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DESIGN AND FABRICATION OF A QUADRUPOLE RESONATOR FOR SAMPLE R&D

R. Monroy-Villa* [1,2], W. Hillert[2], S. Keckert[3], O. Kugeler[3], P. Putek[4], D. Reschke[2], D. Tikhonov[3], U. van Rienen[4,5], M. Wenscat[1,2], S. Zadeh[4],
[1]Institute for Experimental Physics, Universität Hamburg, Hamburg, Germany
[2]Deutsches Elektronen-Synchrotron, Hamburg, Germany
[3]Helmholtz-Zentrum Berlin, Berlin, Germany
[4]Institute of General Electrical Engineering, Universität Rostock, Rostock, Germany
[5]Department Life, Light & Matter, Universität Rostock, Rostock, Germany

Abstract

Being able to obtain BCS surface resistance and material properties from the same surface is necessary to gain a fundamental understanding of the evolution of SRF surfaces. A test resonator which will allow to obtain BCS properties from samples is currently under development at Universität Hamburg (UHH) and DESY and is based on the Quadrupole Resonators developed and operated at CERN [1] and HZB [2]. The current status of the necessary infrastructure, the procurement process and design considerations are shown. In addition, an outline of the planned R&D project with the Quadrupole Resonator will be presented and first RF measurements and surface analysis results of samples will be shown.

INTRODUCTION

Modern accelerator facilities study the performance of superconducting radio frequency (SRF) niobium cavities in vertical test stands which allows for the understanding of radio frequency properties, i.e. the accelerating field, the quality factor or the peak magnetic and electric fields. Moreover, new surface treatments techniques such as nitrogen-doping, thin-film deposition or nitrogen-infusion have been developed to further reduce the surface losses and the operational cost of SRF cavities.

Samples of superconducting materials are studied in a different approach that aims for the understanding of the atomic composition of the lattice. Information about the mean free path, surface resistance or the London penetration depth can be obtained, but no radio frequency properties. Additionally, these samples are usually cheaper, easier to handle and can also be treated to form different materials, e.g. Nb_3Sn [3] and S-I-S structures [4].

Bridging the gap between SRF studies of cavities and material studies on samples is possible with the Quadrupole Resonator.

THE QUADRUPOLE RESONATOR

The characterization of different superconducting materials is performed at laboratories around the world with tools such as the TE host cavity, the Sapphire loaded cavity, and/or the Hemispherical cavity [5]. Another important tool, developed in 1998 at CERN, is the Quadrupole Resonator (QPR) [6].

The advantages of the QPR over other systems are the ability to perform measurements at frequencies and temperatures typical for SRF cavities, the capacity to add a magnet system which allows the study of flux pinning effects, the possibility to change multiple parameters freely and at low frequencies to study the contributions of the residual and BCS resistance [7].

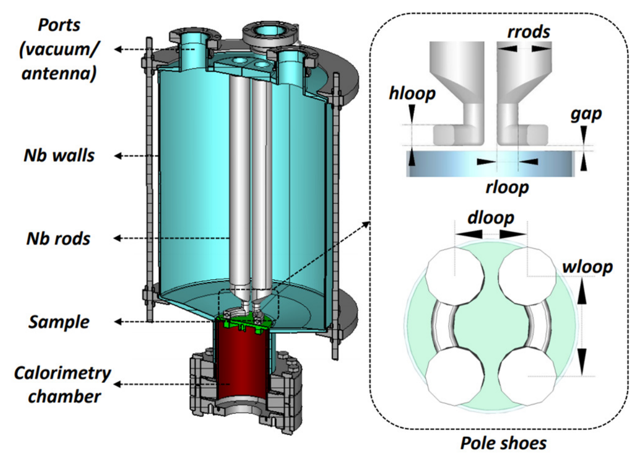

Figure 1: Cross-sectional view of a quadrupole resonator (left) and a parametrized model of the pole shoes (right) [8].

