Achievement of 26.5 T at 1.8 K and 24.0 T at 4.4 K in a Free Bore of 68-mm Diameter: Successful Commissioning of the HOMER II LTS/HTS High-Field Facility Upgrade

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***Abstract*—As an upgrade for higher fields, a REBCO high-temperature superconductor (HTS) insert coil with a remarkable cold bore of 68-mm diameter has been constructed with the goal to be routinely operated to attain total fields of 25 T and beyond in HOMER II. HOMER II is the most advanced superconducting high-field facility of the Institute for Technical Physics at the Karlsruhe Institute of Technology. With its basic magnet configuration, consisting of NbTi and $(NbX)_3Sn$ low-temperature superconductor solenoid sections, HOMER II can generate a magnetic field of 20 T in a large bore of 185-mm diameter at a Helium bath temperature of 1.8 K. The REBCO HTS insert coil was manufactured using the rarely implemented concept of layer winding technology and consists of five nested solenoids. In this article, we report on the design of the insert, its construction, and commissioning as well as related aspects. In the initial operation period, magnetic fields of up to 26.5 T were obtained at 1.8 K and 24.0 T at 4.4 K, respectively, without training steps and quenching or other problems.**

***Index Terms*—High-field magnets, high-temperature superconductors, insert coils, layer wound coils, superconducting magnets.**

I. Introduction

MAGNETS were and still are the dominant application of superconductors. The latest milestone in the development of high-field all-superconducting magnets is—in our opinion—the introduction of insert coils made of high-temperature superconductors (HTS) in *user* or even *commercial high-field facilities*. In 2017, the previous world record of 32 T was reached at the National High Magnetic Field Laboratory, Florida, by a user magnet with a cold bore of 32-mm diameter and an HTS field contribution of 17 T [1]. Comparably outstanding in 2019 was the market launch of the 1100-MHz and 1200-MHz high-resolution NMR spectrometers by BRUKER BioSpin. These systems, which are the result of a joint magnet development between our laboratory and BRUKER, produce by means of HTS insert coils 25.8 T and 28.2 T in a warm bore of 54-mm diameter [2]. Further recent highlights in the development of all-superconducting high-field magnets—including demonstrators—can be found in [3]–[6].

In addition to the cooperation with BRUKER, the high-field laboratory (HFL) of the Institute for Technical Physics at Karlsruhe Institute of Technology (KIT) concentrates on superconducting magnet technology development as well as the operation and advancement of the existing superconducting high-field facilities JUMBO, HOMER I, and HOMER II [7].

II. HOMER II—Past Efforts to HTS Insert Upgrade

The most advanced superconducting high-field facility of the HFL is HOMER II. Its basic magnet configuration consists of two NbTi sections and three inner sections made of $(NbX)_3Sn$ with $X =$ Ta, Ti. At a Helium bath temperature of 1.8 K, a magnetic field of 20 T is provided in a large bore of 185 mm [8], [9]. The intention was always to upgrade HOMER II to (at least) 25 T in a bore of (at least) 50 mm for routine high field in house investigations and measurements. Even before its commissioning in 2006, a first approach for an HTS-upgrade of HOMER II was tried. After characterization of commercial 1G HTS [10]–[13], a stack of 16 double pancakes made of reinforced Bi2223 tape was manufactured and tested in HOMER I. With 5.4 T, the insert surpassed its design field of 5 T, but was destroyed during warming up due to the penetration of superfluid Helium (He II) into the voids of the Bi2223 filaments causing ballooning of the tape [14], [15]. After this setback in 2004, it took almost a decade and the transition from 1G to 2G REBCO HTS to find an appropriate wire for a second upgrade approach.

