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Magnetization ac loss reduction in HTS CORC® cables made of striated coated conductors

M Vojenčiak[1,2], A Kario[1], B Ringsdorf[1], R Nast[1], D C van der Laan[4], J Scheiter[3], A Jung[1], B Runtsch[1], F Gömöry[2] and W Goldacker[1]

[1] Karlsruhe Institute of Technology, Institute for Technical Physics, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
[2] Institute of Electrical Engineering, Slovak Academy of Science, Dúbravská cesta 9, 841 04, Bratislava, Slovakia
[3] Leibniz Institute for Solid State and Materials Research, Department of Superconducting, Materials, 01171 Dresden, Germany
[4] Advanced Conductor Technologies, Boulder, CO 80301, USA and Department of Physics, University of Colorado, Boulder, CO 80309, USA

E-mail: michal.vojenciak@savba.sk

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Abstract
High temperature superconductors (HTSs), like for instance *RE*BCO (*RE* = rare earth) coated conductors, are of high potential for building large superconducting magnets. Some magnets, such as accelerator magnets, require the use of superconducting cables to allow fast ramping, and low magnetization loss to mitigate field quality issues. One of the methods to lower ac loss is to divide the superconducting layer in the tape into filaments. In this paper, conductors with copper stabilization for practical applications are laser scribed into narrow filaments. Striated tapes are then wound into conductor on round core (CORC®) cables. The critical current and magnetization ac loss of single tapes were measured. We found that the stabilizing copper layer causes difficulties for laser scribing. The degradation of the critical current is more pronounced than in the case of non-stabilized tapes. The selection of the number of filaments is therefore a compromise between critical current degradation and reduction of ac loss. Based on the results obtained from single tape experiments, the optimum number of filaments in 4 mm wide tapes was chosen, and CORC® cables with 2, 3 and 4 layers of tapes with and without filaments were manufactured. Magnetization ac loss measurements at 77 K showed a reduction of ac loss in the cables with filaments. This reduction corresponds almost to the number of filaments. Measurement at different frequencies also showed that the coupling loss in CORC® cables with a short twist-pitch is relatively small in comparison to hysteretic loss.

Keywords: high-temperature superconductor, coated conductors, cables, AC loss, filaments, laser scribing

(Some figures may appear in colour only in the online journal)

1. Introduction

Several types of high temperature superconductors (HTSs) are potential candidates for building high magnetic field magnets; the current carrying capacity at fields over 15 T is higher in comparison to low temperature superconductors (LTSs). *RE*BCO coated conductors (CCs) are currently the most promising type of HTS. Commercially available *RE*BCO CCs exhibit outstanding properties and they are already produced in lengths of several hundred meters by different manufacturers [1–4].

Several HTS coil demonstrators have been built and tested using single-tape windings. However, there are still challenges to building large HTS magnets, such as the need for superconducting magnet cables with low ac loss. In comparison to single conductor windings, cables offer a higher current, resulting in a lower magnet inductance. As CCs have a completely different architecture in comparison to LTS wires, cabling concepts are not straightforward. In the last few years, significant progress on cabling concepts has been made within which different *RE*BCO cable geometries are being developed: Roebel Coated Conductor Cables (RACCs), Conductor On Round Core (CORC®) and Twisted Stack-Tape Cables (TSTCs) [5–10].

Magnetization ac losses of *RE*BCO conductors are relatively high, because of the large width of the superconducting layer. Reduction of ac loss by dividing the superconductor into filaments using various techniques was proven on short samples by several groups [11–14]. Filaments reduce the hysteretic magnetization ac loss, but at the same time, additional coupling losses are introduced. The level of coupling loss depends on the quality of the striation process. If there are low resistance bridges between filaments after the striation process, the coupling loss is high even in short samples [14]. With an increase of the tape length, the coupling loss further increases. To limit the level of coupling loss, it is needed to transpose the filaments, which can be achieved when tapes are cabled, as we show later in this paper.

Terzieva *et al* showed that the creation of filaments by laser scribing on complicated RACC structures is feasible and filaments reduce the magnetization ac loss [15]. The RACC structure itself does not transpose filaments within the strand, therefore the coupling loss would be an issue on longer cable lengths. However, RACCs can be used as strands in Rutherford structures, which ensures also the transposition of filaments [16].

Our previous study has shown that the CORC® cable approach is effective in limiting coupling currents between filaments of the same tape, as well as between individual tapes [17]. This is a consequence of twisting the tapes and thus a substantial reduction of the voltage induced between tapes and filaments. Coupling currents are limited even when the tapes are soldered to low resistance current leads. A one-layer CORC® cable with 3 tapes, each with 5 filaments was wound on an 8 mm diameter round core. With this configuration, the magnetization ac loss was reduced by a factor of almost 5. In that study, tapes stabilized only by a silver cap layer were used. This was advantageous for the laser scribing process, but not foreseen in magnet applications.

Electrical stabilization is an important issue for practical cables. Stabilization of *RE*BCO tapes is usually provided by a copper layer about 20 μm thick. Laser structuring of copper covered tapes has been studied in several papers. Common conclusions were that the level of coupling currents in such samples is high [14] and it is significantly higher than in the case of tapes without a copper layer [18]. To keep coupling currents in copper stabilized tapes at a reasonable level one should twist the tape with a relatively short twist pitch. Currently, the CORC® cable architecture offers the shortest twist pitch of all HTS cable concepts. In practical CORC® cables, the twist pitch might be shorter than 20 mm, while in other cable concepts this length is about 150 mm for TSTC [8] or about 100 mm [5, 15] for RACC cables.

