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Establishment of an easy I_c measurement method of HTS superconducting tapes using clipped voltage taps

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Abstract

The critical current, I_c of HTS superconducting tapes can be measured by transport or contactless method. Practically, the transport method using the four-probe method is the most common. In this study, a simple test procedure by clipping the voltage lead taps have been introduced instead of soldering which reduces time and effort and thereby achieving a much faster measurement of I_c. When using a pair of iron clips, I_c value decreased as compared with the measured one by standard method using soldered voltage taps and varies with the width of the clipped specimen part. However, when using a pure Cu clip, both by clipping and by soldering voltage taps give a comparable result and I_c measured are equal and close to the samples specification. As a result, material to be used as voltage clip should be considered and should not influence the potential voltage between the leads during I_c measurement. Furthermore, the simulation result of magnetic flux during I_c measurement test showed that the decrease of I_c observed in the experiment is due to the magnetic flux density, B_y produced at the clipped part of the sample by the operating current with iron clips attached to the sample.

Keyword: Critical current, clipped voltage taps, I_c measurement, magnetic flux density

1. INTRODUCTION

The electrical property of superconducting wires is an important performance parameter to electric power device applications. The critical current, I_c of the HTS wires or tapes is one of the principal engineering design properties to most device applications [1]. Moreover, the I_c depends strongly on the microstructure condition of the superconductor material particularly its grain boundary and defects [2, 3]. Thus, it varies greatly from sample to sample. For these reasons, critical current measurement is indispensable and therefore the most ubiquitous cryogenic measurement.

There are lots of things to consider in critical current measurements. One must be knowledgeable enough on the process including its test configurations, instrumentation, and trouble shooting in case a problem occurred. A good I_c measurement system includes data-acquisition protocol to protect the sample from burnout. Ekin identified some of the protocol checklist for high temperature I_c measurements including those for quench detection, bad sample, safe zone for first curve, current reversibility and Lorentz force reversibility when testing under magnetic field [4].

In addition, the first consideration in analyzing the data during the measurement test is to define how to determine the critical current from the obtained current-voltage (I-V) curves. There are three commonly used criteria for determining the critical current namely the electric-field, resistivity and offset criteria.

Goodrich emphasized that the I_c measurement system must be extremely sensitive to the small differential voltage that is present across the test specimen as it changes from the zero resistance state to the resistive state. However, it must be insensitive to the other sources of voltage that might otherwise corrupt the measurement [5].

In this study, I_c measurement of short HTS CC samples at self-field is presented. A simple test procedure by clipping the voltage taps instead of soldering is introduced. Two different clip materials were used in the tests, an iron one coated with Cu and a pure Cu one. It was found out that the material of the voltage clip such as iron affected the measured critical current. Furthermore, 2D simulation test for the effect of iron clips on the self-field is also presented.

2. EXPERIMENTAL PROCEDURE

2.1. Sample

RCE-DR IBAD-processed GdBCO CC samples with different substrate materials were used to assess the I_c measurement method using clipped voltage taps. The CC tapes have a critical current of more than 200 A per 4 mm tape width. Samples may have either a Hastelloy or stainless steel substrate and may be a Cu-stabilized only or with additional brass laminate on both sides.

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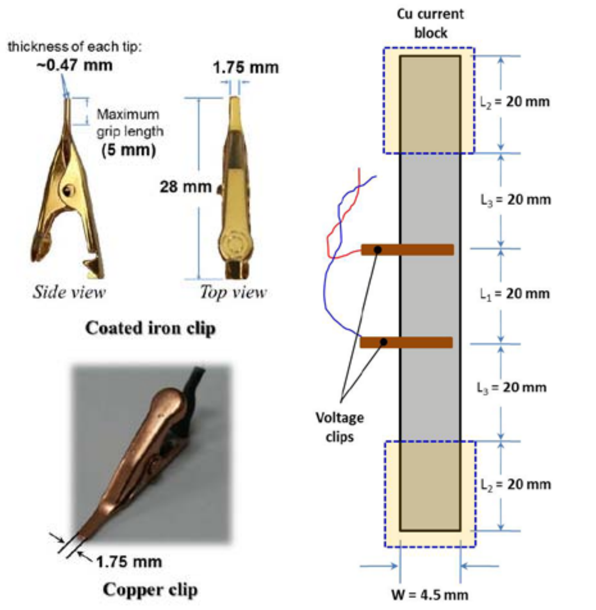

(a) (b)

Fig. 1. (a) Dimensions of the metallic voltage clips and (b) schematic of the four-probe method for I_c measurement by using clips for voltage lead taps instead of soldering them on to the tape sample.