III. HOMER II—2G HTS Layer Wound Insert

A. Fujikura FYSC-SC05 2G HTS

Parallel to the continuous development of 2G-coated conductor HTS by an increasing number of manufacturers, (nearly) all commercially available tapes were (and are) investigated

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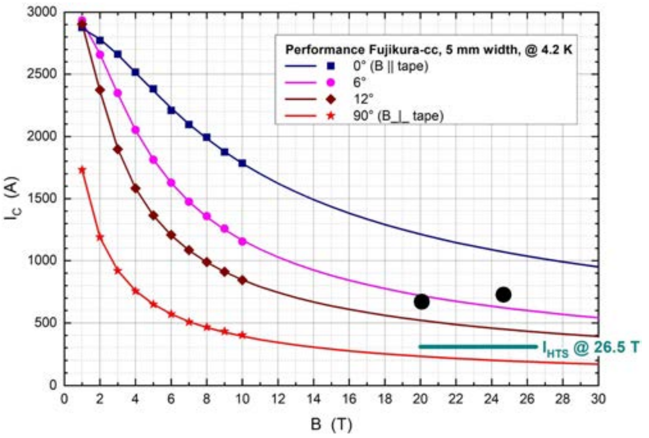

Fig. 1. Angle-dependent critical current of the 5-mm width Fujikura FYSC-SC05 tape at 4.2 K. The measured data up to 10 T were extrapolated to high field. The field angle is defined as angle between magnetic field vector and tape surface. The details given at higher field are discussed later in the article.

Fig. 2. Photomicrograph (cross section) of Fujikura 2G-HTS FYSC-SC05 used for the insert coil (here without insulation). The 5.0-mm-wide and 0.22-mm-thick wire consists of a 100-μm substrate of Hastelloy (bottom), a GdBaCuO-layer of almost 3 μm and 100-μm single-sided Cu lamination as stabilization (top).

in our laboratory in high fields and He bath temperature with regard to the angle dependence of their critical current, $I_C(B, \Phi)$, and n-value, $n(B, \Phi)$. Details of the measurements and a part of the results can be found in [16] and [17]. Due to its—even by today's standards—extraordinary high-field low-temperature performance (see Fig. 1) and excellent properties for high-field use, the "FYSC-SC05" wire made by Fujikura was convincing (see Fig. 1). This 5-mm width wire consists of a 100-μm substrate of Hastelloy, a relatively thick GdBaCuO-layer of almost 3 μm, and a 100-μm single-sided Cu lamination as stabilization (see Fig. 2). Furthermore, intensive investigations revealed that this wire is compatible with He II, and in later batches, the manufacturer solved initial delamination problems. Based on these data, initially an insert design of two series connected nested stacks of double pancakes made of Fujikura 2G HTS was devised as a HOMER II upgrade [18]. During the procurement phase, the long length availability of the wire increased. High-quality pieces of up to almost 500-m length without splices were available, so that a layer wound insert design became feasible [19]. Table I summarizes the main properties of the delivered Fujikura FYSC-SC05 wire procured in 2014. In 2015, Fujikura changed their 2G HTS architecture, so that this wire type is no longer available.

B. Insert Design: Five Nested Layer Wound Sections

Technology development—also with regard to the NMR application—was a main driver to go for a layer wound insert instead of double pancakes. Layer windings consist usually of fewer winding packs, i.e., have less (in case of HTS) normal conducting joints (roughly a factor of 10), resulting in less dissipation and—essential for NMR persistent mode operation—a better temporal stability of the field. On the other hand, layer winding may be more challenging due to the tape form of the wire and required in-plane bending. In addition, longer piece lengths are needed, raising the conductor costs as the price per meter for long pieces is usually considerable higher. To test the feasibility and reliability of our winding concept, a prototype layer wound section using one of the delivered Fujikura 2G HTS pieces was manufactured and tested intensively in high fields and He II bath. With a maximum hoop stress of 476 MPa during operation, the tests were successful without any quench or degradation [19].

