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Rotating magnetization method for inspection of local defect in HTS conductor

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Rotating magnetization method for inspection of local defect in HTS conductor

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Abstract. High temperature superconducting (HTS) magnet used for a accelerator for high energy physics or a large-scale magnetic confinement system for nuclear fusion requires large current capacity HTS conductor in order to dump the stored magnetic energy quickly to protect the coil when quench has been occurred. To realize the HTS conductor, superimposed or stacked HTS tapes conductors are invented. However, local degradation of the critical current has been observed in the production of HTS conductors. Therefore, to confirm the soundness of the HTS conductor, it is necessary to establish the non-destructive detection method for the observation of degraded HTS tapes. In this study, we have investigated to inspect the degradation position in stacked HTS tapes by adopting rotating magnetization measurement method. This measurement method is measuring magnetization signal by rotating and transporting stacked HTS tapes in a static magnetic field. As a result, intentionally introduced buckling defect positions were detected by this measurement method.

1. Introduction

High temperature superconducting (HTS) magnet has a potential ability to generate higher magnetic field utilizing the high magnetic field characteristic exceeding that of a conventional low temperature superconductor (LTS), and can realize a helium-free cooling system because of the high critical temperature. Among them, HTS magnet used for a accelerator for high energy physics or a large-scale magnetic confinement system for nuclear fusion requires large current capacity HTS conductor in order to dump the stored magnetic field quickly to protect the coil when quench has been occurred. To realize high current capacity HTS conductor, superimposed or stacked HTS tapes conductors are invented [1-5]. However, local degradation of the critical current has been observed in the production of HTS conductors. Differ from the LTS wire, which is produced by strip processing from a billet, REBCO tapes cannot guarantee the performance by measuring both ends of the tape. Therefore, inspection of the soundness over the entire length becomes standard. For this reason, it is necessary to establish a method for full-length inspection of conductors assembled with REBCO tapes. However, HTS conductors themselves are still under R&D, and their inspection method has not been sufficiently investigated. In this study, we have investigated non-destructive and non-contact measurement method for the local degradation of stacked HTS tapes using rotating magnetization method.

2. Rotating magnetization method

In typical magnetization measurement, magnetic field is applied perpendicularly to the flat surface of HTS tape. The magnetization which induced by electromagnetic induction is measured by a Hall sensor or a pickup coil [6,7]. From the obtained magnetization distribution, critical current density is evaluated and defect position is detected. However, the HTS conductors are twisted for the purpose of equalizing current and reducing AC loss, magnetic field cannot always be applied perpendicularly to the tape surface. Therefore, if the magnetic field becomes closely parallel to the tape surface, it becomes difficult to magnetize the HTS conductor sufficiently. For the sake of magnetize the HTS conductor, we have adopted magnetizing method of rotating the HTS conductor in a static magnetic field. As shown in Fig. 1, it can be assumed that when a magnetic field is applied to the stacked REBCO tapes, because the superconducting layer has a very thin structure, the magnetic moment m is induced in the perpendicular direction to the tape surface. Namely, the induced magnetic moment has anisotropy behavior. Therefore, when the conductor is rotated in the static magnetic field, the magnetic field against on the tape surface is apparently the same as that sweeping the magnetic field. When the Hall sensor measures the magnetic moment vector m_T of the magnetic moment m in the transverse direction, the magnetization signal m_T having two peak values as shown in Fig. 2 which is obtained from the front side and the back side of the stacked tapes. From this method, stacked REBCO tapes can be magnetized without considering the direction in which the tapes are stacked.

