

Scan Measurements on ROEBEL Assembled Coated Conductors (RACC)

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Abstract. The application of RE-BCO coated conductors (cc's) in high field magnets as well as in electrical machinery decisively depends on the ability to produce conductors with high current densities and small losses. The production process of the conductors restricts the thickness of the superconducting layer and therefore the current. It is possible to enhance the current carrying capability by combining several conductors to a cable. The ROEBEL bar concept is the most suitable solution because of reduced ac losses. Cc's are suitable for shaping ROEBEL strands and to perform the cabling. We employed different scan techniques to get an overview of the conductor properties. The magnetoscan, which was successfully applied to cc's, was optimised for scanning a prototype of such a RACC-cable. The resulting map of the magnetic field reflects the superconducting properties of the conductor and allows analysing the defect structure and the critical currents. Due to the complex configuration of the RACC-cable some considerations concerning the effects at conductor edges and the transitions between the strands were necessary. The field map of the ROEBEL-cables can be used to optimise them.

1. Introduction

The properties of coated conductors (cc's), second generation (2G) HTS superconductors, improved dramatically during the last years. Therefore, the use of such conductors in large devices, such as electrical machines or magnets for fusion power plants, will become feasible in the near future. Especially their potential for applications in high magnetic fields at relatively high temperatures (50-77 K) is of great interest. Many current investigations focus on the improvement of the conductor architecture, the increase of the critical current density over long lengths and improvements of the production process. These efforts resulted in a variety of commercially available conductors in long lengths with critical currents above 300 A per cm width. Because of the production process, the maximum critical current of one strand is limited by the thickness of the REBCO layer (RE = rear earth element). Currents in the kA range, which are needed for applications, can be reached only by a configuration consisting of several conductors. The concept of a ROEBEL bar seems to be favorable for the flat shaped cc's [1] and has been realized for other superconductors for reduced AC loss cables [2] [3].

As already shown earlier [4], the magnetoscan technique can be used to analyze the homogeneity and the current carrying capability of coated conductors. With this technique defects in a conductor

can be localized and their influence on the critical current determined. This is very helpful for the production of ROEBEL strands, e.g. by monitoring the cc's during the cutting process. Low critical current density (J_c) segments can be removed from the strands and the entire current carrying capability of the ROEBEL bar increased. The ROEBEL bar itself can be scanned by the magnetoscan technique to analyze the structure and the magnetic properties. The influence of different twist pitches, step over angles and interstrand connections can be tested. This work reports of first results on magnetoscan measurements on ROEBEL cables.

2. Experimental setup

The scan setup consists of a scan table with stepper motors, an open liquid nitrogen dewar, a measuring adapter and the sample holder [5]. The measuring adapter is attached to the scan table and can be moved in all directions. In most cases the scan direction is along the x-axis (along the tape length). The sample holder and the measuring adapter are placed inside the dewar, which is filled with liquid nitrogen (Figure 1).

During the magnetoscan, a permanent magnet is moved over the sample surface to induce local currents. A Hall probe between the permanent magnet and the sample measures continuously the resulting magnetic field. The setup allows to change the permanent magnet and the distance between the permanent magnet and the sample surface, in order to vary the magnetic field intensity at the sample surface. The diameter of the magnet is fixed to 10 mm because of the shape of the measurement adapter. The field can be varied between 20 and 250 mT. The Hall probe has an active area of $50 \times 50 \mu\text{m}$, is always positioned 0.2 mm above the sample surface and located 2 mm away from the centre of the permanent magnet [6]. The conductor with a maximum length of 25 cm is fixed at the bottom of a liquid nitrogen bath.

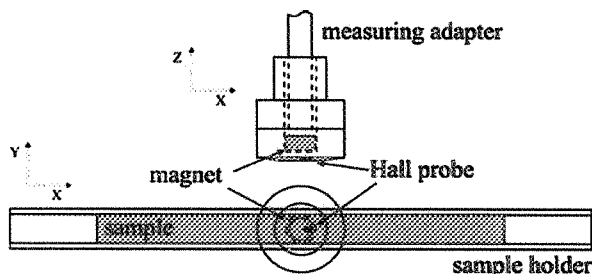


Figure 1. Sketch of the experimental setup.

3. Samples

To form a ROEBEL cable, the cc is pre-shaped into a ROEBEL specific geometry [9]. Therefore, the cc's are cut mechanically, followed by the assembling process to the ROEBEL Assembled Coated Conductor (RACC) cable structure. The present ROEBEL bar sample was made from THEVA coated conductors [7]. These DyBCO-tapes are able to carry a transport current of more than 300 A/cm at 77 K [8]. The original tapes had a width of 10 mm and were cut into 4 mm wide ROEBEL strands with special punching machine, which provides very sharp cutting edges with minimum variation of the width. Also the damage of the superconductor is minimal. The transposition section was made with an angle of 30° . The critical current of the individual strands was approximately 92 A. To assemble the ROEBEL bar 11 strands were used (Figure 2a). A twist pitch of 127 mm was chosen to restrict the length of the sample to fit into the AC loss equipment [10]. To achieve a compact ROEBEL bar, the strands are glued together with Ag-epoxy paste for electric coupling (Figure 2b). The result is a ROEBEL bar with good mechanical performance. The sample was produced and pre-characterized at FZK.