TABLE I
SPECIFICATIONS OF FUJIKURA 2G-HTS USED FOR INSERT COIL

Subject	Details / Specifications
Manufacturer	Fujikura Ltd., Japan
HTS type	FYSC-SC05 2G coated conductor HTS manufactured in 2014
Production process	IBAD and PLD
Procurement	2380 m in 9 pieces w/o splices (160 m ≤ piece length ≤ 460 m)
Tape width	5.0 mm w/o insulation, ≤ 5.25 mm insulated
Tape thickness	0.22 mm w/o insulation, ≤ 0.29 mm insulated
Insulation	polyimide tape, 12.5 µm thick, half-overlapping wound
Substrate	100 µm Hastelloy
Superconductor layer	2.4 µm – 2.9 µm GdBaCuO (variation over the pieces)
Stabilisation	100 µm single-sided Cu lamination
I_c @ 1 µV/cm, 77 K, self field	minimum 255 A – 352 A (variation over the pieces)

Based on this experience and the procured piece lengths, a design of five nested electrically series connected sections was engineered, as shown in Table II and Fig. 3. The four innermost sections H01 to H04 consist of one HTS length each, whereas for the outermost section, H05, two pieces—connected by a copper terminal—were used. This connection method had already been implemented for test purposes in the prototype section. For quench detection, on the outer diameter (OD) of each section, a single layer of enameled copper wire was wound. The complete insert has a free bore of 68 mm, an OD of 183.6 mm, and consists of almost 1.6-km wire. The operating current for 6.5-T field contribution is 308.5 A with an average current density in the winding packs of 233 A/mm^2 (not including area between windings). More details of the insert can be found in Table III.

In the design, no additional reinforcement is implemented. Therefore, the strain of the superconducting tape caused by the Lorentz force is given by its stress–strain relationship. With Young's modulus of about 119 GPa measured at 77 K [20], a maximum strain of approximately 0.40% is reached at the outer winding radius of the insert coil at 26.5 T. In contrast, the maximum bending strain occurs at the innermost layer with a value of approximately ±0.30% at the tape surfaces. For the superconducting layer located in the neutral fiber of the tape,

TABLE II
LAYER WOUND HTS INSERT COIL: PARAMETERS OF THE FIVE NESTED SECTIONS

Parameter	Unit	Section H01	Section H02	Section H03	Section H04	Sub-Section H05-1	Sub-Section H05-2
Inner HTS winding radius	mm	36.5	47.2	57.8	68.4	79.6	82.4
Outer HTS winding radius	mm	41.4	52.0	62.6	73.8	82.4	85.2
Winding height	mm	158.0	184.9	212.2	236.2	265.4	266.6
Number of layers		19	19	19	21	11	11
Number of turns		576.7	673.8	782.7	966.9	567.0	569.6
HTS length (no splices)	m	132.6	199.1	283.3	403.5	265.4	294.3
Insert field contribution	%	19.5	19.1	19.1	20.9	21.6[a]	
Turns of enameled copper wire on OD for quench detection		632	738	844	1141	1035[a]	

[a]Sum of the two subsections H05-1 and H05-02 of the outermost section H05.

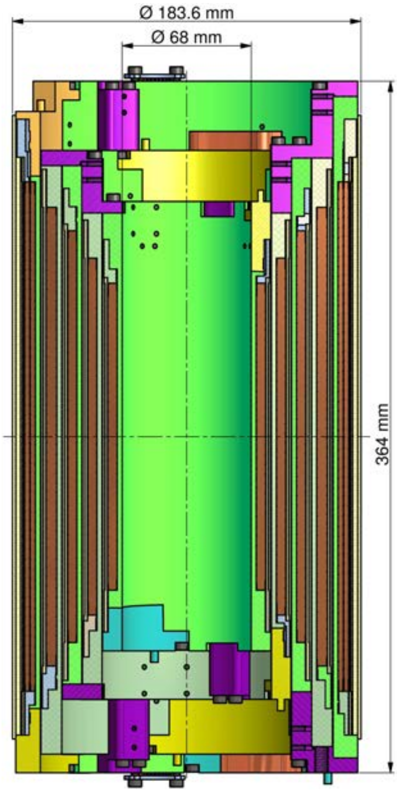

Fig. 3. Cross-sectional drawing of the layer wound insert consisting of five series connected nested layer wound sections with a free bore of 68-mm diameter. For the outermost section, two HTS lengths connected by a Cu terminal were used.

