This difference may be conditioned by simple joint resistance difference. Or it may appear due to difference in index $n$ at background magnetic field as we see in figure 3.

We developed the model described current transfer between chains of resistances and parallel superconductors with standard VCC, like: $E = E_0 (I/I_c)^n$. Here $E_0 = 1 \mu$V/cm, $I$ and $I_c$ are transport and critical currents correspondingly. In more details the model will be published later. In figure 4 the example of calculations for current distribution is shown. One can see the qualitative coincidence of calculated VCC shapes with experimental ones.

Quantitative analysis could be difficult due to uncertainty about real effective resistances between terminations and tapes. Very little difference in resistances is enough to lead to non-uniform current distribution. We continue our work to find out effective resistance between superconductors and terminations in our experiments.

4. Conclusion.
We measured voltage-current curves of eight samples made of two non-symmetric 2G HTS tapes. In some cases non-uniform current distribution among layers takes place depending on YBCO layer orientations, joint type and magnetic field. It affects critical current determination – proper voltage taps location should be used. The non-uniformity of currents is due to difference in effective resistance between superconductors and terminations. Optimal configuration is when YBCO layers face each other. It keeps uniform current distribution in self field and in magnetic field. Critical current of two tapes is slightly less than sum of critical currents of single tapes due to self field like it was shown before [1].

References
[1] V. E. Sytnikov, V. S. Vysotsky, I. P. Radchenko, N. V. Polyakova, A. V. Rychagov and G. G. Svalov, Study of HTS Conductors Made From Combinations of HTS Tapes, J. Phys.: Conf. Ser. 43 1059-1062, 2006