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COMMISSIONING OF A NEW MAGNETOMETRIC MAPPING SYSTEM FOR SRF CAVITY PERFORMANCE TESTS*

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Abstract

Magnetic flux trapped in the niobium bulk material of superconducting radio frequency (SRF) cavities degrades their quality factor and the accelerating gradient. The sensitivity for flux trapping is mainly determined by the treatment and the geometry of the cavity as well as the niobium grain size and orientation. To potentially improve the flux expulsion characteristics of SRF cavities and hence the efficiency of future accelerator facilities, further studies of the trapping behavior are essential. For this purpose a magnetometric mapping system to monitor the magnetic flux along the outer cavity surface of 1.3 GHz TESLA-Type single-cell SRF cavities has been developed and is currently in the commissioning phase at DESY. Contrary to similar approaches, this system digitizes the sensor signals already inside of the cryostat to extensively reduce the number of required cable feedthroughs. Furthermore, the signal-to-noise ratio (SNR) and consequently the measuring sensitivity can be enhanced by shorter analog signal lines, less thermal noise and the μ-metal shielding of the cryostat. In this contribution test results gained by a prototype of the mapping system are presented.

INTRODUCTION

Based on the first magnetometric-mapping approach at Helmholtz-Zentrum Berlin (HZB) [1, 2] a system using Anisotropic MagnetoResistive (AMR) sensors of type Sensitec AFF755B [3] has been developed at DESY to study the flux expulsion characteristics of 1.3 GHz TESLA-Type single-cell cavities. A prototype of this system already underwent a successful perfomance test described in [4] to evaluate the system capabilities, detect potential weak spots and find options for improvements. Before the production of the final card sets, the prototype was used again to study the flux expulsion characteristics of the test cavity 1DE9 after three hour ultra high vacuum (UHV) 300 °C mid-T furnace treatment because of the impact on the cavity's sensitivity to trapped magnetic flux S. Here, S is given by:

$$S = \frac{\Delta R_s}{B_{trap}} \tag{1}$$

where ΔR_s depicts the increase of the surface resistance R_s per unit of trapped magnetic flux B_{trap} [5]. Contrary to the in-situ mid-T bake treatment of Fermi National Accelerator Laboratory (FNAL) [6] based on the work of Palmer et al. [7, 8], the by High Energy Accelerator Research Organisation (KEK) introduced and here used modification [5] mid-T furnace baking exposes the inner cavity surface to air after the furnace treatment. Both procedures showed unprecedented high intrinsic quality factors Q_0 of up to $5 \cdot 10^{10}$ at 2 K and quench fields between 20 − 37 MV/m [5, 6, 9]. Furthermore, the anti-Q-slope phenomenon appeared in all tests which is usually observed at cavities treated by nitrogen-doping [5, 6, 9]. Indeed, an increased S was observed at FNAL and KEK [5, 6].

The measurement setup (except the test cavity) used for the studies at DESY and shown in Fig. 1 as well as the sensor calibration procedure and the analog-to-digital converter settings are identical to the former system performance test described in [4].