TABLE III
PARAMETERS OF COMPLETE HTS INSERT COIL

Parameter	Unit	
Free bore diameter	mm	Ø 68.0
Outer diameter (OD)	mm	Ø 183.6
Total height	mm	364
Number of turns		4136.7
HTS length	m	1578.2
Inductance	H	0.72
Data for HTS field contribution of 6.5 T		
Operating current	A	308.5
Average winding current density	A/mm^2	233
Stored energy	kJ	34.3
Data for total field of 26.5 T		
Max. hoop stress ($B \times j \times r$)	MPa	510
Max. field angle	°	7.1 @ OD
Calculated inhomogeneity over 1 cm diameter spherical volume (DSV)	ppm	220

Fig. 4. Layer wound sections of 2G HTS insert coil. The four innermost sections are complete while the outermost is being wound.

only the magnetic strain is of relevance. The linear superposition of both strain effects results in a nearly constant total strain of about 0.52% at the outer tape surface, independent of the winding radius.

C. Manufacture of Sections and Assembly of Insert

The individual sections of the insert, as shown in Fig. 4, were engineered and manufactured in-house using the same materials, methods, and techniques that were already qualified with the successfully tested prototype layer, which are as follows.

1) Layer winding of the tape without additional reinforcement on a coil former made of G10. At the transition to the next layer, suitably cut strips of self-adhesive PTFE-coated glass fabric were used as fill material at the coil ends. For current feeding, the beginning and end of the tape are soldered to copper terminals.
2) Vacuum impregnation of the section using wax. Impregnation with epoxy resin involves the risk of delamination of the tape due to strong adhesion between epoxy and tape.
3) Turning down the cylindrical surface.
4) Bandaging using Araldite/Aradur epoxy and glass fabric tape.

Fig. 5. 2G HTS layer wound insert coil attached to HOMER II insert and ready to be mounted and operated.

5) Turning down repeated.
6) Winding of a compensation layer of enameled copper wire on the OD.
7) Bandaging and turning repeated.
8) Assembly of the five sections; electrical connection and instrumentation. The current path across the insert coil is designed in such a way that adjacent sections are connected electrically at the same end to each other, thus avoiding connections running axially along the coil.
9) Mounting of a Hall sensor and a pick-up coil in the center of the insert.

Fig. 5 shows the completed HTS insert coil, attached to the HOMER II insert and ready to be mounted and operated.

D. Electrical Setup, Quench Detection, and Protection

The three magnet subsystems NbTi, $(NbX)_3Sn$, and HTS are run independently using separate electrical circuits, i.e., three current supplies. In case of a quench, all power supplies are disconnected simultaneously using three switchgears. Subsequently, the magnetic energy is dissipated in three dump resistors. The protection circuits are designed in such a way that during a shutdown, no overcurrents occur, so that the excessive hoop stress is avoided. For test purpose, several low-field switch-OFFs were carried out, which confirmed the calculated shutdown behavior.

