Design and Fabrication of a Quadrupole Resonator for SRF R&D.

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R. Monroy-Villa[1,2,*], W. Hillert[1], D. Reschke[2], J. H. Thie[2], M. Wenskat[1], P. Putek[3], S. Zadeh[3]

[1]Institute for Experimental Physics, Universität Hamburg, Hamburg, Germany

[2]Deutsches Elektronen-Synchrotron, Hamburg, Germany

[3]Institute of General Electrical Engineering, Universität Rostock, Rostock, Germany

Introduction

Niobium is the material of choice for the construction of superconducting radio frequency (SRF) cavities in modern particle accelerators. Since the accelerating fields in these SRF cavities are reaching their theoretical limit, materials such as Nb_3Sn and multilayer structures (SIS) and treatments like N-doping and N-infusion of Nb are being shown to increase quality factors and the maximum fields they can support. However, further research is required before a cavity made from these materials goes into operation. An improved version of a device called Quadrupole Resonator (QPR), originally developed and operated at CERN and HZB, has been further developed and built in a cooperation of Hamburg Universität and DESY. It will allow for the systematic study of small superconducting samples over a broad parameter space defined by the resonance frequency, cryostat temperature and applied magnetic field.

Quadrupole Resonator

Our QPR design allows for systematic investigation of **SRF sample properties**, such as:

- Surface resistance $R_s(T, B, f)$
- Critical magnetic field $H_c(T)$
- Superheating magnetic field H_{SH}

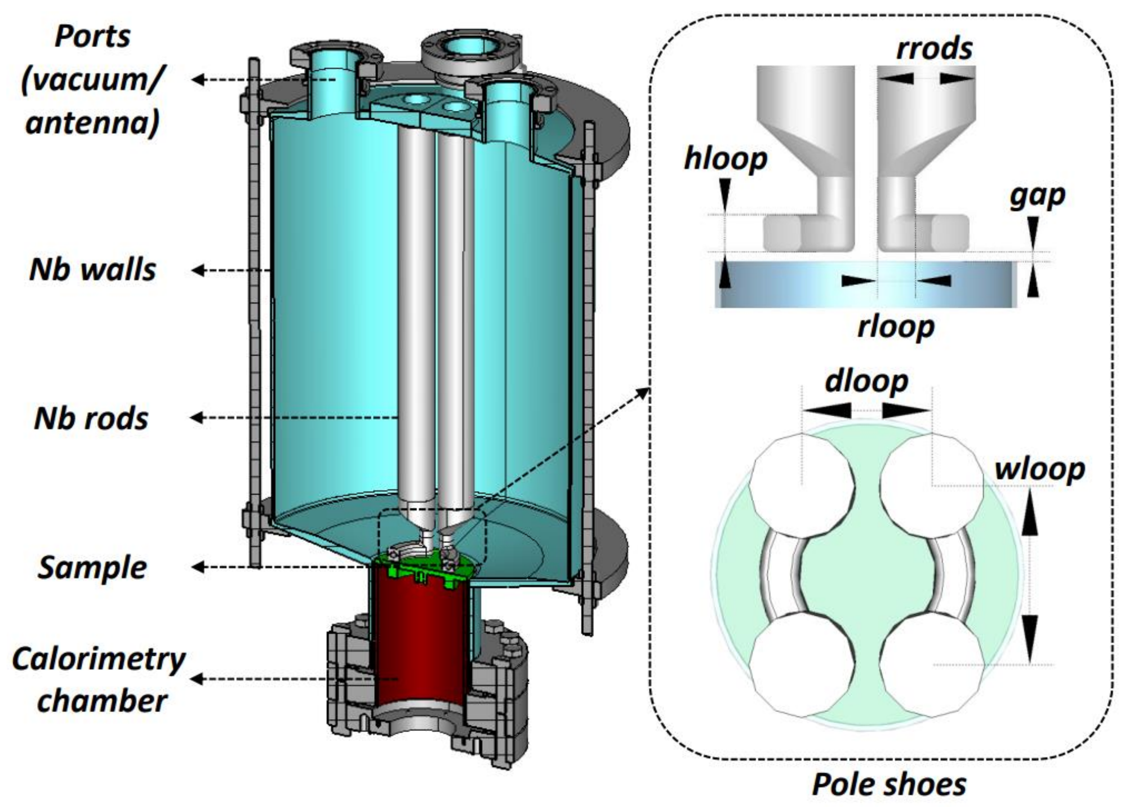
and enables to determine the following **material properties**:

- Penetration depth λ
- Mean free path ℓ
- Critical temperature T_c

P. Putek *et al.*, arXiv, physics.acc-ph, eprint 2004.09470 (2020)

QPR specifications:

T~1.5-4 K, $H_{sample,max}$~120mT and f~433, 870, 1310 MHz



Schematic diagram of the QPR.

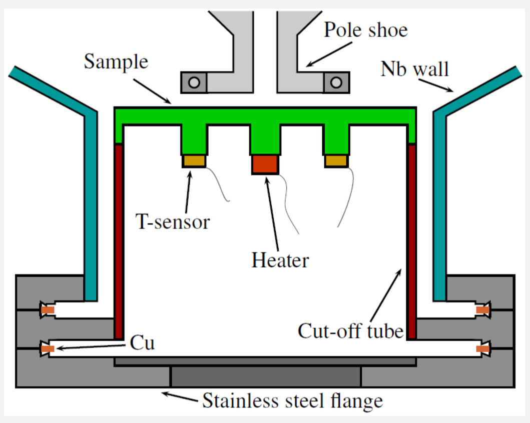
Calorimetric Measurement Principle

- A heater in a closed-loop controller increases the temperature of the sample from T_{bath}, to a desired value $T_{int} < T_c$
- The required heating power P_{DC1} is recorded
- The RF system is turned on and RF dissipation leads to a further increase of the sample's temperature
- The heating power decreases until the temperature of the sample reaches T_{int} again
- The changed heating power P_{DC2} is recorded again

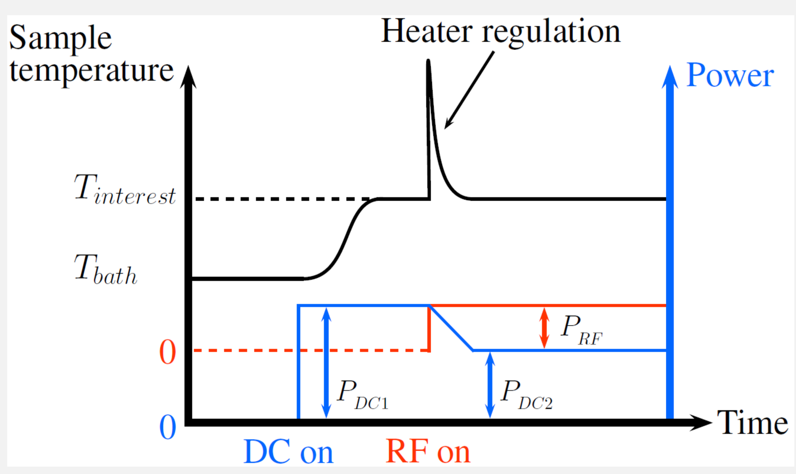
Assuming a constant R_s of the sample, the previous process can be summed up in Eq. (1):

$$R_s = 2 * (P_{DC1} - P_{DC2}) \Big/ \int_{sample} |\boldsymbol{H}|^2 dA \qquad (1)$$