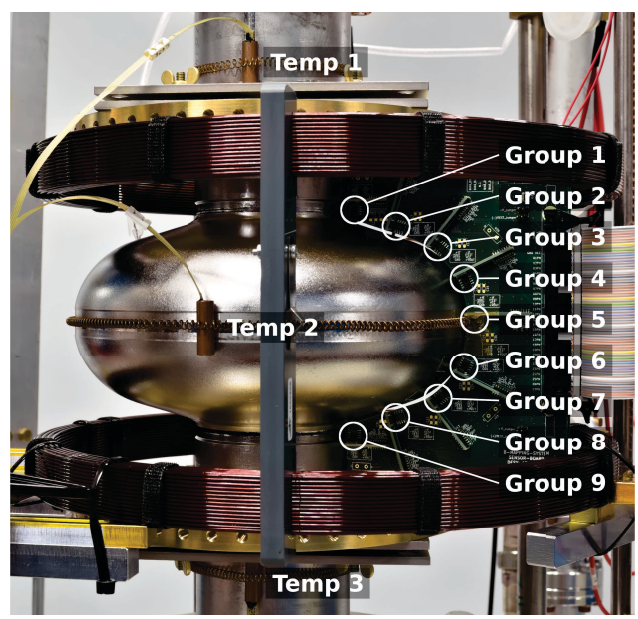

Figure 1: Test setup: Cavity 1DE9 made of fine grain material (after mid-T furnace treatment) equipped with a single sensor board. To monitor the T_c transition at the outer cavity surface three Lake Shore Cryotronics CERNOX CX1030 thermocouples are used. The setup is surrounded by a Helmholtz coil (HC) to apply a defined magnetic flux. Since the HC radius is too small to be centred around the cavity for the given setup, it was mounted with an offset of 29 mm.

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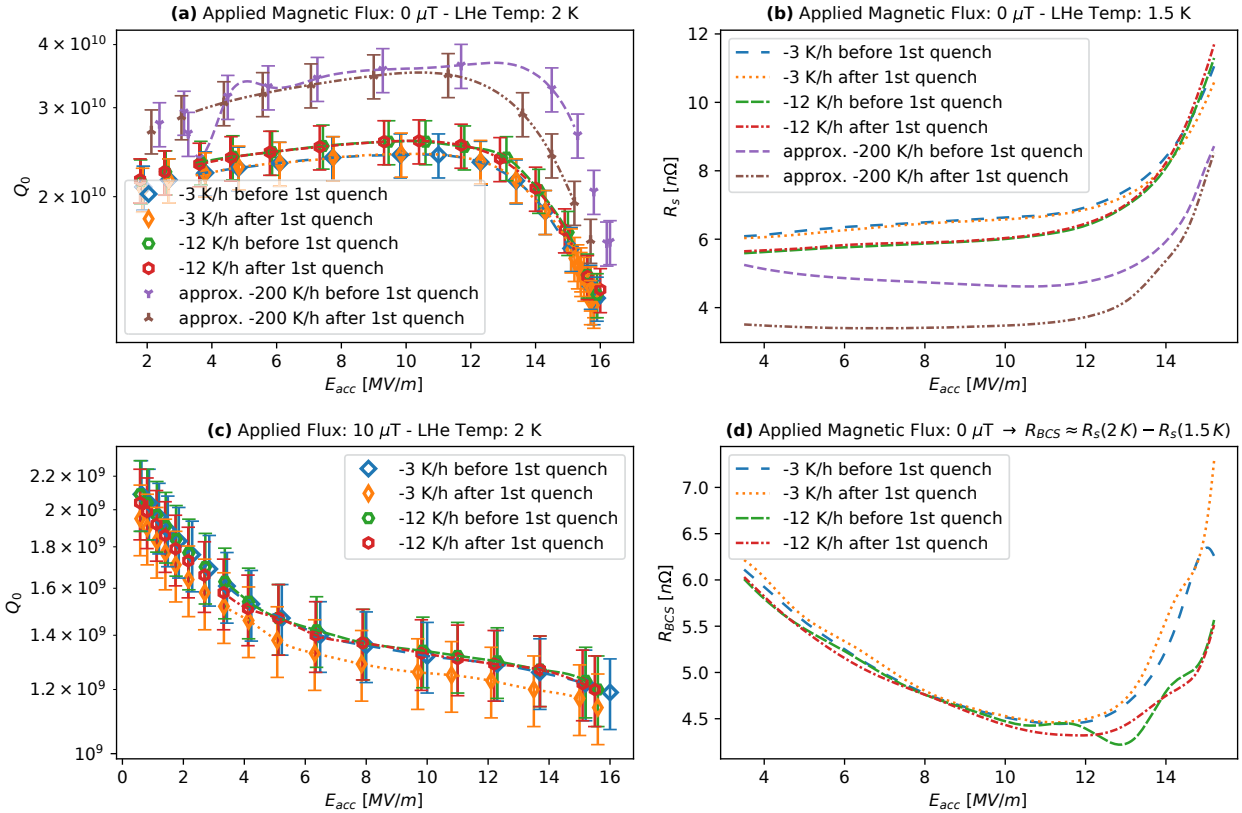

Figure 2: Q_0 vs E_{acc} curves of cavity 1DE9 at 2 K with (b) and without (a) an applied magnetic flux of 10 T. Surface resistance R_s as a function of E_{acc} (c). Bardeen-Cooper-Schrieffer resistance R_{BCS} as a function of E_{acc} (d).

