TEST CAVITY AND CRYOSTAT FOR SRF THIN FILM EVALUATION

Philippe Goudket[1,3], Shrikant Pattalwar[1,3], Oleg B. Malyshev[1,3], Lewis Gurran[1,2], Graeme Burt[2], Edward S. Jordan[4], Thomas J. Jones[4], Dmitry O. Malyshev[1] and Reza Valizadeh[1,3]

[1] ASTeC, STFC Daresbury Laboratory, Daresbury, Warrington, Cheshire, UK
[2] Lancaster University, Cockcroft Institute, Lancaster, UK
[3] Cockcroft Institute, Warrington, Cheshire, UK
[4] TD, STFC Daresbury Laboratory, Daresbury, Warrington, Cheshire, UK

Abstract

In developing superconducting coatings for SRF cavities, the coated samples are tested using various techniques such as resistance measurements, AC, and DC magnetometry which provide information about the superconducting properties of the films such as RRR, H_{c1}, H_{c2} and vortex dynamics. However, these results do not allow the prediction of the superconducting properties at RF frequencies. A dedicated RF cavity was designed to evaluate surface resistive losses on a flat sample. The cavity contains two parts: a half-elliptical cell made of bulk niobium (Nb) and a flat Nb disc. The two parts can be thermally and electrically isolated via a vacuum gap, whereas the electromagnetic fields are constrained through the use of RF chokes. Both parts are conduction cooled hence the system is cryogen free. The flat disk can be replaced with a sample, such as a Cu disc coated with a Nb film. The RF test provides the cavity Q-factor and thermometric measurements of the losses on the sample. The design advantages are that the sample disc can be easily installed and replaced; installing a new sample requires no brazing/welding/vacuum or RF seal, so the sample preparation is simple and inexpensive.

INTRODUCTION

Superconducting coatings (SC) for radio-frequency (RF) cavities in particle accelerators have been used since the 1980s [1]. They provide many advantages such as combining the good thermal conductivity of copper and the superconducting properties provided by a thin niobium film. However, the RF performance of these SC cavities (such as Q_0 and E_{max}) has always been lower than those made of bulk niobium. Several research laboratories around the world have put in an effort to improve the quality of SC cavities [2-4]. This required understanding the correlation between (a) deposition parameters and conditions, (b) surface analysis, (c) superconducting properties and (d) performance in an RF field. To enable the UK capability in SC cavity production and to improve the quality of SC cavities the ASTeC team has employed a number of systems to evaluate the properties of the coated layer. Deposited samples are studied with surface analysis systems to study the film compositions and morphology, chemical bonding, grain size, crystal structure and phase. They then undergo the superconducting properties characterisation: measurements of quantities such as RRR, T_c, H_{c1} and H_{c2} (residual resistivity ratio, critical temperature, and critical H-fields 1 and 2) with DC and AC magnetic susceptibility methods [5–7]. However, these measurements do not allow the prediction of the behaviour of such a film in RF conditions. Depositing the coating on a different cavity for each type of film would be too expensive and time consuming; therefore a test cavity for quick evaluation of planar samples is required. This paper is devoted to the RF, cryogenic and mechanical design along with the implementation of such a cavity.

EXPERIMENT SETUP

As the cavity is not completely coated in the thin film, it is necessary to separate the losses on the bulk Nb walls from that on the sample. A convenient way of doing so is using a calorimetric method using a DC heater placed underneath the sample plate: the temperature of the sample is measured with no RF, then the RF is switched on while the DC heater is turned down to keep the sample at the same temperature, hence the losses on the sample are equal to the reduction in heater power. However for this measurement to be accurate it is necessary to thermally isolate the sample from the cavity.

Here we propose to have a vacuum gap between the two structures with RF chokes to prevent RF leakage. Both parts are conduction cooled to avoid having the cavity immersed in a LHe bath. The experiment is then placed in a large vacuum chamber, eliminating the need for any vacuum seals between the two parts. As such the cavity and the sample require no physical connection between them. The chokes increase the cavities transverse size hence a cavity frequency of 7.8 GHz is proposed in order to fit in the conduction cooling cryostat. The cavity will be used to measure BCS resistance as a function of cavity field. Due to the fact that R_{BCS} at 1.8 K will be 165 nΩ it will not be possible to measure the residual resistance.

RF CAVITY DESIGN

The project required the design of an RF structure capable of subjecting the sample surfaces to surface currents. In order to keep the sample as simple as possible, it was decided to design a cavity able to test a planar sample plate. Additionally, in order to avoid having to deal with the uncertainties of joints between materials or parts, and complication of requiring an RF or vacuum seal on the structure, it was decided to investigate the use of a two-part cavity sealed with RF chokes. The initial approach was to use a 2-choke cavity, which was tested at 3.9 GHz and then at 7.8 GHz. A third version with an additional choke was subsequently designed and manufactured.