In this paper, we focus on applying laser scribing to tapes with standard, 20 μm thick, copper stabilization. We studied in detail the current carrying capability of single tapes after their laser structuring. Subsequently, we tested their limits to withstand mechanical deformation during cabling. The final step for single tapes was the measurement of their magnetization ac loss with their wide face perpendicular to an external magnetic field.

Based on the I_C and ac loss reduction measured for single tapes, we selected the number of filaments for use in CORC® cables. The former diameter of the CORC® cables was chosen, taking into account the mechanical properties of the tapes with filaments. Two sets of CORC® cables containing various numbers of layers were made—one containing tapes with a continuous superconducting layer, and one containing tapes with filaments. Magnetization ac losses measured on cables with striated tapes were compared to those of the cables made of tapes with a continuous superconducting layer.

2. Laser scribing technology

The tapes used in this study were purchased from SuperPower [1], were 4 mm wide and contained a 50 μm thick Hastelloy substrate, a 2 μm thick silver cap layer and a 20 μm thick stabilization layer surrounding the tape. The 20 cm long tapes were cut and a 15 cm long section in the center of the tapes was structured using an infrared Nd:YAG laser with a wavelength of 1030 nm. For the structuring of these samples 50% of the power (12.5 W) with 50 repetition cycles for each single groove was used. Samples with 3, 5, 7 and 10 filaments were prepared. More detail on the laser scribing technique can be found in [19]. The critical current for each tape was measured by the transport method in self-field at a temperature of 77 K before and after the striation process. The samples were microscopically investigated after they were striated. Scanning electron microscopy (SEM) was used to measure the width of the laser grooves, which showed an average width of about 40 μm. A focused ion beam (FIB), using gadolinium ions, was used to cut the samples perpendicular to the laser groves. The obtained cross sections of the laser grooves are shown in figure 1. The FIB cut was performed in several places over the length and the width of the tape. The laser groove cross-sections are irregular in shape and a re-deposition layer with variable thickness is visible, which contains mainly copper and Hastelloy components. The width of the laser groove, determined from the FIB cuts is between 20 and 37 μm at the location of the *RE*BCO layer, measured in different places along the length of the groove. The groove gets wider when approaching the surface of the tape.

In our previous work [17] we found that the coupling current can flow between filaments on opposite edges of the tape through the metallic stabilization deposited on the edges

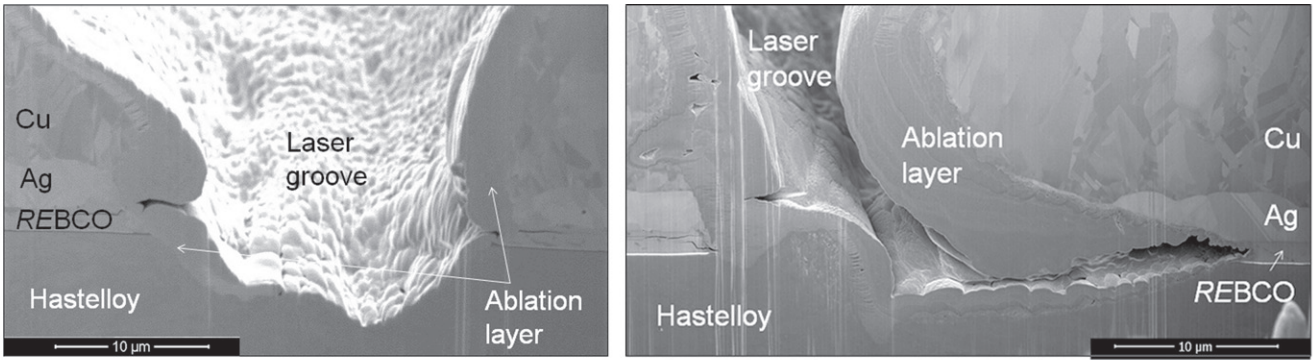

Figure 1. SEM pictures after FIB cross-section cut of the laser groove: two different shapes of the cross-section.

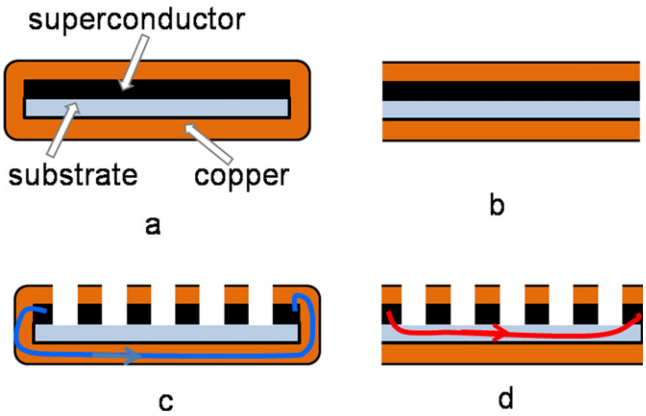

Figure 2. Architecture sketch of samples (not to scale). a—original tape; b—sample with cut edges; c—sample with filaments and Cu on edges; d—sample with filaments and cut edges. Arrows show possible transverse path of the coupling current.