TEST SERIES

To study the impact of the cooldown velocity on the cavity's flux expulsion characteristics a series of cooldowns was performed as follows. Each cooldown was started at a temperature of 15 K at the equator (Temp 2) to ensure, that the complete cavity is above its transition temperature of 9.2 K in the initial state. A fixed cooldown velocity of −3 K/h as well as −12 K/h with respect to Temp 2 was ensured by a control loop for the complete T_c transition of the cavity. For those velocities two cooldowns with an applied flux of 10 T at the coil center as well as without an intentional flux (0 T) were performed each time followed by two Q_0 vs E_{acc} curves of a vertical performance tests at a liquid helium (LHe) bath temperature of 2 K as well as 1.5 K.

RESULTS

Neither for the performance with- nor for the tests without an applied flux by the HC significant differences in the Q_0 vs E_{acc} behavior for the two cooldown velocities could be measured during the test series as shown in Fig. 2(a) and (c). The cavity achieved an average maximum for Q_0 of $2.5 \cdot 10^{10}$ when no flux was applied and reached a quench field of 16 MV/m in all tests of the series. Also minor differences between the Q_0 vs E_{acc} curves recorded before and after each first quench are not significant. Here, a performance reduction would be a hint for additional trapped flux at the quench spot. However, by taking a look at the sensor group (positions marked in Fig. 1) readings shown in Fig. 3 a slightly but significantly better flux expulsion for the larger cooldown velocity of −12 K/h can be observed for all sensor groups except Group 4 by comparing the normalized sensor group readings for the two cooldown velocities in the superconducting state.

The required extrema to derive the percentage of flux expelled from the cavity cell (flux completely trapped and flux completely expelled) were obtained by a SIMULIA CST Studio Suite model. This model is considering the coil dimensions, the coil's center point offset and the distance of the equator sensor group (Group 5) to the cavity surface. During the slower cooldown with a velocity of −3 K/h about 97 % of the flux was trapped in the cavity cell and 94 % in case of the faster cooldown velocity of −12 K/h. Since the flux trapping is already almost in saturation at the larger cooldown velocity this is likely the reason for the similar Q_0 vs E_{acc} performance independent of the cooldown velocity in the chosen range and the curve order (before or after the first quench). This conclusion gets supported by the better Q_0 vs E_{acc} curves also shown in Fig. 2(a) recorded directly before the test series after the usual extensively larger cooldown velocity of approximately −200 K/h. Here, a maximum for Q_0 of $3.6 \cdot 10^{10}$ was measured with just a minor change of the quench field and a significant performance reduction could be measured for the curve recorded after the first quench of the cavity.

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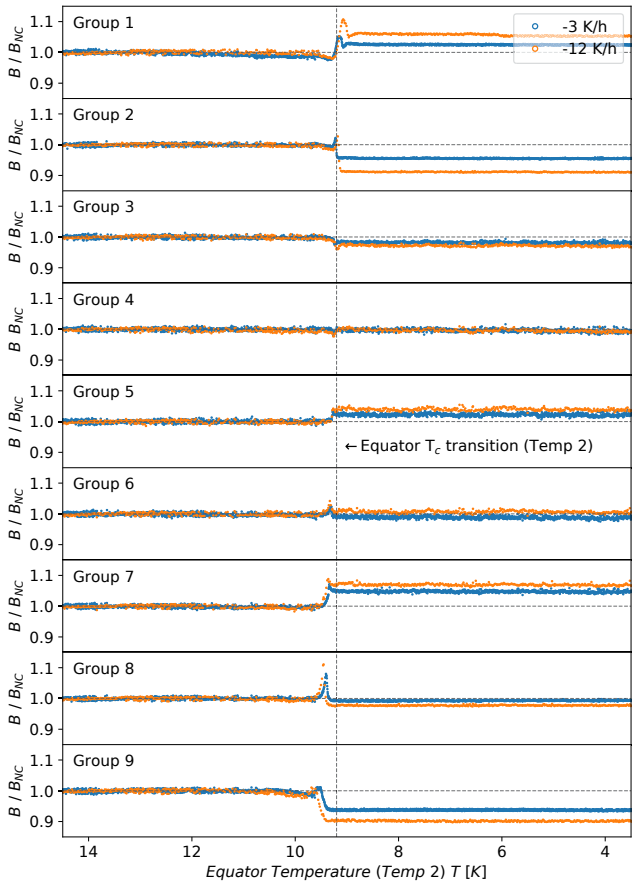

