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DESIGN, ASSEMBLY AND COMMISSIONING OF A NEW CRYOGENIC FACILITY FOR COMPLEX SUPERCONDUCTING THIN FILM TESTING

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Abstract

An ongoing study on the superconducting thin films for future superconducting RF cavities requires an intense testing of various superconducting properties. We have designed, built and tested a new facility for complex superconducting thin film testing that includes: (1) RRR measurement with and without magnetic field, (2) planar and (3) tubular magnetic field penetration experiments, (4) a superconducting coaxial resonator for bulk niobium and superconducting thin film characterisation. The system is based on a closed cycle refrigerator, eliminating the need for liquid helium, thus making it simple and safe to operate. The details of the design and commissioning will be presented at the conference.

INTRODUCTION

The ASTeC team working on thin film superconducting RF (TF SRF) is developing the UK capability to coat TF SRF cavities. To meet this ambition, the team is working in a few directions:

- Surface preparation before deposition (material choice, cleaning, polishing, etc.);
- Thin film deposition (PVD, CVD) [1-4]
- Thin film characterisation with various surface and material analysis techniques and facilities [1-4];
- DC/AC superconductivity characterisation [5-6];
- RF superconductivity characterisation [7-9].

A lot of characterisation work has been done in good national and international collaborations. However, it would be convenient to have all the facilities and to do all this work within the same team. Thus, ASTeC TF SRF team has developed a new cryogenic test facility for DC and RF superconductivity characterisation.

THE FACILITY LAYOUT

Traditionally (as well as in our previous generation facilities) the TF SRF samples are tested using LHe, whereas our new facility is based on a closed cycle refrigerator (PTR cooler). That allows being independent of LHe suppliers and a reduction of operation costs. The layout of the facility and it's photo are shown in Figs. 1 and 2, respectively. The cryocooler and two Vacuum Tubular Inserts (VTI-A and VTI-B) as well as a few flanges for vacuum and electrical instrumentation are mounted on a top flange of the vessel.

Stage 1 and Stage 2 plates are thermally connected to corresponding cryocooler stages with thermal links. The VTIs, in turn are connected to Stage 1 and Stage 2 plates. Additionally a radiation screen is thermally connected to Stage 1 plate which protects Stage 2 plate and VTIs from direct radiation from the room temperature.