The QPR specifically can be used to characterize the surface resistance R_s, London penetration depth λ_L, the mean free path ℓ and the critical magnetic field H_c in a continuous or pulsed wave mode of niobium samples with a diameter of 75 mm. These properties are typically measured at temperatures (T) of 1.5 to 4 K, with magnetic fields (B) up to 120 mT (equivalent to an accelerating gradient of 25 MV/m in a TESLA shaped cavity) and frequencies (f) of 0.42, 0.86, and 1.3 GHz. A schematic overview of the QPR and its most relevant parameters is given in Fig. 1.

Furthermore, a close-up of the calorimetry chamber is observed in Fig. 2, where more detail can be seen of the position of the temperature sensors and heater on the sample.

* ricardo.monroy-villa@desy.de

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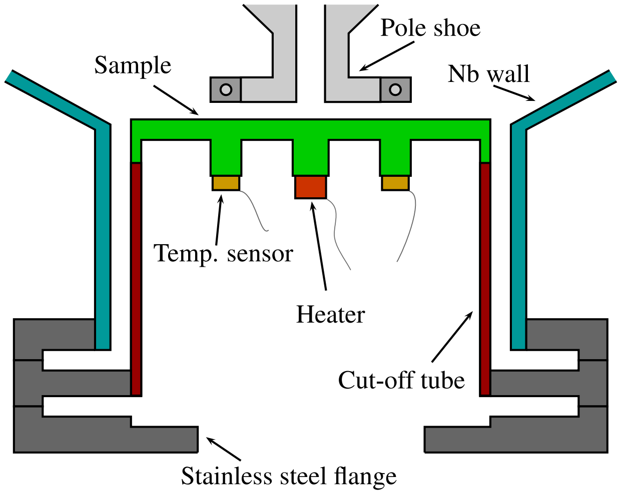

Figure 2: Detailed view of the calorimetry chamber. The temperature sensors and heater are placed on the surface of the sample. The cut-off tube and Nb walls are screwed to stainless the steel flanges.

Measurement Principle of the QPR

The process to obtain the surface resistance of the superconducting sample with the QPR is explained below.

First, a heater connected in a closed-loop controller with temperature sensors increases the temperature of the sample from T_{bath} to a desired value ($T_{interest}$). The power P_{DC1} required by the controller is recorded. Then, the RF system is turned on, heating up the sample. The heater decreases its temperature until reaching thermodynamic equilibrium. Finally, the new power P_{DC2} required by the controller is recorded. The previous process can be schematically seen in Fig. 3.

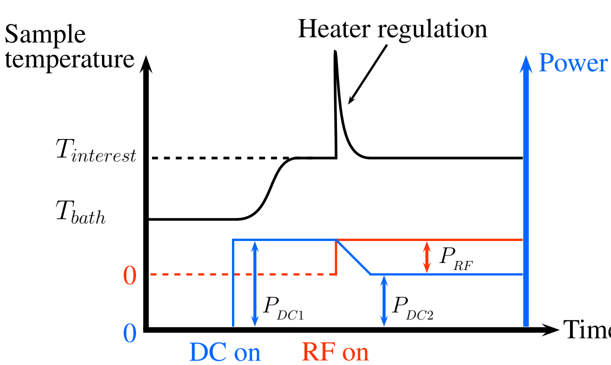

Figure 3: Schematic representation of the measurement principle of the QPR [2].

Assuming the R_s of the sample is constant, it can be calculated with Eq. (1)

$$R_s = \frac{2*(P_{DC1} - P_{DC2})}{\int_{sample} |\boldsymbol{H}|^2 \, dA}. \quad (1)$$

A more detailed description of the measurement of R_s including the calculation of λ_L, ℓ, and H_c, can be found in Refs. [1,9] .

Q_{ext} Calculation for the UHH/DESY QPR

The UHH/DESY QPR is mostly based on the design of the HZB QPR, but some changes need to be made due to material availability or just to further reduce systematic inconsistencies in the measurements detected in other test resonators. One of these important changes is the increase of the diameter of the antennas feed-throughs from 36 mm to 40 mm and 2 mm in its radial separation.

In order to study the effect of these changes, simulations in CST using the HZB QPR and the modified UHH/DESY QPR design were performed to obtain the external quality factor (Q_{ext}) values. In Fig. 4, a comparison of the Q_{ext} of the HZB QPR and the UHH/DESY QPR for the first three quadrupole modes is reported.