Figure 3: Normalized sensor group readings B as a function of the temperature. The readings are normalized by the averaged magnetic flux before the T_c transition B_{NC}. To minimize the stray impact by a partially superconducting cavity the recorded samples in the range from 14.5 K down to 12.0 K were used. A flux of 10 T was applied to improve the SNR and to operate the system in a defined environment.

Analog to the mid-T bake studies at FNAL [6] a decrease of the Baardeen-Cooper-Schieffer resistance R_{BCS} as a function of E_{acc} was observed in the range up to 11 MV/m. This decrease of R_{BCS} originates the anti-Q-slope behavior during all tests without an applied flux [6]. Here R_{BCS} was approximated by substracting R_s at 2 K from the surface resistance at 1.5 K. For both temperatures R_s was obtained from the Q_0 and the geometric factor G given by the cavity design by:

$$R_s = \frac{G}{Q_0} \tag{2}$$

under the general assumption of a homogeneous distribution of R_s. Due to an inhomogeneous flux applied by the for the application comparatively small HC and the HC's center point offset, S is not given for cavity comprehensive performance comparisons.

Since the cavity only reached a quench field of 16 MV/m and field emission was identified above 15 MV/m it was high pressure rinsed after the test series and showed an increased quench field of 24 MV/m with no field emission as well as a significantly enhanced Q_0 of 4.7 MV/m during a retest.

SYSTEM REVISION

To enable an active flux cancellation under the assumption of a homogeneous stray flux, a set of three Helmholtz coils with an extended inner diameter of 550 mm allowing a symmetrical assembly to the cavity will be used to cancel the magnetic flux of each spatial axis. After the here analyzed test series, the sensor boards underwent a revision to improve the accuracy of the relative sensor calibration. Before, the sensor housing included test coils used to induce a magnetic reference flux for calibration were all connected in series. Consequently, a test current driven to the series lead to an altered flux through sensors in vicinity and an unnecessary loss of calibration accuracy. To reduce this stray impact, the coil series has been separated into three independent and alternating driven lines for each spatial axis in the new board design.

CONCLUSION

A new approach of a magnetometric mapping system to enable high resolution spatial magnetic flux measurements along the outer surface of 1.3 GHz TESLA-Type cavities has been developed at DESY. After a first successful performance test [4], a prototype card set of the system was used to study the flux expulsion characteristics of the test cavity 1DE9 after three hour UHV 300 °C furnace treatment (mid-T furnace bake [5]) in dependence of the cooldown velocity. Independent of the chosen cooldown velocity no significant impact on the Q_0 vs E_{acc} performance could be measured in the range from −3 K/h to −12 K/h. Also no performance reduction could be observed for the Q_0 vs E_{acc} curve recorded after the first quench. Indeed, it could be shown, that already for the larger used cooldown velocity (−12 K/h) 94 % of the flux was not expelled from the cavity cell and 97 % in case of the lower cooldown velocity. Consequently, the cavity was already almost saturated at the larger velocity which is the reason for the described Q_0 vs E_{acc} performance. Analog to former studies at FNAL and KEK, during all tests without an applied flux the anti-Q-slope phenomenon caused by a decreasing Bardeen-Cooper-Schieffer resistance was observed.

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