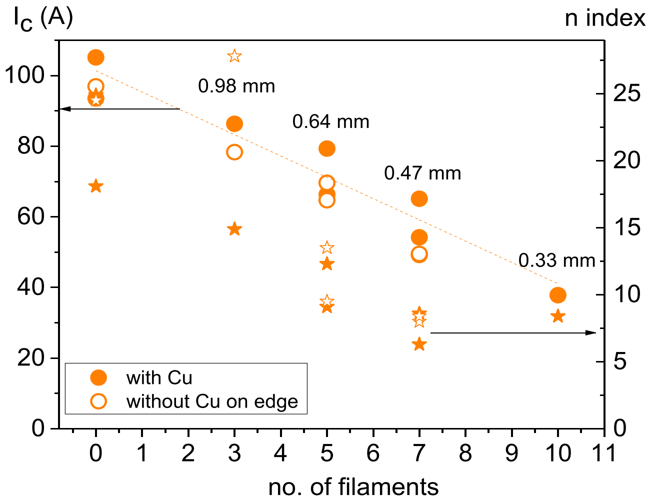

Figure 3. Critical current (circles) and n-index (stars) as a function of filament number. Solid symbols represent samples with Cu on edges, open symbols represent samples with cut edges. Numbers above symbols indicate filament width.

and the bottom of the tape—figure 2(c). We tested the idea of eliminating this current path by cutting the edges of the tape and forcing the coupling current to flow in different paths with a much higher resistance—figure 2(d). For this purpose we prepared both kinds of sample—with copper on the edges (like figure 2(c)) and with cut edges (like figure 2(d)). Note that the copper on the side of the substrate is in the samples with cut edges (figures 2(b) and (d)) insulated from the superconductor and does not act as stabilization any more.

After direct I_C measurements were performed, the ends of the samples were cut off and only the 15 cm inner part containing filaments were used for ac magnetization loss measurements using a calibration-free method [20].

3. Single tape measurements

The goal of this work is to prepare CORC® cables with filaments for magnetization ac loss reduction. For this purpose, the number of filaments on a single tape needs to be chosen. Accordingly, tapes with different number of filaments: 0, 3, 5, 7 and 10 with and without copper edges were prepared. The dependence of the critical current reduction on the number of filaments is shown in figure 3. The critical current (I_C) of the tapes is inhomogeneous, and is determined on two reference samples whose I_C differs by 11 A. The reduction in I_C caused by removing superconducting material is significant and much stronger than in the case of samples without copper stabilization [18]. The critical current of samples with 10 filaments is only 40% of the original I_C, which is not acceptable for applications. For the sample with 3 filaments, I_C decreases only by 8%; for samples with 5 filaments, the reduction of I_C is between 15 and 35%.

3.1. Off-axis bending experiment

To be able to assemble CORC® cables from CC tapes, those tapes need to withstand off-axis bending stress, which will be applied during cable winding. Tapes with different numbers of filaments oriented with the superconducting layer on the inside were tested using off-axis bending equipment—figure 4. This equipment allows bending the tape over a chosen former (in this case 5 mm diameter) and changing the winding angle, as described in more detail in [16]. Tapes with 3 (circles), 5 (squares) and 7 filaments (triangles) with edges were measured; a sample with 5 filaments was measured without the edge as well (diamonds). Measurement of the tape I_C showed the level of superconductor degradation. The

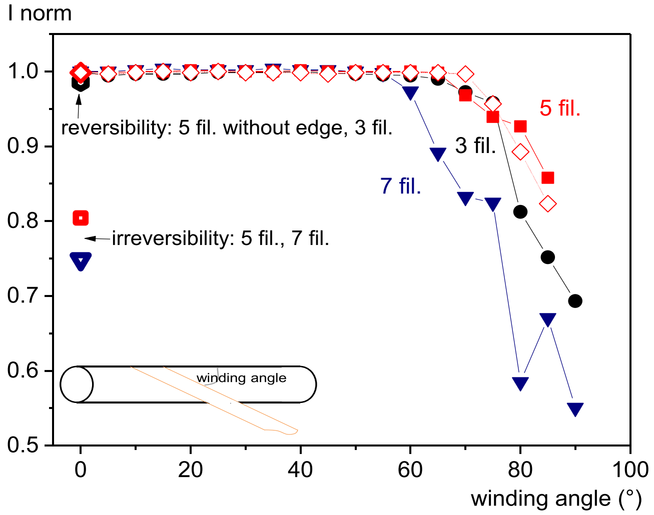

Figure 4. Off-axis-bending of the tapes with different numbers of filaments (closed symbols—with tape edges, open symbols—tape without edges). The former diameter in the bending set-up is 5 mm.

winding angle represents the angle between the cable axis and the tape axis (graph inset). I_C of the tape with 7 filaments started to decrease with a 60° winding angle and reached 55% I_C degradation at a 90° winding angle, where the maximum bending strain along the tape is 1% compression. Tapes with 5 and 3 filaments are more resistive against winding; I_C starts to decrease at a 70° winding angle. The degradation in I_C depends on the stress component parallel to the filaments of the tape. Reversible reduction of the I_C was found for tapes with 3 filaments with edges and 5 filaments without edges. Irreversible current degradation was measured in tapes with 5 and 7 filaments (with edges). In CORC® cables, the winding angle depends on the diameter of the former, the number of tapes in the layer, and the spacing between tapes. The winding angle in CORC® cables is usually between 36 and 54° [21]. Such a winding angle is within the safe region in which no I_C degradation of striated tapes was measured.