2.2. I_c measurement system and set-up

An easy way of attaching the voltage leads by using clips is introduced, unlike in our previous reports [6-8] in which they are soldered on the sample. This easy method is intended for measuring I_c of short samples under no mechanical strain application. Coated iron and pure Cu clips were used as shown in Fig. 1a, respectively. Voltage lead wires were either soldered on the clip or they are just attached on the sample by using the clips. Schematic of the I_c measurement test at 77 K under self-field by four-probe method is shown in Fig. 1b where L_1, L_2 and L_3 are the length of the voltage tap separation, current contact, and current transfer, respectively. In Fig. 1b, the voltage lead wires are soldered on the clips. Sample holder is made of GFRP and the current terminal blocks were made of Cu. LABVIEW program was used to acquire the current and voltage data through the NI-DAQ system and devices. Quad twist 36 AWG wires were used as voltage leads. Terminal block each for current and voltage signals having multiple channels with a maximum of seven voltage leads was used. Current ramp rate is usually 2 A/sec. An electric field criterion of 1 μV cm^{-1} was adopted to define the critical current of HTS superconducting tapes.

3. RESULTS AND DISCUSSION

3.1. Clipped voltage taps using iron and copper clips during I_c measurement tests at 77 K under self-field

The attachment of voltage lead wires to the sample by using clips is termed here as the "easy" method. Easy method introduced in this paper was done in two ways; either the wire is soldered to the clip or it is attached to the sample mechanically by clipping. By doing this, voltage leads can be easily installed to or removed from the sample, consequently reducing the soldering procedure to every I_c measurement for each sample in the conventional or standard way. And the detachment of wires is less likely to occur but depends on the clip grip force. On the other hand, the direct soldering of voltage lead wires to the sample is then called "conventional" one.

The critical current of the RCE-DR GdBCO CC sample was premeasured using the conventional method to check if it is consistent with the tape specification as supplied by the manufacturer. The I_c value of ~248 A at 1 μV cm^{-1} determined from the I-V curves conforms with the samples specification. The integrity of the easy method was evaluated by adopting the two methods at the same time as shown in Fig. 2 to compare directly the behavior of the I-V curves during I_c measurement test. The critical current using these two methods were measured simultaneously. I-V curves obtained during the test were almost similar as shown in Fig. 3. However, it is evident that I_c value of ~156 A determined from both curves is only 60% of the pre-measured one. The I_c was measured again adopting just the iron clips and similarly it showed low I_c value. The lower I_c value obtained could be then due to the iron clips. The voltage along the sample is likely affected by the iron clip material during transport of high current through it.

Therefore, we have tried to use another clip made of pure Cu. Figure 4 shows the result of the I_c measurement tests. Similar I_c value was measured during the simultaneous test using the two methods and it also showed same result even when the Cu clips were removed. This means that the Cu clip has no effect on the I-V curves compared with the cases using iron clips and therefore the pure Cu is a viable material for voltage clip.

3.2. Effect of iron clips during I_c measurement tests at 77 K with varying clipped width

The effect of iron clip on the V-I curves during I_c measurement test has been investigated by varying the

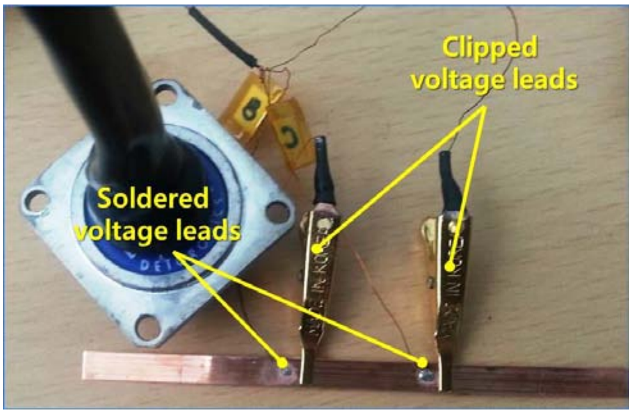

Fig. 2. Conventional and easy methods (the voltage lead wires are soldered to the clips) adopted simultaneously in the I_c measurement of RCE-DR Cu-stabilized GdBCO CC tape with Hastelloy substrate.