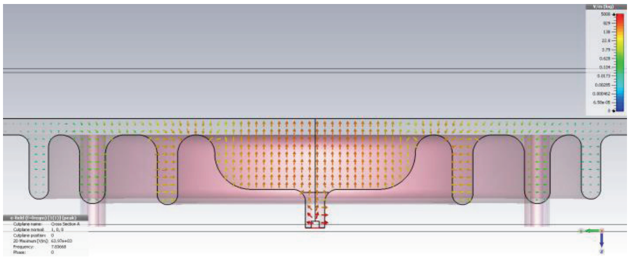

Figure 1: Electric field map of the three-choke cavity.

The cavity was simulated in CST Studio Suite [8] using a tapered RF absorber after the final choke to prevent reflections. RF optimisation of the chokes was done using several methods. The initial approach was to minimise the RF power being deposited into the absorber at the resonant frequency. In order to investigate higher performance structures, a second method was to minimise the electric field amplitude outside the last choke, again at the resonant frequency. The optimal electric field outside the three-choke cavity is calculated to be 55 dB below the field in the centre of the cavity in the best configuration found. Different choke widths were chosen in order for them to have different bandwidths and increase the chance of them overlapping when taking manufacturing errors into account.

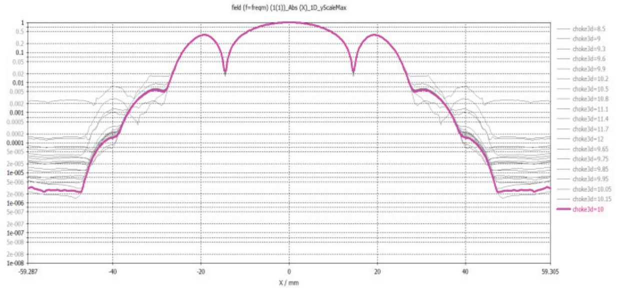

Figure 2: Normalised electric field intensity (in dB) measured along the cavity/sample gap in the three-choke cavity optimisation.

PROTOTYPE TESTS

A 3.9 GHz aluminium prototype with two chokes was designed and tested at room temperature (Figure 3). The RF design was performed using CST Microwave Studio, and only considered the desired RF properties of the structure.

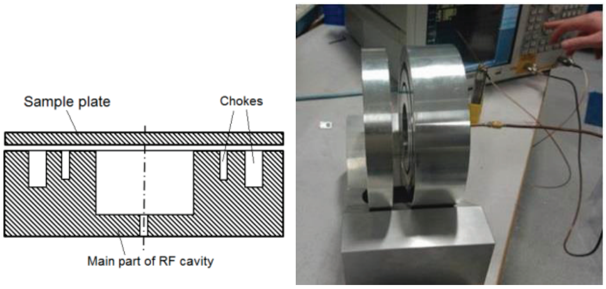

Figure 3: The 3.9 GHz aluminium prototype cavity.

Based on the success and limitations of the prototype, an iteration of the design was performed in view of building a niobium structure. It was decided to double the frequency in order to reduce the size of the cavity, as the sample plates could not exceed 10 cm in diameter using the available deposition apparatus. This allows the sample to be a single surface with no joints on the RF surface. As the structure is similar to a two-plate system, multipactor studies were performed and curvature was added to the chokes in order to preclude stable multipacting trajectories. This first iteration of the design was manufactured both in aluminium and niobium by Niowave Inc. [9].

The structure has been tested extensively at room temperature as part of a surface resistance study of a number of materials [10]. It is estimated a Q_L of 10^6-10^8 is the maximum this structure could reach due to some RF leakage persisting through the gap, However this is not an issue for the experiment as we only measure the losses on the sample, but means that a higher RF input power is required.

As these tests suggested RF leakage remained an issue, a three-choke iteration of the design was manufactured; simulations suggest it should have a Q-factor increase of a factor of 100 through reduction of the leakage. Subsequent room temperature tests suggest performance is at least as good as the original two-choke design, but cryogenic tests will be needed to confirm the performance improvement.

Cryogenic tests will be performed on both niobium structures and will give a better benchmark of the ultimate performance of the design.

CRYOSTAT AND INSERT DESIGN

A dedicated liquid helium cryostat shown in Fig. 4 has been developed for measuring the surface resistance of the coated samples. The cavity support cradle (A) is thermally attached to the bottom of the liquid helium vessel (B) and resides inside a separate vacuum chamber (C). An access port (D) surrounded by liquid helium vessel is used for evacuating the cavity chamber as well as to route the instrumentation cables.