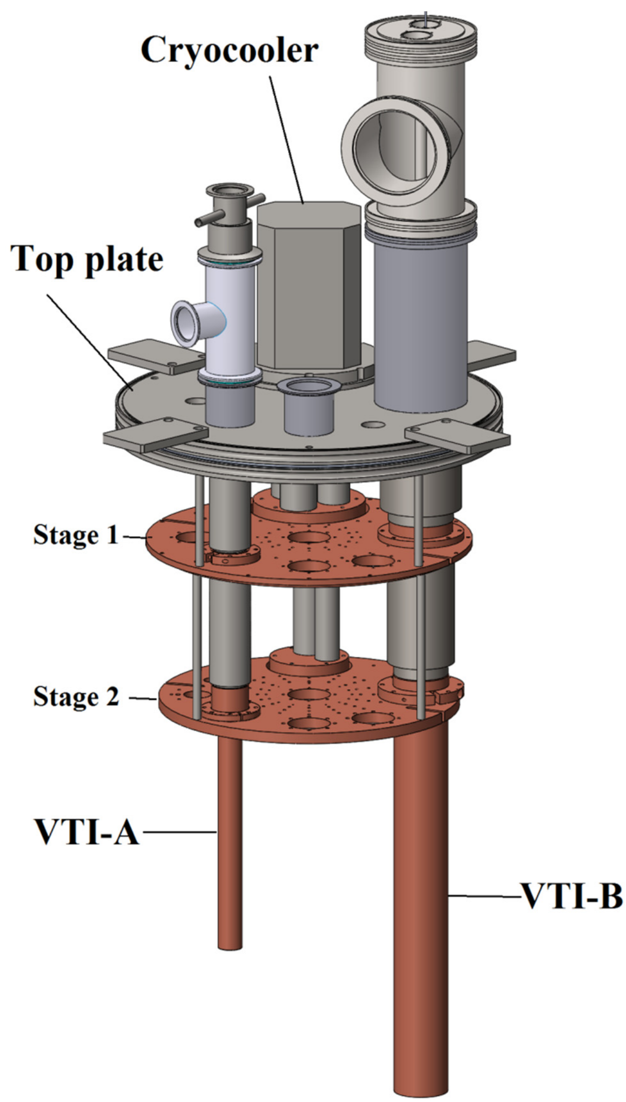

Figure 1: Layout of a new cryogenic facility.

Cryocooler

The cryocooler is a key part of this facility. The cooling capacity should be sufficient to reach the temperature of interest, which is at least 4.2 K. The characteristics of the cryocooler used in this facility are shown in Table 1.

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Table 1: Achieved characteristics of Sumitomo RP082B2 cryocooler

	Specification	Achieved
Stage 1 power	45 W at 45 K	~ 40 W
Stage 1 lowest temp.	45 K	50 K
Stage 2 power	1 W at 4.2 K	1 W
Stage 2 lowest temp.	3.0 K	3.5 K

VTI-A

The VTI-A is a 23-mm inner diameter insert with a length of ~350 mm below the Stage 2 plate to provide RRR measurements with and without magnetic field. It can also be used for the magnetic field penetration experiment on tubular samples. The VTI-A is equipped with a 1 Tesla superconducting coil shown in Fig. 3. The samples are cooled using helium exchange gas at a pressure between 200 and 600 mbar.

Figure 2: Experimental facility photo.

VTI-B

The VTI-B is a 48-mm inner diameter insert with a length of 350 mm below Stage 2 plate to provide the magnetic field penetration experiment on planar samples. This VTI is also used for a tubular resonator.

Cryostat Testing

The insulation vacuum chamber and VTIs were pumped down to ~10^{-5} mbar, then the cryocooler compressor was started. After 12 hrs of cooling the temperature measured at the cryocooler corresponds to its specification. In the first cooldown the lowest temperature obtained on Stage 1 plate was 70 K and Stage 2 plate was 6.8 K, the temperature on both VTIs does not go below 7.5 K even after a few days of cooling. It is suspected this is due to a weak heat leak between the thermal shield and the Stage 2. Another problem is that SC coil heats up when operated. This problem is suspected to be due to the delamination of high temperature superconductor (HTSC) current leads. These problems are presently under investigation.

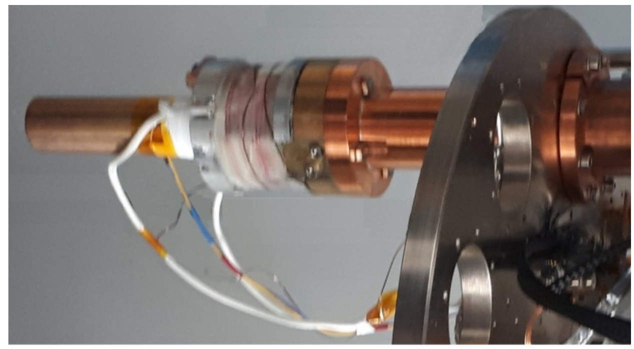

Figure 3: A 1-T superconducting coil on VTI-A.

THE EXPERIMENTS

Four different experiments can be performed on this facility. Each experiment is mounted on a dedicated removable insert as described below.

RRR in VTI-A

The RRR test is conducted using a standard four-point probe method. This measurement is a first test to check if the deposited film is superconducting or not, and to measure the critical temperature T_c. The samples for these measurements are deposited on a planar non-conducting substrate (such as SiO, MgO, etc.) or deposited on copper which is then etched, the sample sizes are approximately 5 mm × 15 mm. This experiment is currently operational.

The RRR measurements in a magnetic field allow additionally the obtaining of the electron mean free path. The sample is mounted normally to the magnetic field.