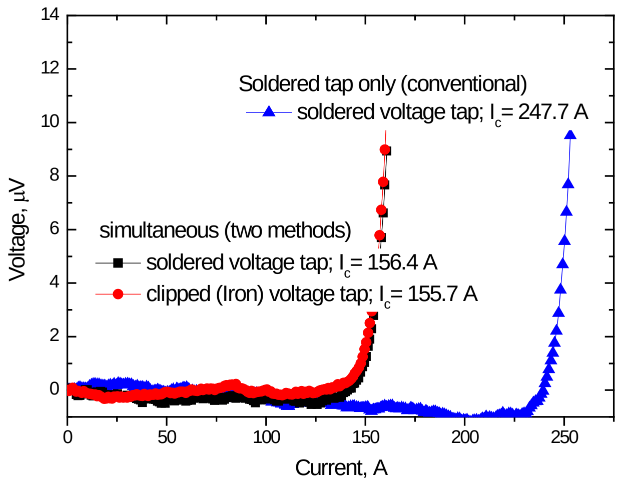

Fig. 3. V-I curves using both soldered and clipped (with iron clips) voltage taps on to RCE-DR Cu-stabilized GdBCO CC tape with Hastelloy substrate.

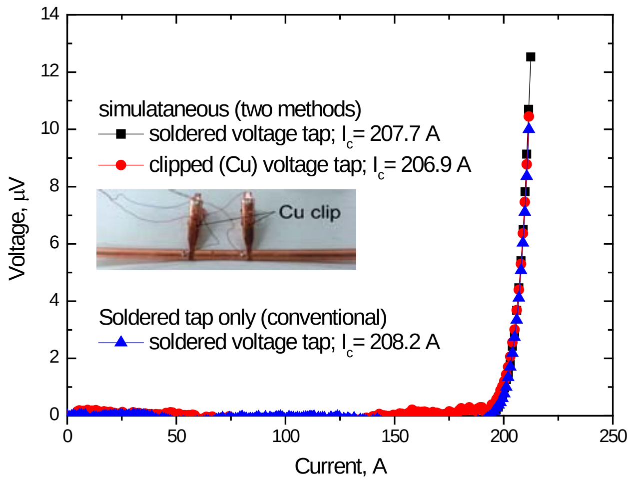

Fig. 4. V-I curves using both soldered and clipped voltage taps (with copper clips) on to RCE-DR Cu-stabilized GdBCO CC tape with STS substrate. Inset photo shows the simultaneous use of the two kinds of voltage taps technique.

clipped width in the sample as shown in Fig 5. The clipped width in each sample is different; (a) 4 mm (at full width) and (b) 1 mm (at the edge). Result of the I_c measurement tests with varying clipped width in the sample is shown in Fig. 6. Critical current was pre-measured using soldered voltage leads and a 247 A was determined as shown in Fig 6. The voltage wire leads were clipped within the full width of the samples as shown in Fig. 5a. Similarly with the first tests described above, the I_c was almost 60% of the pre-measured one. To minimize the effect of iron clip, the voltage lead wires were then clipped at the edge of the tape as shown in Fig. 5b. It could be found that the I_c increased to 213.7 A but this is only around 85% of the pre-measured one. These results proved that when iron clips are attached to the sample, it influences the V-I curves and this effect was also found during the I_c measurement test of other superconducting tape samples regardless of substrate material and configuration.

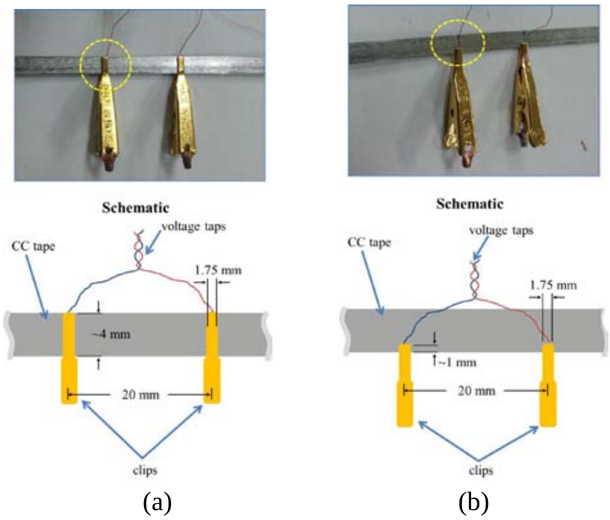

Fig. 5. Samples with clipped voltage taps. Schematics shows the clipped width of iron voltage taps of (a) 4 mm full width of the sample and (b) 1 mm width at the edge part of CC tape.

On the other hand, the effect of iron clips on the I-V curves was investigated by simulating the I_c measurement test. Figure 7 shows the result of the 2D simulation showing the distribution of magnetic flux density and vector arrow at the part of the iron clip. It can be found that the operating current produces self-field and magnetizes the iron clips. The vertical component, B_y of this magnetic flux density acts perpendicularly to the surface plane of the sample thus reducing the measured I_c value when using iron clips as voltage lead taps. This degradation can be compared on the effect of external magnetic field on I_c. In addition the maximum value of the B_y is usually located at the tip of the clips. However, the average value of B_y decreases with the clipped width as shown in Fig. 8. This is the reason why the effect is much lesser when the clips were attached at the edge part of the sample as described in Fig. 6.