R. Kleindienst, Ph.D. thesis, Universität Siegen, Siegen, Germany (2017)



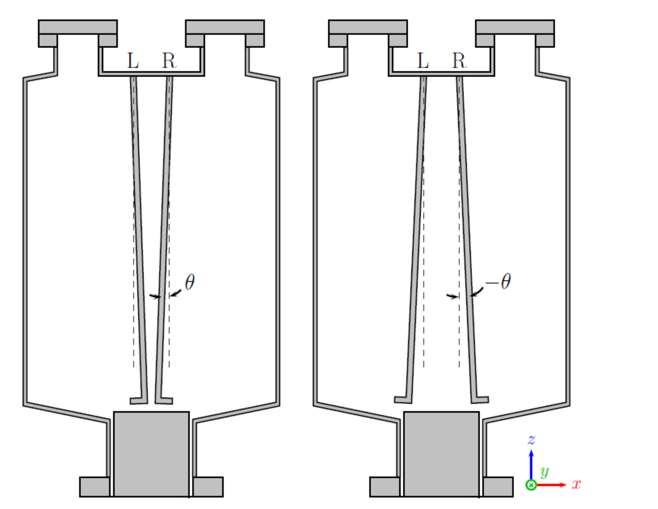
Schematic drawing of the calorimetry chamber



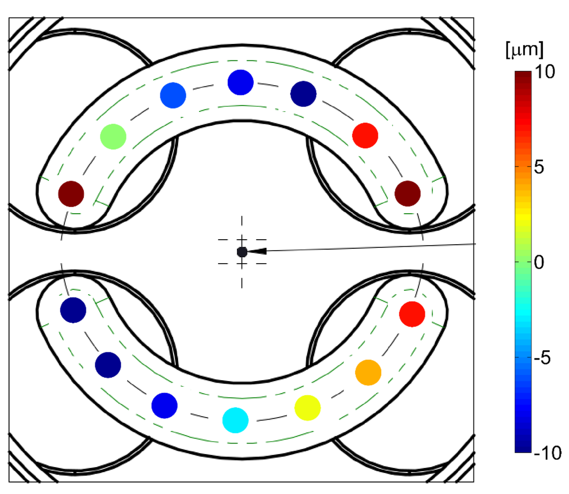
Schematic representation of the measurement principle of the QPR.

Static detuning study

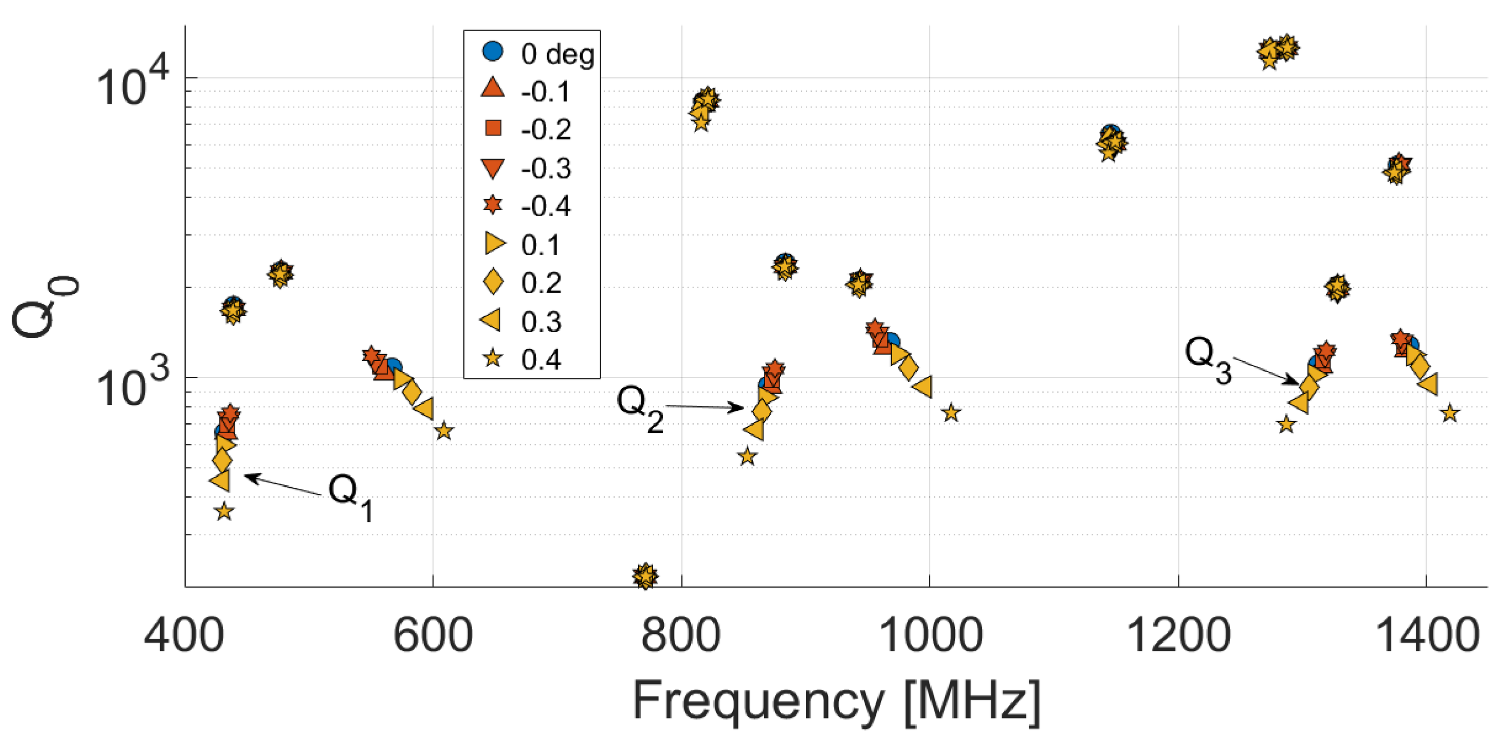
Fabrication errors, deformations after pump down and/or microphonics cause **angle deviations of the Nb rods**. This could result in a simultaneous excitation of a quadrupole mode plus other **unwanted neighboring modes**. To study such a phenomenon in our design, simulations were carried out using CST MICROWAVE STUDIO® varying the angle of the right rod, both rods and both pole shoes. In the case of the bending of both rods, a spread of the quadrupole modes on the *f*-axis was observed and an **exchange** of the third quadrupole mode with the previous dipole happened for 0.4°.