For quench detection, in-house built analog bridge circuit voltage comparators with adjustable voltage levels and integration times are used. For each of the five low-temperature superconductor (LTS) sections (2× NbTi and 3× $(NbX)_3Sn$), three comparators were applied, one balancing the two halves of the section when ramping the magnet subsystem itself and two balanced for ramping the two other magnet subsystems. It is well known that the quench propagation velocity with regard to HTS is comparatively low (in the order of about 10 cm/s for low-temperature high-current applications [21]), so that a quench is harder to detect by a resistive signal. On the other hand—as discussed later—the HTS insert is operated with a high I_C-margin (ca. 50% I_C), so that no spontaneous quenches are expected. Accordingly, the test of our prototype layer wound HTS section revealed that 2G HTS coils are very stable when operated well below I_C. With this background, the voltage comparator technique was also used for quench detection of the HTS insert. In detail, the five individual HTS sections were balanced against their compensation layers made of enameled copper wire when ramping the HTS insert itself. In addition, the two outermost HTS sections were balanced against the three inner ones for ramping the HTS insert, the NbTi magnet subsystem, and the $(NbX)_3Sn$ part. In total, 23 voltage comparators were utilized. A common shutdown of all magnet current circuits is triggered when all three comparators of a single LTS section or the three comparators of the complete HTS insert release simultaneously.

TABLE IV
INITIAL HIGH FIELD RUNS OF UPGRADED LTS/HTS FACILITY HOMER II

#	Total field	Bath temp.	LTS field	HTS field	HTS current	HTS hoop stress
1	25.1 T	1.8 K	20.0 T	5.1 T	240.4 A	397 MPa
2	26.1 T	1.8 K	20.0 T	6.1 T	289.7 A	479 MPa
3	24.0 T	4.4 K	17.6 T	6.4 T	304.4 A	443 MPa
4	26.5 T	1.8 K	20.0 T	6.5 T	308.5 A	510 MPa

IV. OPERATION OF 2G HTS LAYER WOUND INSERT

In the initial operation period of one week, several high field runs of the upgraded HOMER II facility were carried out (for details, see Table IV). It should be noted that all runs were performed successfully without any training steps, quenching, degradation, or other problems.

1) At first—in accordance with the initial goal—25 T (more precisely 25.1 T) were executed at a He II bath temperature of 1.8 K. For this, the current of each magnet subsystem was increased separately in steps. Due to the occurrence of voltage spikes during ramping the HTS insert, as a precaution, the insert was ramped to its target field contribution of 5.1 T before the highly inductive NbTi magnet subsystem was finally brought to full field. Regardless of this precaution, these spikes, which can presumably attributed to flux jumps, are nevertheless too short to trigger the voltage integration of the quench detection system. The aforementioned procedure was retained for all subsequent high-field runs.
2) In the second run, the maximum hoop stress already reached in the prototype HTS section was set as goal. This resulted in a total field of 26.1 T with an HTS contribution of 6.1 T and a hoop stress of 479 MPa in the HTS.
3) In the third, the magnet system was operated in refrigeration mode of the liquefier at 4.4 K. At this temperature, the LTS basic magnet system provided only 17.6 T. With an HTS contribution of 6.4 T, a total field of 24.0 T was

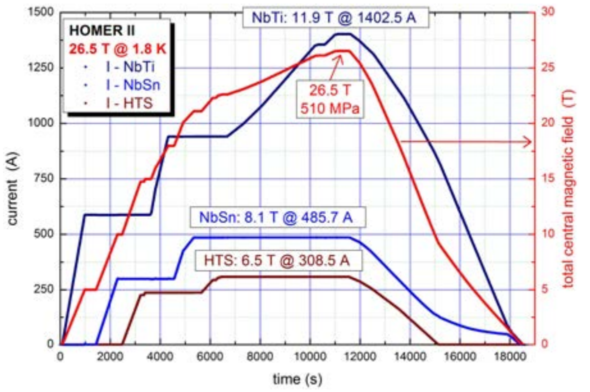

Fig. 6. Stepwise increased currents of the three magnet subsystems NbTi, $(NbX)_3Sn$, and HTS as well as the total magnetic field when ramping up to the maximum field of 26.5 T within 3 h at a Helium bath temperature of 1.8 K. The maximum hoop stress, $B \times j \times r$, occurring in the HTS insert reaches 510 MPa.

reached, showing that a 1-GHz NMR magnet (corresponding to 23.5 T) is feasible *without subcooling* using a layer wound HTS insert.