Figure 2. Photo of a ROEBEL cable a) before interstrand coupling b) after coupling

4. Results

A typical result of a magnetoscan measurement is shown in Figure 3. The maximum applied magnetic field at the position of the Hall probe was 50 mT and the step size between the measurement points was 0.25 mm. High shielding currents (i.e. high magnetoscan fields) are observed on both sides of the ROEBEL cable, where the individual strands are lying on top of each other. The field measured at the position of the strands is around 24 mT, i.e. smaller by 26 mT than the applied field. The peaks in the middle of the cable result from the stray fields due to the discontinuity of the strands in x-direction.

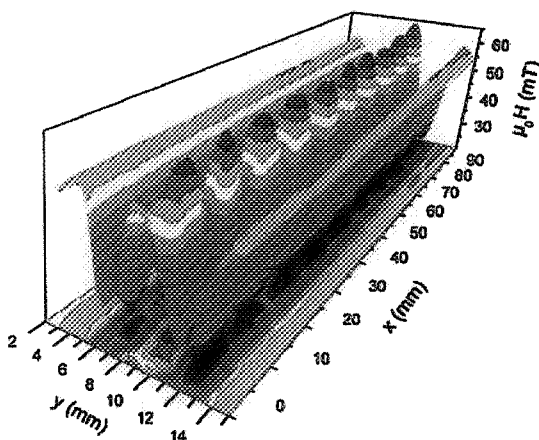


Figure 3. Experimental result of a magnetoscan.

The structure of the ROEBEL cable is clearly observed in a contour plot (Figure 4). The characteristics of the single strands and their displacements are displayed in the field map. The contour of the cable, extracted from a photograph, is projected onto the field map (black solid lines) to emphasize the good agreement. Also small variation in the structure is observed. The conductor next to the surface changes because of the transposition, i.e. the experimental results can be divided in sections, where different strands are on the top of the cable. The conductor next to the surface and, therefore, closest to the Hall probe has the largest influence on the experimental results. The field maps of different sections are very similar indicating that the tapes are quite homogeneous. The width of the space between the strands can be observed in the field map as well. High stray fields are found in the middle of the tape, where the field increases to a maximum of 62 mT, 12 mT above the applied field. Especially in the nose corner high stray fields are observed.

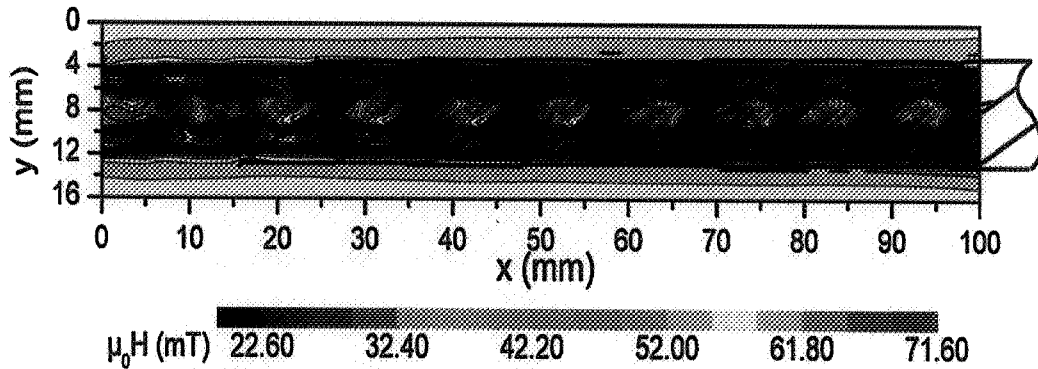


Figure 4. Contour plot of the field map and contour of the sample.

Magnetoscan measurements at other fields led to similar results (Figure 5 for 230 mT). The field along the length of the sample is plotted for three y position in Figure 5c. Outside the sample we measure only the field of the magnet, which is 230 mT in this case. In the middle of the tape ($y = 9$ mm) we obtain a periodic variation, where the minimum indicates strands which cross the cable near the surface. The width of the strands can be determined by measuring the distance between two points, where the measured field reaches the applied field. At the position, where the strands lie on top of each other, ($y = 12$ mm) the field varies also along the x -direction. The main reason is the difference in the number of strands laying on top of each other. The distance between the maxima is correlated with the ROEBEL structure. At the strands ends (cutting edge) a step occurs and increases the distance between the superconductor and the Hall probe. This reduces the measured field in combination with stray fields (circles in Figure 5c).