3.2. Ac loss measurement

Samples with higher critical currents were chosen from each set of tapes with the same number of filaments for ac loss measurements. The length of the samples was 145 mm for all tapes. The ends without filaments (needed for I_C measurement) were cut-off by a laser, and only the part with filaments was measured. The magnetization ac loss in a magnetic field was measured by means of a calibration-free method [20] in which the field had the form $B = B_a \cos \omega t$, with frequency $f = \omega/2\pi$ and amplitude B_a. The magnetic field was generated by a race-track ac magnet and applied perpendicular to the wide face of the tape. The voltage on the sensing wire of the ac magnet winding was measured using a phase sensitive voltmeter–lock-in amplifier. The reference phase was derived from the electric current by energizing the magnet I_{mag} using a Rogowski coil. We recorded both parts of the fundamental harmonic component of the signal: the voltage in-phase with the current U_{loss} and the out-of-phase voltage U_{ind}. In our calibration-free setup the power dissipated in the sample is obtained directly by multiplying the in-phase voltage by the ac magnet current, and the loss per cycle is then determined as:

$$Q_{loss} = \frac{U_{loss} I_{mag}}{f} \quad (1)$$

We analyzed the results in terms of the complex ac magnetic susceptibility. Its imaginary part, χ'', is linked to the volume density of the loss, q_{loss}, as [22]:

$$q_{loss} = \pi \chi'' \frac{B_a^2}{\mu_0} \quad (2)$$

where $\mu_0 = 4\pi.10^{-7}\,\mathrm{H\,m^{-1}}$. For the sample of length L and cross-section S the conversion of the measured total loss generated in the sample, $Q_{loss,}$ to the loss density is obtained as

$$q_{loss} = \frac{Q_{loss}}{LS} \quad (3)$$

Then with the help of equations (1)–(3) the imaginary part of the magnetic susceptibility is expressed as

$$\chi'' = \frac{\mu_0 U_{loss} I_{mag}}{\pi f L S B_a^2} \quad (4)$$

The real part of the magnetic susceptibility, χ', is obtained by an analogous formula [23] utilizing the inductive voltage U_{ind} in place of the loss one U_{loss}:

$$\chi' = \frac{\mu_0 U_{ind} I_{mag}}{\pi f L S B_a^2} \quad (5)$$

The advantage of using the complex susceptibility parts instead of the 'loss function' is that for some regular shapes, the absolute values of the susceptibility are predictable. In this paper, the cross-sectional area was calculated using the physical width and thickness of the tape, including the non-superconducting parts (4 mm × 0.1 mm). The reason is that we do not know the exact thickness of the superconducting layer itself. The same numbers were also used for the striated tapes, neglecting the fact that they include less superconducting material. Both parts of the complex susceptibility measured at a frequency of 130 Hz are shown in figure 5 for samples with different filament counts.

A superconductor expels magnetic field from its volume and its close environment. Therefore the real part of the susceptibility is always negative. The highest negative values are at low fields, where the applied magnetic field penetrates only a small part of the superconductor at its edges. The most effective in shielding magnetic field was the original tape. A simple theoretical model [24] for it provided a low-field susceptibility around −31.6. The shielding observed in our experiments with the original tape was slightly weaker; χ' is lower than predicted. This might be caused by a lower critical current density at the edges of the tape [25, 26]. The tape with cut edges had an even lower shielding capability, which has