4) The final goal was to explore the limits of the insert magnet—under the premise that HOMER II with its upgrade is an in-house use facility and not an experimental demonstrator. Regarding the critical current, the radial field components (field angles) at the coil ends are of importance. Fig. 1 shows these data (thick dots) for the innermost (24.6 T at 4.0°) and outermost (20.2 T at 7.1°) HTS section at a total field of 26.5 T. The corresponding critical currents are well above (at least a factor of 2) the operating current of the HTS insert (thick line in Fig. 1). In other words, *the maximum attainable field is force-limited and not by the critical current of the HTS*. With this background, at 1.8-K He II bath temperature, 26.5 T in a free bore of 68-mm diameter were finally achieved, with an HTS field contribution of 6.5 T at 308.5 A and a hoop stress of 510 MPa, as shown in Fig. 6.

It is well known that radial field components penetrating 2G HTS tapes induce shielding currents that may lead to "field errors" [22]. However, during operation, no such systematic deviations between measured and calculated field value and a relaxation of the field were detectable by the Hall sensor located in the coil center beyond the scattering of the measurement data in the range of ±0.1 T. Further investigation is needed to explain this result.

V. Conclusion

With the successful upgrade of the superconducting high-field facility HOMER II by means of a nested layer wound 2G HTS insert, a magnetic field of up to 26.5 T in a bore of 68-mm diameter is available for in-house investigations at KIT. Without subcooling the Helium bath, up to 24.0 T are attainable. As a brief outlook, initial studies show that—based on the present wire quality and applied average current density in the winding—for further upgrades of HOMER II, the following main scenarios could be feasible: First, the extension of the existing insert by two additional layer wound sections resulting in a field of 28.8 T in a bore of 30-mm diameter. Second, if 2G HTS piece lengths of 1 km without splices were available, the construction of a new layer wound insert consisting of three sections, providing 32 T in a bore of 50-mm diameter.