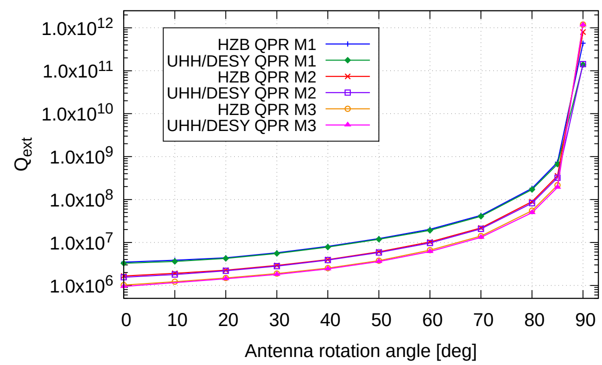

Figure 4: Q_{ext} vs. angle between the antenna loop and the magnetic field. These values correspond to the first three QPR modes which are M1=0.42 GHz, M2=0.86 GHz, and M3=1.3 GHz.

The new design of the QPR antennas feed-throughs has a minor effect on the Q_{ext} values for angels between 0 and 80 deg. Hence, the observed difference is neglectable and no performance change of the QPR itself is expected.

Another important change is an increased stiffening structure inside the rods to reduce mechanical vibrations of the QPR (symmetry breaking of the quadrupole modes), which are most likely caused by Lorentz Force Detuning, exciting additional dipole modes that increases the measurement of the surface resistance in the 3rd QPR mode [9].

More sophisticated multiphysics simulations in collaboration with Universität Rostock are underway and presented in Ref. [10].

First UHH/DESY Sample at the HZB QPR

To further improve the versatility of the quadrupole resonator, a first approach to design a detachable sample holder has been done [11]. The current sample design requires that the calorimetry chamber be welded to the sample. As a consequence, flat samples would be possible, which are

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easier to treat and analyze in comparison to samples welded to the calorimetry chamber.

In-house fabricated and treated detachable sample, as shown in Fig. 5, was tested at the HZB QPR.

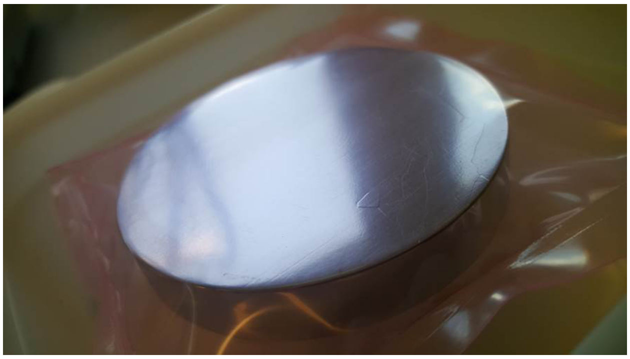

Figure 5: Large-grain sample (75 mm diameter) after BCP. Fabricated and treated in-house.

First measurements showed an abnormal high surface resistance which is probably caused by currents across the gap between sample and sample holder, see Fig. 6.

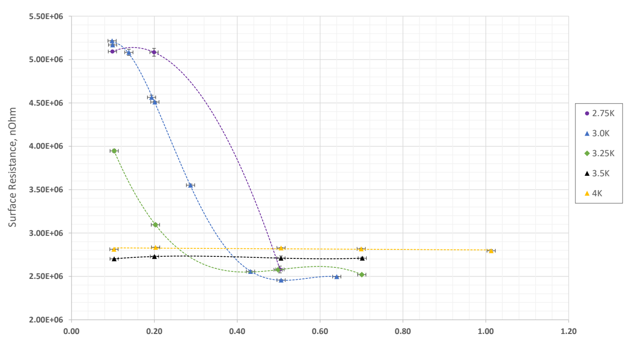

Figure 6: Surface Resistance vs. B-Field on sample at 1.3 GHz. The resistance is several orders of magnitudes higher than for cavities.