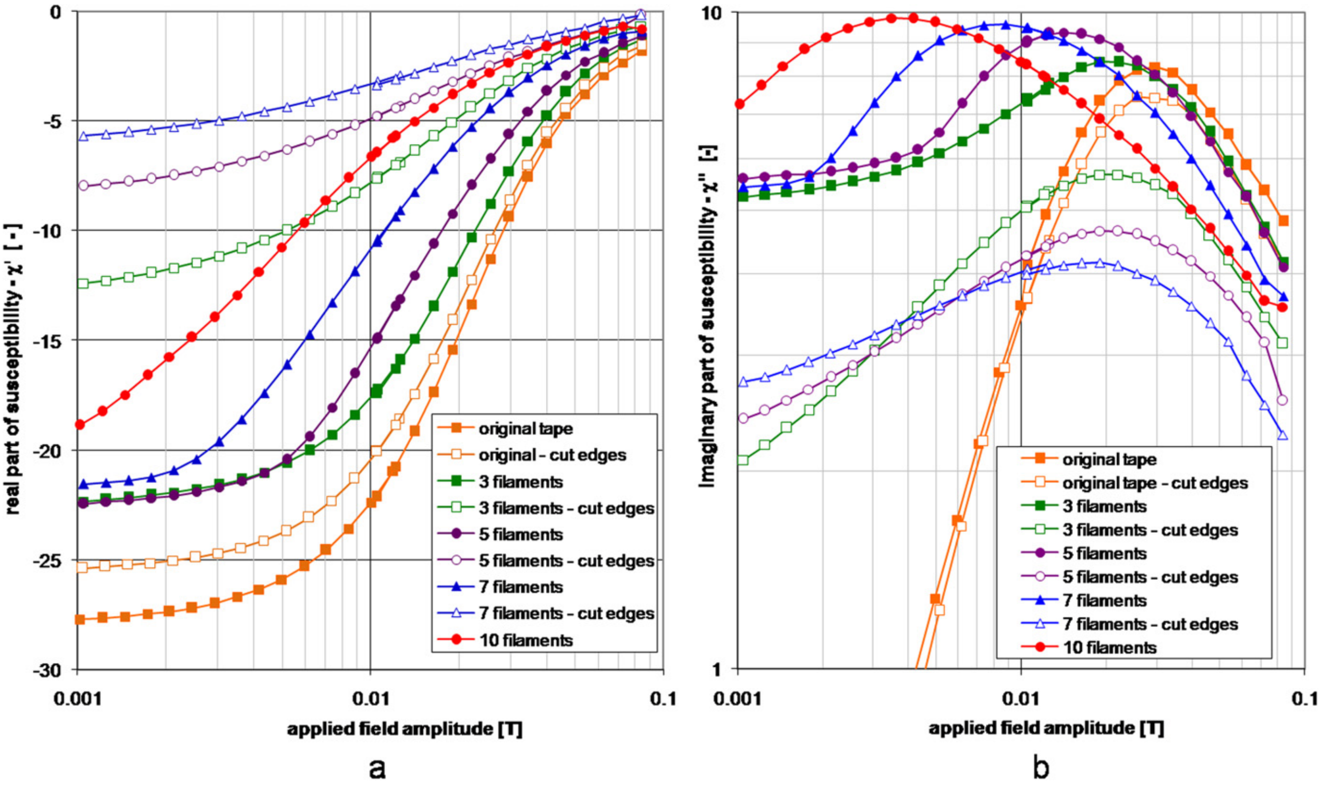

Figure 5. Complex susceptibility parts (a—real part, b—imaginary part) for single CC tapes with different numbers of filaments, with and without tape edges. The measurements were performed at a frequency of 130 Hz.

two causes. First, it is slightly narrower, because the laser cut to remove the copper edges also removed a small part of the superconductor. Second, the edges of the tape are affected by the high temperature during laser cutting.

Samples with 3 and 5 filaments that included copper at the edges had almost the same χ' at low fields. At these fields the coupling currents were flowing in the outer part of the outermost filaments and thus it did not depend on how many filaments the sample contained. At a field amplitude of about 5 mT, the coupling current saturated the outer filaments of the sample with 5 filaments and shielding was no longer as effective as in the case of the sample with 3 filaments. The same behavior was observed in the sample with 7 filaments at a field amplitude of about 2 mT, and in the sample with 10 filaments at a field amplitude of less than 1 mT (outside of the measured range).

The coupling currents were significantly reduced in the case of the tapes with cut edges, because the coupling current could not flow through the highly conductive copper on the bottom side of the tape (see figure 2(d)). The magnetic field could easily penetrate into the gaps between the filaments. As a result, the applied magnetic field was less disturbed by the presence of the sample. The higher number of filaments meant more gaps in the same space occupied by the superconductor, therefore χ' decreased with increasing number of filaments. This is in qualitative agreement with the low-field χ' calculated using an analytical model of infinite x-arrays [24]. This model results in χ' being equal to -18.8, -10.96 and –7.4 for samples with 3, 5 and 7 filaments, respectively.

The loss in the sample without filaments and with cut edges was slightly lower than the loss in the original tape because the tape was slightly narrower and also the critical current density was slightly reduced at the edges. This can be seen from the imaginary part of the susceptibility χ'' in figure 5(b). In the striated samples with cut edges, the losses were higher at low applied fields. This is caused by the penetration of the applied field into all filaments. The magnetic field penetrated into a larger volume of the superconductor, while in the original tape a high fraction of the superconductor was shielded from the magnetic field. However, at high magnetic fields, tapes with filaments had a loss lower than the original tape.

Losses in samples with copper on the edges were much higher than in samples with cut edges. At low applied fields, χ'' was almost constant in samples with copper edges. In this range of fields, the coupling loss, which increased with the square of the applied field, dominated. At higher amplitudes, the magnetic field penetrated a higher fraction of the superconducting material and also the hysteretic loss started to play a role.

The effect of the filaments on loss reduction is visible in figure 6. The ratio of the loss measured on processed tapes over the loss of the original tape is shown. At low amplitudes, the losses in samples with filaments were much higher than in the original tape; losses were reduced (ratio is lower than 1) only at high amplitudes. Ideally, this ratio at high fields should be constant and equal to 1/the number of filaments, e.g. the ratio should decrease to a value of 0.143 for a sample

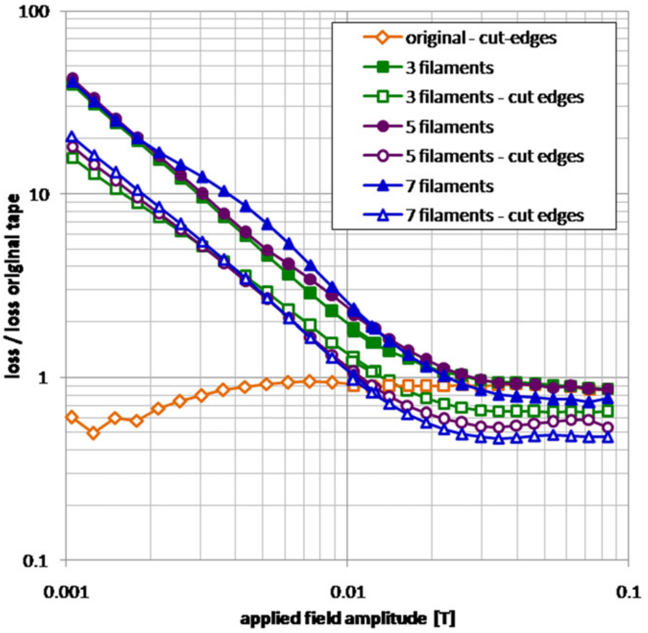

Figure 6. Effect of filaments on the magnetization ac loss measured at a frequency of 130 Hz. Samples with different numbers of filaments with and without copper on the edges are included.

with 7 filaments. The measured value does not reach this number due to the non-negligible coupling loss. The conclusion is that cutting the superconducting layer into filaments increases the loss at low ac field amplitudes but reduces it at large amplitudes.