References

[1] NHMFL, "New world-record magnet fulfills superconducting promise," 2017. [Online]. Available: https://nationalmaglab.org/news-events/news/new-world-record-magnet-fulfills-superconducting-promise
[2] BRUKER, "Ascend GHz-class magnet technology," 2019. [Online]. Available: https://www.bruker.com/products/mr/nmr/magnets/ascend.html
[3] S. Awaji *et al.*, "First performance test of a 25 T cryogen-free superconducting magnet," *Supercond. Sci. Technol.,* vol. 30, 2017, Art. no. 065001.
[4] S. Yoon, J. Kim, H. Lee, S. Hahn, and S.-H. Moon, "26 T 35mm all-$GdBa_2Cu_3O_{7-x}$ multi-width no-insulation superconducting magnet," *Supercond. Sci. Technol.,* vol. 29, 2016, Art. no. 04LT04.
[5] Y. Suetomi *et al.*, "30 T generation using an intra-layer no-insulation (LNI) REBCO coil in a 17 T LTS magnet," Fri-Mo-Or27-02 MT26, Oct. 2018.
[6] J. Liu *et al.*, "World record 32.35 Tesla direct-current magnetic field generated with an all-superconducting magnet," *Supercond. Sci. Technol.,* vol. 33, 2020, Art. no. 03LT01.
[7] A. Rimikis, F. Hornung, and T. Schneider, "High field magnet facilities and projects at the Forschungszentrum, Karlsruhe," *IEEE Trans. Appl. Supercond.,* vol. 10, no. 1, pp. 1542–1545, Mar. 2000.
[8] H. Lahn, W. Lehmann, M. Stamm, and M. Süßer, "Cryogenics for the HOMER II-high field magnet-test facility at the Forschungszentrum, Karlsruhe," *AIP Conf. Proc.*, vol. 613, pp. 114–122, 2002.
[9] T. Schneider *et al.*, "Superconducting high field magnet engineering at KIT," *IEEE Trans. Appl. Supercond.,* vol. 20, no. 3, pp. 624–627, Jun. 2010.
[10] F. Hornung, A. Rimikis, R. Kimmich, and T. Schneider, "Investigation of Bi-HTS wires for high field insert coils," *IEEE Trans. Appl. Supercond.,* vol. 11, no. 1, pp. 2304–2307, Mar. 2001.
[11] F. Hornung, M. Kläser, H. Leibrock, H. Müller, and T. Schneider, "Suitability of Bi-HTS wires for high field magnets," *Physica C,* vol. 401, pp. 218–221, 2004.
[12] F. Hornung, M. Kläser, and T. Schneider, "Usage of bi-HTS in high field magnets," *IEEE Trans. Appl. Supercond.,* vol. 14, no. 2, pp. 1102–1105, Jun. 2004.
[13] F. Hornung, A. Rimikis, and T. Schneider, "Current sharing and critical current distribution in Bi-2223 tapes," *IEEE Trans. Appl. Supercond.,* vol. 20, no. 3, pp. 1589–1592, Jun. 2010.
[14] M. Beckenbach, F. Hornung, M. Klaser, P. Leys, B. Lott, and T. Schneider, "Manufacture and test of a 5 T Bi-2223 insert coil," *IEEE Trans. Appl. Supercond.,* vol. 15, no. 2, pp. 1484–1487, Jun. 2005.
[15] F. Hornung, M. Kläser, and T. Schneider, "Degradation of Bi-2223 tape after cooling with superfluid helium," *IEEE Trans. Appl. Supercond.,* vol. 17, no. 2, pp. 3117–3120, Jun. 2007.
[16] P. M. Leys, M. Klaeser, F. Schleissinger, and T. Schneider, "Angle-dependent U(I) measurements of HTS coated conductors," *IEEE Trans. Appl. Supercond.,* vol. 23, no. 3, Jun. 2013, Art. no. 8000604.
[17] P. M. Leys, M. Klaeser, F. Schleissinger, and T. Schneider, "Analysis of the anisotropic critical current behaviour of HTS coated conductors," *J. Phys. Conf. Ser.,* vol. 507, 2014, Art. no. 022013.
[18] T. Schneider, M. Eisele, F. Hornung, M. Klaeser, P. M. Leys, and C. Ruf, "Future upgrade of the superconducting high field facility HOMER II to 25 T," *IEEE Trans. Appl. Supercond.,* vol. 25, no. 3, Jun. 2015, Art. no. 4600704.
[19] F. Hornung, M. Eisele, M. Klaeser, P. Leys, C. Ruf, and T. Schneider, "From double-pancake coils to a layer wound 5 T REBCO-HTS high field insert coil design," *IEEE Trans. Appl. Supercond.,* vol. 27, no. 4, Jun. 2017, Art. no. 4300604.
[20] K. Osamura, S. Machiya, K.-P. Weiss, and G. Nishijima, "Stress-strain relation and tensile stress dependence of critical current of practical REBCO wires," MEM, vol. 16, 2016. [Online]. Available: https://nationalmaglab.org/images/news_events/events/mem/talks/s6_osamura.pdf
[21] J. van Nugteren, M. Dhallé, S. Wessel, E. Krooshoop, A. Nijhuis, and H. ten Kate, "Measurement and analysis of normal zone propagation in a ReBCO coated conductor at temperatures below 50 K," *Phys. Procedia,* vol. 67, pp. 945–951, 2015.
[22] N. Amemiya and K. Akachi, "Magnetic field generated by shielding current in high T_c superconducting coils for NMR magnets," *Supercond. Sci. Technol.,* vol. 21, 2008, Art. no. 095001.

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