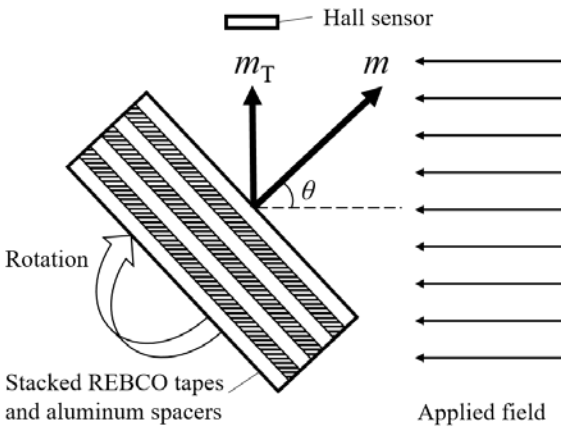

Figure 1. Schematic diagram of the magnetization behaviour when rotating stacked REBCO tapes

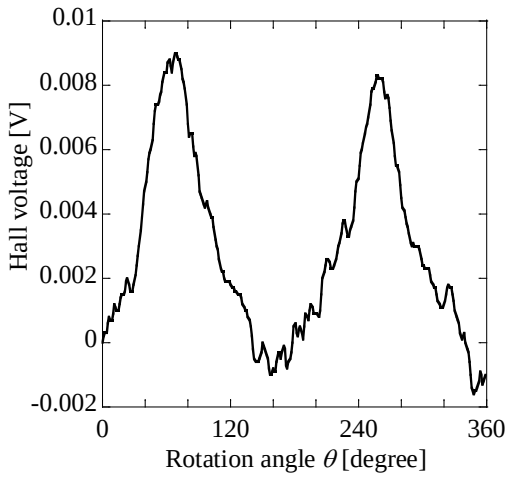

Figure 2. As the configuration of Fig. 1, experimentally obtained Hall voltage data from three REBCO tapes stacked which are rotated in a static magnetic field at 77 K, magnetized by permanent magnets.

3. Experimental set up

3.1. Experimental device and measurement method

As shown in Fig. 3, in order to examined defect detection using rotating magnetization method, we have manufactured a device which has capable of rotation and transportation by using a *z*-axis motorized stage and a rotating stage. The shaft is connected to each stage, and a slit for setting the stacked sample is provided at the lower end of the shaft. In the lower part of the device, there is a mounting place of permanent magnets and a Hall sensor. The lower part is immersed in liquid nitrogen for cooling. Fig. 4 shows a schematic diagram of the measurement part. The shaft has a slit-shaped hole, in which the stacked REBCO tapes are inserted. The stacked REBCO tapes inserted the shaft are magnetized by being conveyed while rotating between permanent magnets having a surface magnetic field of 0.5 T. The magnetization signal in the transverse direction is measured by the Hall sensor. The permanent

magnet is a cube of 20 mm on one side and its residual magnetization is 1.38 T. The magnets are lined with a gap of 9 mm. Therefore, the central magnetic field where the shaft passes is about 0.74 T, calculated by the magnetic charge model. This value is also confirmed by the Hall sensor.

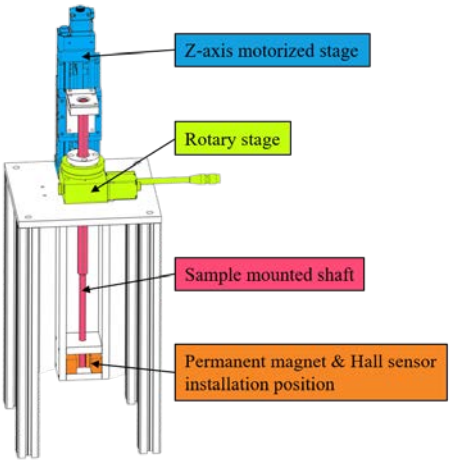

Figure 3. Measurement device that measures magnetization while rotating and transporting stacked REBCO tapes in liquid nitrogen.