4. CORC® cables with striated tapes

We prepared 6 different CORC® cables. Three reference cables with 6 tapes wound in 2 layers (sample R1), 9 tapes wound in 3 layers (sample R2) and 12 tapes wound in 4 layers (sample R3) were assembled. Every second layer was wound in the opposite direction. The same layer architecture was used for three additional cables where tapes with filaments were used. These samples were labeled as S1, S2 and S3. Tapes were wound on the former with an angle of about 45 degrees, which resulted in a twist pitch of about 18 mm.

Taking into account the results described in section 3, tapes with 5 filaments and with cut copper edges were chosen for the CORC® cable construction. The number of 5 filaments is a compromise between ac loss reduction and degradation of the critical current. In the cases of 7 and 10 filaments, reduction in I_C is too high, which would lead to a low I_C of the cable with such tapes. Coupling losses are too high in samples with copper at the edges, therefore we chose tapes with cut edges. Edges were cut in the reference samples, as well as in those with filaments.

Tapes with lengths of 32 cm were used to assemble the cables. The critical current of each piece was measured before further processing by edge cutting or edge and filament cutting, and after laser processing. All cables used a flexible polyethylene tube as a former and brass current leads. The

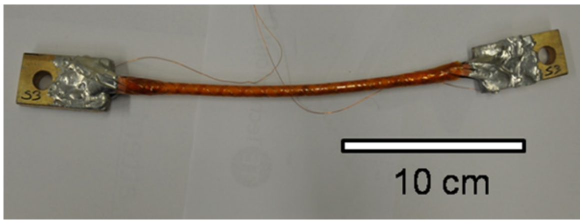

Figure 7. Assembled CORC® cable (S3) with current leads. All cables were 21 cm long, the diameter of the former was 5.5 mm. The outer surface of the cables was insulated using Kapton tape.

brass current leads were chosen to increase the contact resistance, potentially lowering the coupling currents between the tapes. The shape of the terminals did result in some local damage to the striated tapes of the cables. Cables were assembled at Advanced Conductor Technologies; experiments were performed at Karlsruhe Institute of Technology and at the Institute of Electrical Engineering. Cable S3 with current leads is shown in figure 7 as an example of the cable layout.

The current–voltage characteristics of each cable were measured using a dc current. We found that the current did not distribute into individual tapes evenly because of the shape of the terminals, and we could not accurately determine the critical current from the measured curves. The measured voltage reached the criterion for I_C estimation at very low currents (below 100 A), even though the middle parts of the individual tapes did not show degradation. Such behavior can be explained by uneven contact resistances between current terminations and individual tapes. This topic was recently discussed by Willering *et al* [21] and highlights the importance of the termination layout of the HTS cables. To have an idea about the I_C of the prepared cables we summed up the I_C values of all tapes used in a particular cable. The critical currents of single tapes were measured after laser processing and before cabling. An overview of the estimated critical currents is shown in table 1.

After transport measurements, the current leads were cut off using a wire saw. The central part with a length of 125 mm was cut from each cable; this part contained about 7 twist pitches. The magnetization ac losses were measured by the calibration free method and analyzed in the same way as in the case of single tapes—see section 3.2. For the cross-section S in equations (4) and (5) we used the total cross-section area of the particular cable (including the central hole in the former). Figure 8 shows the results of the magnetization ac loss measurements—both parts of the complex susceptibility for all 6 cables.

Reference cables R1–R3 shielded the entire cross-sectional area and thus changed the magnetic flux density in a large space. With increasing number of layers, the shielding improved, as can be seen from the behavior of the real part of the susceptibility, χ', at low fields. For the cable with 4 layers of tapes it has nearly reached -2, which is the theoretical value for a continuous superconducting tube [23]. On the other hand, χ' was significantly lower for cables made of striated tapes, because they allowed the magnetic flux to