Further tests to analyze dependencies and material influence were done using an initial prototype of a flat sample produced at DESY. Unusual temperature, frequency and field dependencies are observed in the measurements. Another R&D project has been established recently and will carry out extensive simulations and experiments to identify the problems and optimize the flat sample holder design to gain the higher versatility of the detachable sample design.

OUTLOOK

The last steps to finalize the UHH/DESY QPR design will be made by the end of the second quarter of 2019. The UHH/DESY QPR designing process is in its final phase. After fabrication and handling issues are resolved and minor changes have been decided, the consequences of this changes are currently simulated. In-house simulations to study the fabrication tolerances and multiphysics simulation to understand dynamic processes such as Lorentz force detuning, mode excitation and propagation and the influence of symmetry breaking by fabrication are currently done.

A call for tenders is currently fixed and the technical drawings will be finalized after the results of the simulations. The material is now purchased. Existing vacuum and low level RF infrastructure is currently modified, or necessary parts will be purchased. New samples, already welded to the calorimetry chamber, are prepared within our collaboration. Those samples will be studied in our CW studies, including thermal nitrogen treatment and coating of niobium surfaces. The antennas will be made in-house and designed first based on the CST simulations. A future, planned R&D project will study the fields in the coaxial gap and currents on the sample holder surface and will further optimize the detachable sample holder design.

The commissioning of the quadrupole resonator is foreseen to be in Spring 2021, while sample preparations, treatments and measurements will be pursued until then in collaboration with HZB.

CONCLUSION

The construction of the QPR at DESY will allow for further studies of superconducting materials; including nitrogen doped or nitrogen infused niobium samples and layered structures applied to niobium or copper surfaces. The HZB QPR is a powerful tool and only minor modifications where made for the DESY design. Our studies show that the changes which were made at the new design do not alter the RF performance.

To further improve the versatility of the QPR, a detachable sample holder which is not limited by a significant higher surface resistance has to be designed. First studies of the in-house production of such samples were successful, although the measurements were limited again by the holder design.

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REFERENCES

[1] T. Junginger, "Investigations of the surface resistance of superconducting materials," Ph.D. thesis, Ruprecht-Karls-Universität, Heidelberg, Germany 2012.

[2] R. Kleindienst, "Radio Frequency Characterization of Superconductors for Particle Accelerators," Ph.D. thesis, Universität Siegen, Siegen, Germany 2017.

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-THP004

[3] A. M. Valente-Feliciano, "Superconducting RF materials other than bulk niobium: a review," *Superconductor Science and Technology*, IOP Publishing Vol. 29, No. 11, pp. 113002, 2016.

[4] A. Gurevich, "Enhancement of rf breakdown field of superconductors by multilayer coating," *Appl. Phys. Lett.* 88, 012511, 2006.

[5] P. Goudket, T. Junginger and B. P. Xiao, "Devices for SRF material characterization," *Superconductor Science and Technology*, IOP Publishing Vol. 30, No. 1, pp. 013001, 2016.

[6] E. Haebel, E. Brigant, and E. Mahner, "The Quadrupole Resonator, design considerations and layout of a new instrument for the RF characterization of superconducting surface samples," in *Proc. of the 6th European Particle Accelerator Conf.*, Stockholm, Sweden, 1998.

[7] H. Padamsee, J. Knobloch, and T. Hays, *RF Superconductivity for Accelerators*, 2nd Ed. Weinheim, Germany: Wiley-VCH Verlag, 2008.

[8] P. Putek *et al*. "Shape optimization of quadrupole resonator for the RF characterization of superconductors," *COMPUMAG 2019*, Paris, France, July 2019.

[9] S. Keckert *et al*., "The Challenge to Measure nΩ Surface Resistance on SRF Samples," In *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, BC, Canada, Apr.-May 2018. pp. 2812–2815.doi:10.18429/JACoW-IPAC2018-WEPML049

[10] P. Putek, "Uncertainty Quantification of a Quadrupole-Resonator for Radio Frequency Characterization of Superconductors," presented at SRF'19, Dresden, Germany, June-July 2019, paper THP102, this conference.

[11] S. Keckert, "Optimizing a Calorimetry Chamber for the RF Characterization of Superconductors," Master thesis, University Siegen, Siegen, Germany 2015.