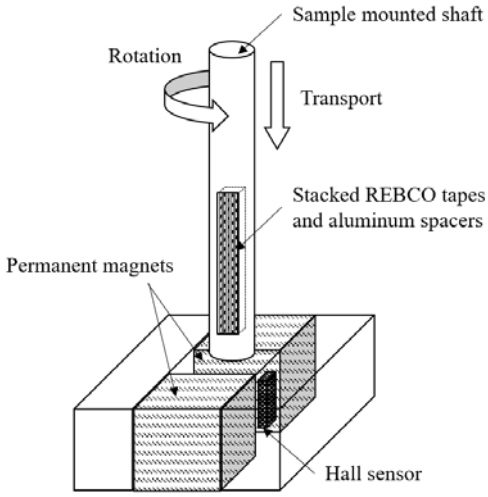

Figure 4. Schematic diagram of the portion where magnetization is measured while being rotated and transported. Stacked REBCO tapes are magnetized by the permanent magnets and the magnetization signal is obtained by Hall sensor.

3.2. Intentionally introduction of defects due to mechanical buckling

REBCO tape (I_c > 100A at 77 K self-field., 4 mm-width, made by Shanghai Superconductor Technology Co., Ltd.) was used for the sample to cut 5 cm in five tapes. The REBCO tape was fixed with a compression testing machine and the jig as shown in Fig. 5, and was applied compressive stress. The distance between the jigs was opened 0.5 mm when the tape was mounted. As shown in Fig. 6, defects were intentionally introduced by compressing through 0.3 mm at five places in the tapes. Fig. 7 shows the observed relationship between the compression stress and the distance. It can be seen that approximately the same yield stress, and the same degree of defects are introduced. Fig. 6 is a picture after compressive stress is applied. The buckling line due to compressive stress can be observed at each number indicated. The REBCO tapes which buckling defects introduced were stacked from top to bottom while 1 mm-thickness aluminum spacers were interlaid in each gap.

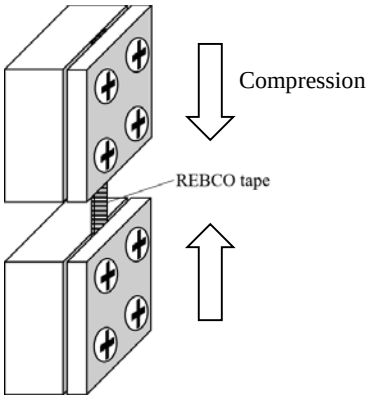

Figure 5. Schematic diagram of the jig which compresses a REBCO tape with a compression testing machine. Clamp the both ends of REBCO tape, then applied compression stress to introduce buckling defect.

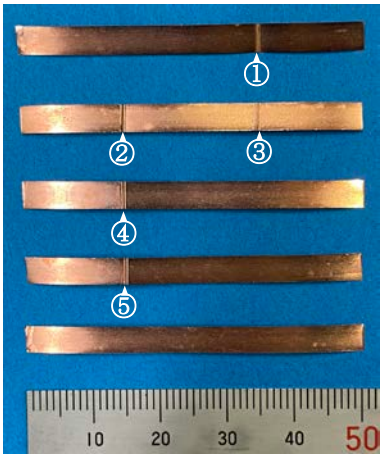

Figure 6. Picture of REBCO tapes before stacked. The buckling defects have been intentionally introduced by compression stress. The positions of the defects are indicated by number. These tapes were stacked from top to bottom while aluminium spacers interlaid in each gap.

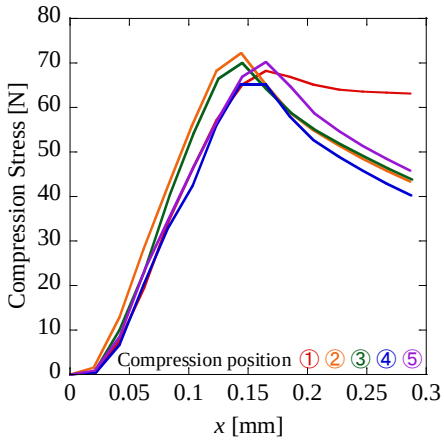

Figure 7. Profile of compression stress at each location in Fig. 6.