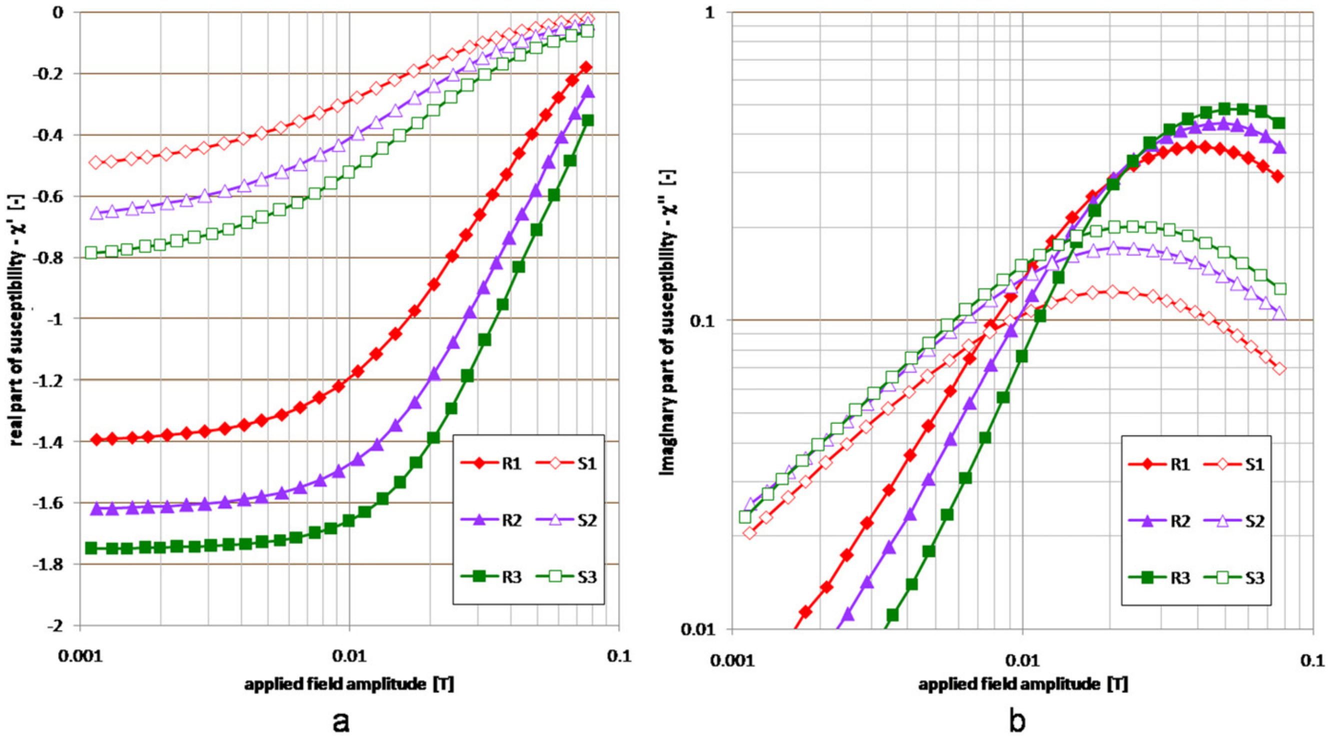

Figure 8. Parts of the complex magnetic susceptibility for CORC® cables with filaments (open symbols) and without filaments (full symbols). Measurements were performed at a frequency of 130 Hz. a—real part of the susceptibility, b—imaginary part of the susceptibility.

Table 1. Predicted critical current of the prepared CORC® cables.

	Reference cables (tapes with cut edges)		Striated cables (tapes with 5 filaments and cut edges)	
Cable architecture	Sample	Sum of tapes I_C [A]	Sample	Sum of tapes I_C [A]
6 tapes in 2 layers (3 × 2)	R1	608	S1	349
9 tapes in 3 layers (3 × 3)	R2	904	S2	542
12 tapes in 4 layers (3 × 4)	R3	1228	S3	768

partially penetrate into the cable volume. The value of χ' is roughly three times lower for the cable made of the striated tapes than for the corresponding reference cable. It is not surprising that the absolute value of χ' was much smaller in the case of round cables than in the case of a single tape—see figure 5(a). The reason is the different shape of the sample, which means a different demagnetizing factor, *N*. In the case of superconductors, it is more usual to use the so-called external susceptibility, χ_0, instead of the demagnetizing factor. Their relation is expressed by the equation:

$$\chi_0 = \frac{1}{1 - N} \tag{6}$$

The cross-section of a CORC® cable is similar to a round tube with $\chi_0 = 2$. The cross-section of a single tape is similar to that of a rectangular strip in a perpendicular magnetic field, where χ_0 is approximately equal to 0.79 times the aspect ratio. Taking into account the cross-sectional area of the entire tape, we find $\chi_0 = 31.6$ [24]. It means that in the case of the cable perfectly shielding its interior, the absolute value of χ' should be almost 16 times smaller than χ' of a standard *RE*BCO CC.

Figure 8(b) shows the imaginary part of the susceptibility. Cable R3, with the highest number of layers, had the lowest loss at low field amplitudes. In this cable, the outermost layer shielded the magnetic field and thus the losses in the inner layers were lower. For the same reason, the horizontal position of the susceptibility peak, related to the field of full penetration, was shifted to higher field amplitudes—about 55 mT. Cables R2 and R1 have fewer layers of superconductor, therefore the magnetic field fully penetrates the cable at lower applied field and the susceptibility peak is at about 50 mT and 40 mT respectively.