Tubular Magnetic Field Penetration in VTI-A

This method was earlier developed and realised in LHe bath [5-6]. A new insert stick has been designed and manufactured. It can accommodate tubular samples with the length of 18 cm ≤ L ≤ 21 cm, and inner and outer diameters: 6 mm ≤ ID ≤ 11 mm and OD ≤ 12 mm. A bulk Nb sample tube and a number of copper substrates have been prepared for thin film deposition on the outside wall for the following tests. The insert stick is awaiting the mounting of thermometers and Hall probes before it is ready for testing.

Planar Magnetic Field Penetration in VTI-B

Based on a new method developed within ASTeC, a new sample insert has been designed and built for this test. It can accommodate planar samples deposited on any substrate with a thickness of 1-2 mm and dimensions that can be fitted within a sample holder with a diameter of 53 mm.

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This insert is also awaiting the mounting of the superconducting (SC) coil, thermometers and Hall probes.

Tubular RF in VTI-B

Coaxial half wavelength resonators have been used for many years to characterise superconducting materials [10]. In this work the resonator consists of a Nb solid rod mounted concentrically inside a Nb outer tube. It is resonant when the inner rod is approximately one half-wavelength long. The structure can also resonate, when the length is a multiple of a half wavelength, i.e. λ/2, λ, 3λ/2, etc. This can allow the determination of surface resistance (R_s) over a fairly wide range of frequencies. The fundamental frequency of this resonator was approximately 712 MHz and fourth harmonic resonances could be measured up to over 2800 MHz. The inner rod is suspended at each end by a single crystal sapphire support. The latter is important to reduce the effect of dielectric losses, see Fig 4.

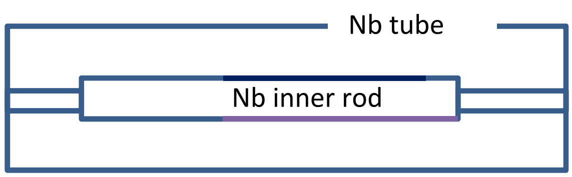

Figure 4: Cross section of coaxial resonator.

The resonator used in this work had an outer tube with an outer diameter of 38 mm and 340 mm long. Since the ends were composed of ordinary metals a substantial gap was required at the end of the inner rod. This was necessary to reduce the conductor losses in the ordinary metal end caps. Such a structure has several advantages: it can allow the measurement of surface resistance at frequencies of around 704 MHz, such as for the ESS project; it can determine R_s over a wide range of frequencies; it is a rotationally symmetric structure so it is easy to analyse using simple 2D electromagnetic modelling packages; it is possible to change the distribution of loss between the outer and inner by changing the ratio of the inner and outer diameter [11]; and finally it provides a simple test structure for deposition of thin films. The latter is very important as although there is a huge amount of work devoted to thin film deposition upon planar surfaces, much less work has been devoted to thin films on curved surfaces. A coaxial resonator has just one radius of curvature so it provides a good stepping stone to surfaces with 2 dimensions of curvature, needed to coat real cavities.

This resonator was designed to enable the possibility to test the same samples used for the tubular magnetic field penetration in VTI-A. This allows a unique comparison of SC properties of TF at DC magnetic field and at the RF conditions.

CONCLUSIONS AND FUTURE DEVELOPMENT

A new ASTeC complex facility for superconducting thin film testing is operational for two experiments, two others are close to being tested. The issue of the sample temperature above the necessary 4.2 K is under investigation. When fully operational, the new system will enhance the ASTeC capability for a systematic study of superconducting properties of TF SRF. The RRR measurements will give T_c and electron mean free path. Magnetic field penetration measurements will allow the comparison of surface science characterisation of the thin films with their SC properties. Comparison of curved tubular samples characterised with magnetic field penetration and coaxial resonator measurements will provide a correlation between DC and RF properties of the thin films. Finally, comparing the results obtained with the coaxial resonator, with a 3-choke pill-box cavity with a planar sample deposited at the same conditions will enable discussions on the effect of curvature on the SRF properties. Thus the new ASTeC complex facility for superconducting thin film testing is a powerful tool to enable the UK TF SRF progress toward TF SRF cavity production.

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