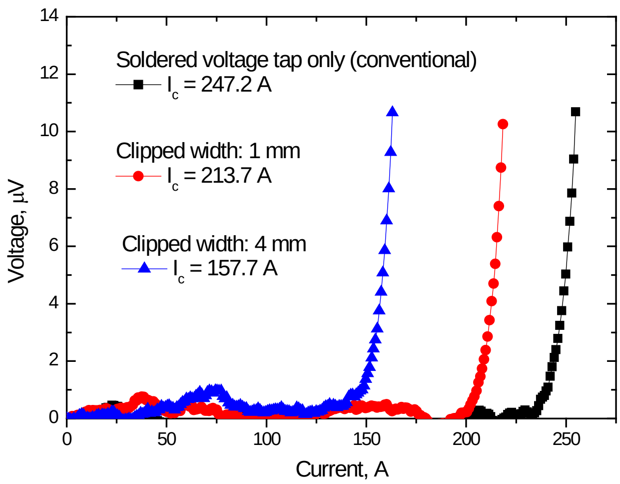

Fig. 6. V-I curves obtained by using the soldered and clipped (with iron clips) voltage taps in RCE-DR Brass-laminated Cu-stabilized GdBCO CC tape with STS substrate.

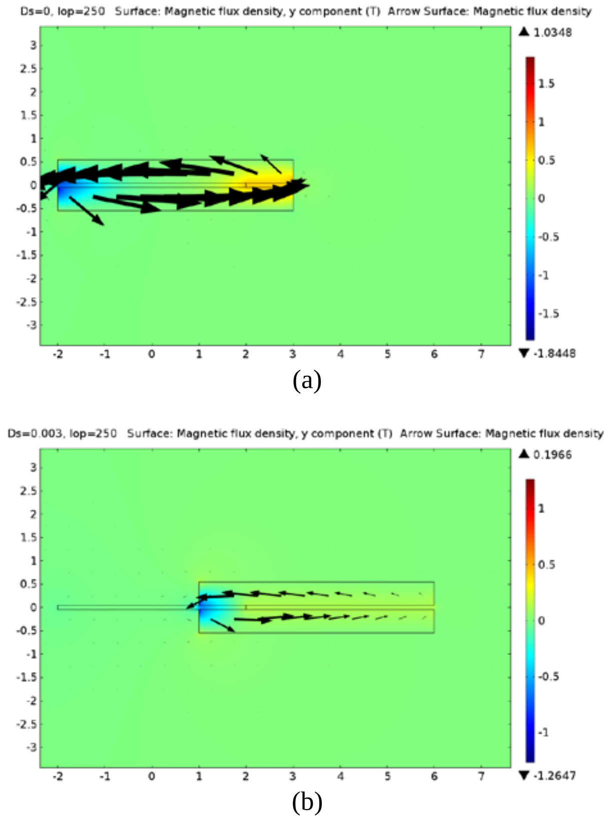

Fig. 7. 2D analysis results showing the distribution of magnetic flux density and vector arrow when the clipped width of iron clip on to CC specimen is (a) 4 mm and (b) 1 mm, respectively.

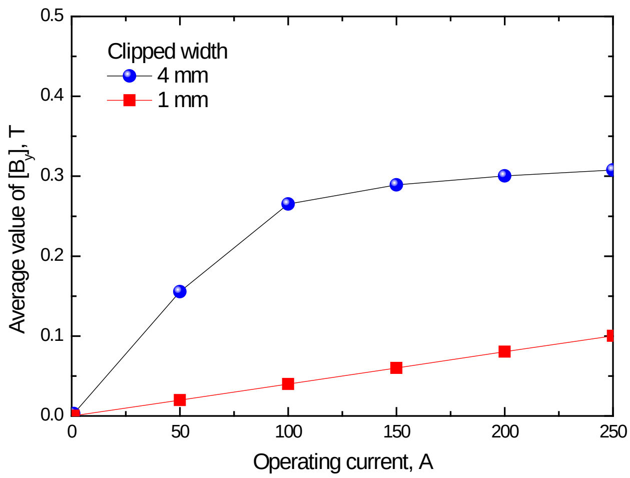

Fig. 8. Average value of B_y generated with the operating current during I_c measurement using iron voltage clips at each voltage clipped width of specimen.

4. CONCLUSION

Even though the introduced voltage tap method resulted to an easier I_c measurement by adopting voltage clips, it could be noted that the selection of clip material and the behavior at the operating environment should be considered and analyzed. With the adoption of solid Cu clips, the easy measurement method introduced was made possible without degradation and showed a reliable and reproducible I_c value.

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