Schematic diagram of the angle variation of the rods.



Parallelism of the pole shoes measured at Zanon Research & Innovation SRL.

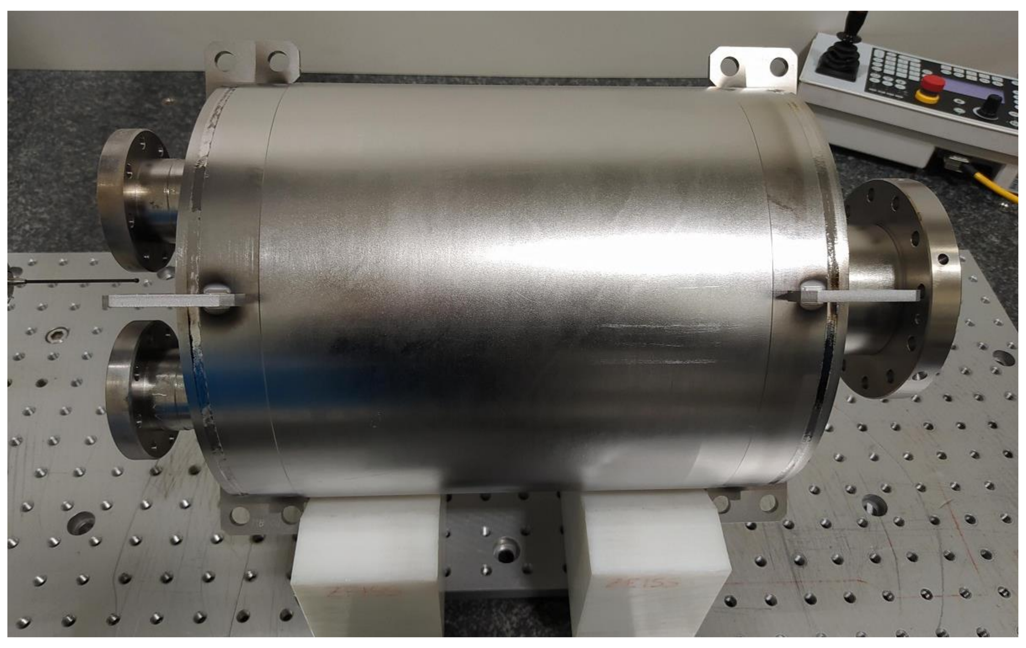


Quality factor vs. Frequency at room temperature with a rotation of the rods around the y-axis.