As it is indicated by χ' shown in figure 8(a), cables from striated tapes allow penetration of the magnetic field into their interior. Similar to the case of a single tape, the loss in cables wound from striated tapes was higher at low amplitudes, because the magnetic flux penetrated a larger volume of the superconductor. Individual filaments are fully penetrated by the magnetic field at lower field amplitudes. Therefore, the peak of χ'' is shifted to fields about two times lower than it is in the case of the reference cables. As a

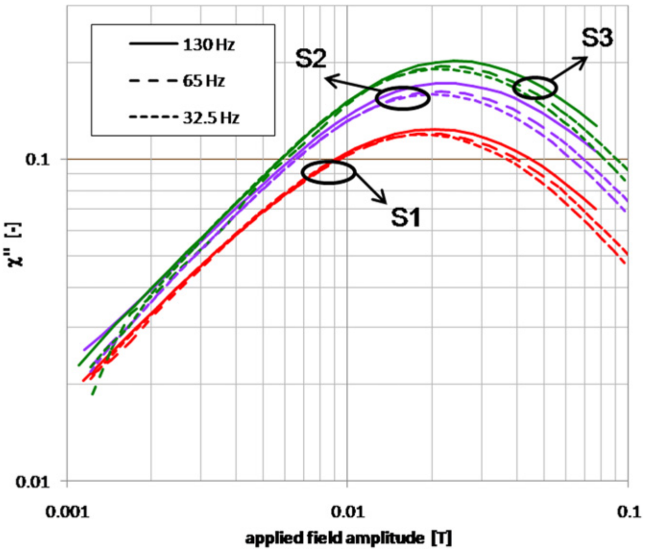

Figure 9. Loss component of the susceptibility measured at three frequencies—32.5, 65 and 130 Hz. The small frequency dependence at high fields shows the presence of a small coupling current.

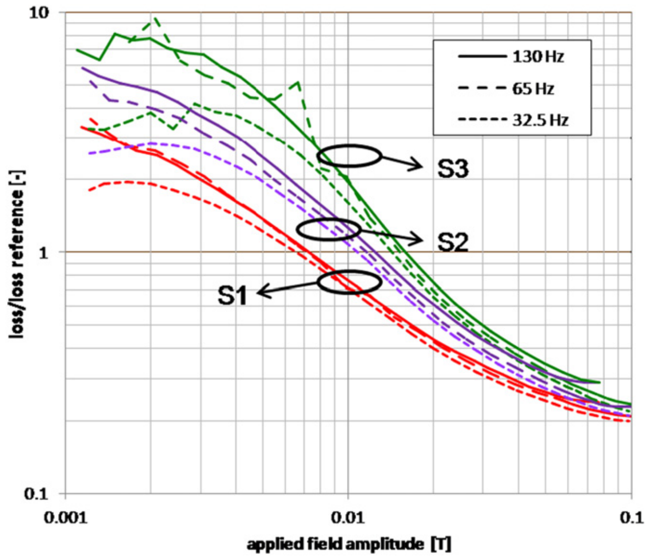

Figure 10. Effect of striation on the magnetization ac loss measured at three frequencies. Loss at high amplitudes and low frequency almost reaches the theoretical loss reduction of 0.2 times the loss of the reference sample.

consequence, the loss was significantly reduced in cables wound from striated tapes in comparison to the reference cables at high field amplitudes. The crossover point is between 8 mT (for the cable with 2 layers) and 15 mT (for the cable with 4 layers). In applications where the cable is exposed to a field higher than this value, it is, from a magnetization ac loss point of view, advantageous to use cables from striated tapes.

The level of coupling loss in the cables wound from striated tapes can be estimated from the frequency dependence of the loss, as shown in figure 9. Losses in the cables were measured at three frequencies: 32.5, 65 and 130 Hz. The contribution of the coupling loss to the total loss was small. This results from the relatively short twist pitch of the tapes in the cable. Note that in comparison to single tapes that are not twisted, the level of coupling loss in CORC® cables does not depend on the sample length, because the coupling loss in the twisted cable is determined by the length of the twist pitch.

To assess the effectivity of the cable loss reduction through striation, we divided the loss of the cable wound from striated tapes by the loss of the corresponding reference cable. The reduction of the loss visualized in this representation is shown in figure 10.

The experimental values at high amplitudes and low frequency almost reach the theoretical loss reduction of 0.2 times the loss of the reference cable. Losses are significantly reduced also in cables with higher numbers of layers, because striated tapes allow for penetration of the field into the inner layers.

5. Conclusions

In this work we tested an HTS cable design for large magnet applications, where the requirements for the conductor are: high current, low ac loss and good stabilization. To fulfil all these requirements we studied CORC® cables made from 4 mm wide *RE*BCO CCs. The conductors were stabilized by 20 μm thick copper plating and filaments were made by laser scribing.

We analyzed in detail the properties of stabilized tapes with laser structured superconducting layers. The critical current of such tapes decreases with increasing number of filaments. The current carrying capability of 4 mm wide tapes with 10 filaments was reduced to less than 40% of its original value. To prevent coupling of edge filaments via the stabilizing layer on the opposite surface of the tape, we proposed to cut the stabilization at the edges of the tape using a laser. Measurements of magnetization ac loss proved that this modification significantly reduced the coupling loss. Samples with 3, 5 and 7 filaments and with cut edges showed a reduction of the magnetization ac loss of between 30 and 50% in comparison to the reference sample at high fields.

As a compromise between critical current degradation and reduction of ac loss we chose tapes with 5 filaments and cut copper at the edges for the construction of CORC® cables. From such tapes we prepared CORC® cables with 2, 3 and 4 layers, with 3 tapes in each layer. Comparison of the measured magnetization ac loss of CORC® cables wound from striated tapes and the reference cables demonstrated a clear reduction of the ac loss at high field amplitudes. In addition, the coupling currents in the tapes were drastically reduced due to the short twist pitch of the CORC® cable. This study has demonstrated the possibility to reduce the ac loss at magnetic fields higher than the field of full penetration by a factor of almost 5 in CORC® cables wound from tapes containing 5 filaments.

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