The upper part of the cavity, Fig. 5, includes a specially designed niobium structure (E) which is thermally attached to a copper heat sink (F) and is held at liquid helium temperature. Three thin walled stainless tubes (G)

ISBN 978-3-95450-168-7

provide necessary mechanical support as well as thermal isolation to the coated sample under test (H) which form the lower part of the cavity. The sample can be changed by dismounting the base plate (I), an operation which is undertaken inside a class-10 clean room.

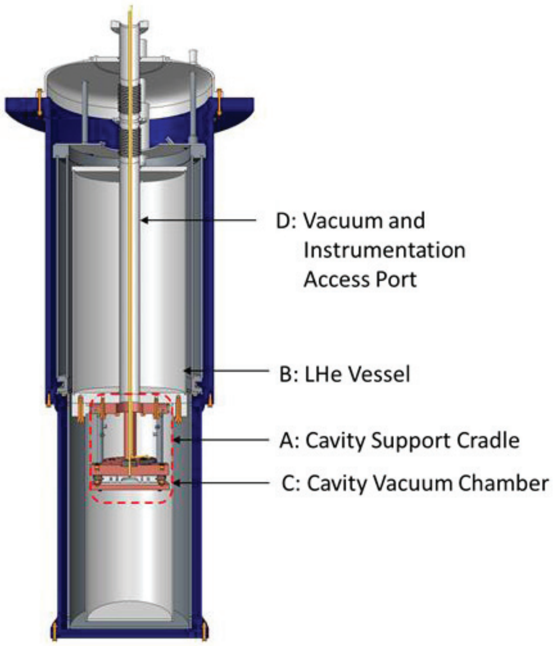

Figure 4: Liquid helium cryostat and the cavity support cradle assembly for RF test of samples at cryogenic temperatures.

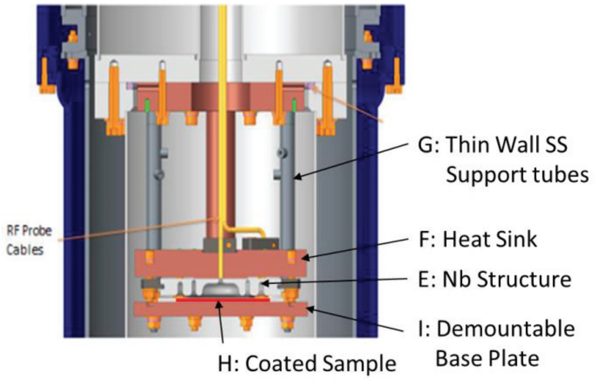

Figure 5: Detail of the cavity support structure and thermal links.

Initially the cavity chamber and all the parts inside are cooled by exchange gas. The coated sample is then thermally isolated by evacuating the cavity chamber. Base temperature of the cavity can be reduced from 4.2 to 1.8 K by reducing the vapour pressure in the liquid helium vessel.

Figure 6: Test assembly of the cavity and sample mounted in its support cradle.

CONCLUSION

A new test cavity and cryostat will be an essential facility for SRF thin film evaluation. The flat disk can be replaced with a sample, such as a Cu disc coated with a Nb film. The dimensions of the cavity allows the testing of flat samples with a diameter of 100 mm which is compatible with available deposition facilities.

The RF test provides the cavity Q-factor and thermal measurements of the losses on the sample. The design advantages are that the sample disc can be easily installed and replaced without the requirement for brazing/welding/vacuum or RF seal, so the sample preparation is simple and inexpensive.

REFERENCES

[1] C. Benvenuti, et al., Appl. Phys. Lett. 45 (1984) 583; C. Benvenuti et al., IEEE Trans. Mag. MAG-21 (1985) 153.
[2] V. Palmieri, Proc. Linac'98, Chicago, IL, p.697.
[3] S. Calatroni, Proc. 12th Int. Workshop on RF Supercond. (2005), Cornell University, NY, p. 151.
[4] C. Baumier et al., Proc. SRF 2013, Paris, p. 789.
[5] S. Wilde et al, Proc. IPAC'2014, p. 2406.
[6] Physical vapour deposition of thin films for use in superconducting RF cavities, S. Wilde et al., IPAC15, these proceedings.
[7] Development of Thin Films for Superconducting RF Cavities, P. Pizzol et al., IPAC'15, these proceedings.
[8] CST AG, Bad Nauheimer Str. 19 Darmstadt, 64289 Germany.
[9] NIOWAVE Inc., 1012 N Walnut St, Lansing, MI 48906.
[10] Test Cavity and Cryostat for SRF Thin Film Evaluation, P. Goudket et al., IPAC15, these proceedings.