Advantages of the QPR

The QPR offers the following advantages over other sample characterization systems:

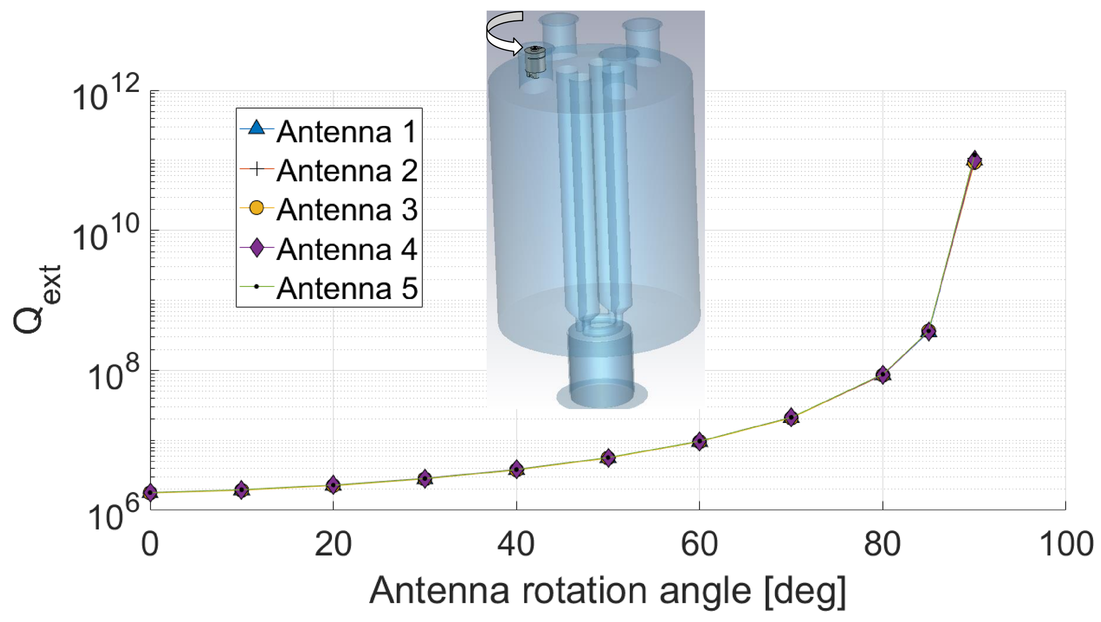
- Measurements performed at RF frequencies f and cryogenic temperatures T **typical for SRF cavities**
- Easier sample preparation and turn-around time at a lower cost
- Operation at the first **two subharmonics** to study the contributions of the residual and BCS resistance
- The capacity to add a magnet system to study **flux pinning effects**.



Finalized QPR at Zanon Research & Innovation SRL.

Other hardware

Input and pick-up antennas, T-sensors, heaters, leak-tight seals and flanges, the low-level RF system and other auxiliary devices are being analyzed. Particularly, a fabrication tolerance study of the input antenna (β~100) in CST showed the expected behavior of the external quality factor Q_{ext}†.



Q_{ext} vs. angle between the antenna loop and the magnetic field.

†S. Keckert et al., In Proc. 9th Int. Particle Accelerator Conf. (2018)

Commissioning of the QPR

The following list of post-production tests will be carried out at **DESY** :

1. Wall thickness of the vessel and pole shoes (Ultrasonic measurements)
2. Bridge coordinate measurement (Check of parallelism)
3. Spectrum of response to mechanical excitations
4. RF spectrum with sample at room temperature
5. Repeat test 2 and 4 after evacuating the QPR (to check for deformation)

Surface treatment:

- Surface treatment (at Zanon Research & Innovation SRL)
- Coarse BCP (>130µm)
- 800°C/3h
- Fine BCP (20-40µm)
- 120°C/48h

*ricardo.monroy-villa@desy.de

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