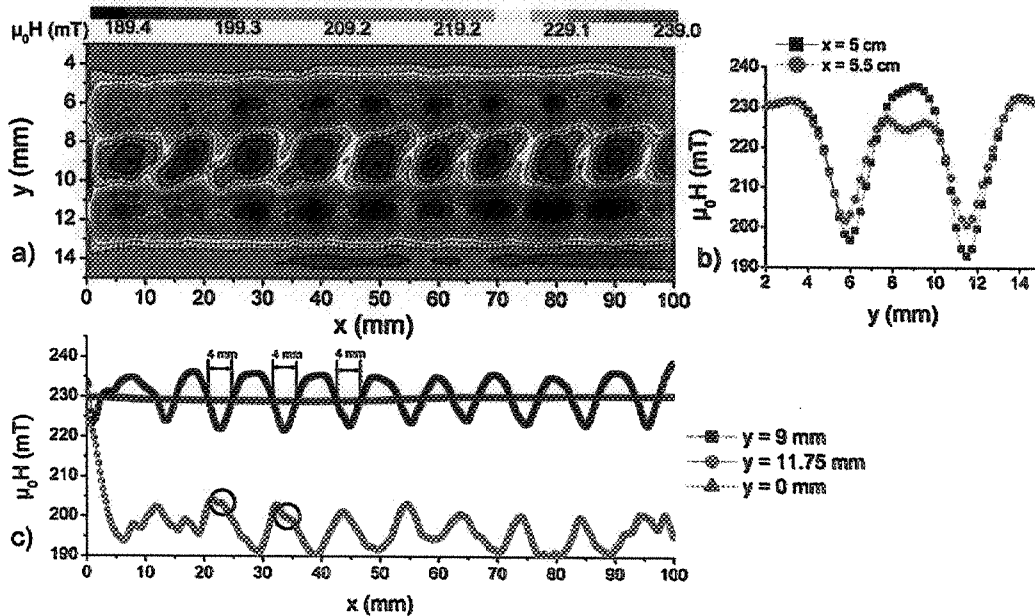


Figure 5. Magnetoscan at higher fields: a) field map, b) fields across the width at different x , c) scans along the length of the sample at different positions along y .

The field dependence along the width of the sample is shown for two characteristic x-positions in Figure 5b. At the first position ($x = 5$ cm) we obtain two Bean-like profiles, which are completely separated. The other profile ($x = 5.5$ cm) is measured at a position, where one strand is crossing the cable. Therefore, the field is reduced in the middle of the sample. Scan measurements before and after interstrand coupling do not show significant changes in the field map. Some small differences can be explained by a small variation in the applied field.

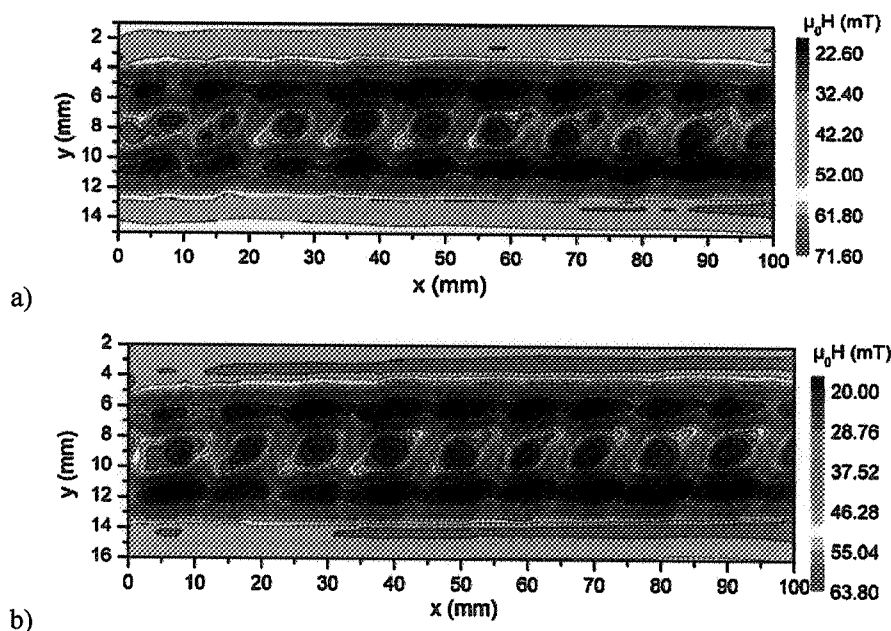


Figure 6. Magnetoscan on a ROEBEL bar before (upper panel) and after interstrand coupling (bottom panel).

5. Conclusion

The magnetoscan technique was successfully applied to ROEBEL bars. The data provide important information on the homogeneity and the structure of the cable and are useful for optimizing their production process and to improve the shape of the strands.

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