4. Experimental result

Fig. 8 shows a result of observed magnetization signal while transporting and rotating the stacked sample while magnetizing it. The *x* axis indicates the longitudinal direction of the stacked tapes, the *y* axis indicates the rotation angle, and the *z* axis indicates the magnetic field obtained by the Hall sensor. By repeating the measurement of rotating by 360 degrees and transporting 0.1 mm to longitudinal direction, we have measured the signal waveform as shown in Fig. 2 over the longitudinal direction of the stacked REBCO tapes continuously. Fig. 9 is a view point of the *x*-*y* axis in Fig. 8. As shown in Fig. 9, it can be confirmed that the magnetization signal intensity is attenuated at the position where the defect is introduced. In addition, the two peak values attenuated to the same extent at the positions where defects were introduced in the center three tapes. Furthermore, the peak values on one side were significantly attenuated at the positions where defects were introduced on one side tapes. From these results, it is possible to determine the deteriorated position based on the strength of the two peak signal values.

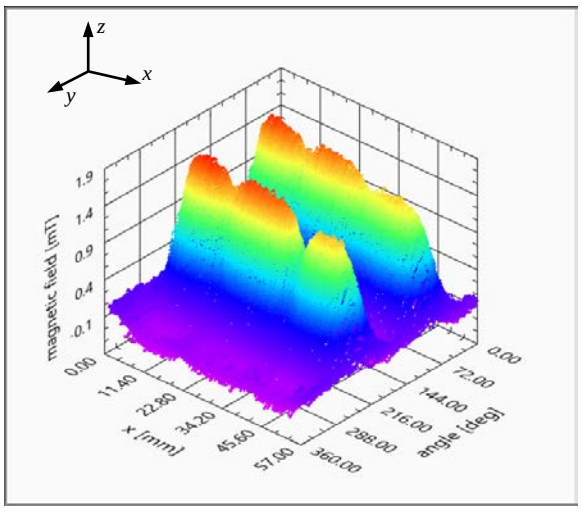

Figure 8. Measurement result of magnetization distribution over the entire length of stacked REBCO tapes.

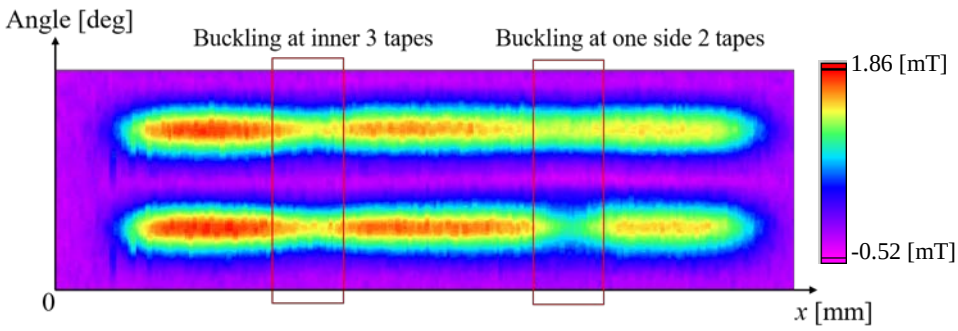

Figure 9. Measured magnetization distribution is plotted, angle on the vertical axis, distance on the horizontal axis. It is indicated that the area corresponding to the position where three inner layers have defects and the position where two outer layers have defects by red frames.

5. Summary

We have investigated the defect detection method of the stacked REBCO tapes by rotating magnetization measurement in a static magnetic field. In order to investigate the method, we have manufactured transport and rotate measurement device. For testing the stacked REBCO sample, each REBCO tapes were intentionally introduced buckling defects by compression testing machine. We have conducted the detection of the buckling position by the device. From the experiment result, the intensity and waveform of the detected magnetization signal was changed at the position where the defect was introduced. Therefore, it became clearly that the defect can be detected by magnetizing the stacked REBCO tapes in this rotation magnetization measurement method. It is expected that non-destructive full length inspection of HTS conductors will be possible by extending the technology of this method. In order to magnetize tens of laminated REBCO tapes, over 5 T magnets are needed. Therefore, we are planning to use superconducting magnets for magnetization in the next stage.

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