ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO15

COMMISSIONING OF UKRI-STFC SRF VERTICAL TEST AND HPR REPROCESSING FACILITY

M. D. Pendleton*, A. Akintola, R. Buckley, G. Collier, K. Dumbell, M. Ellis, S. Hitchen, P. Hornickel, G. Hughes, C. Jenkins, G. Jones, M. Lowe, D. Mason, A. J. May, P. A. McIntosh, K. Middleman, G. Miller, C. Mills, A. Moss, J. Mutch, A. Oates, S. Pattalwar, O. Poynton, P. A. Smith, A. E. Wheelhouse, S. Wilde, J. Wilson,
UKRI-STFC Daresbury Laboratory, Keckwick Lane, Daresbury, WA4 4AD, UK

Abstract

The UK's first and only vertical test facility and associated cleanroom reprocessing suite has been developed, commissioned, and entered steady-state operations at the UKRI-STFC Daresbury Laboratory. The facility is capable of 2 K testing of 3 jacketed SRF cavities in a horizontal configuration per 2-week test cycle. We report on the associated cryogenic, RF, UHV, mechanical, cleanroom, and HPR infrastructure. SRF cavity workflows have been developed to meet the requirements of the ESS high-β cavity project within a newly developed quality management system, SuraBee, in accordance with ISO9001:2015. To support standardisation of measurements across the collaboration, reference cavities have been measured for cross-reference between CEA, DESY, and UKRI-STFC. We further report on commissioning objectives, observations, and continuous improvement activities.

INTRODUCTION

A new Superconducting Radio Frequency Lab (SuRF Lab) which includes a Vertical Test Facility (VTF) and Reprocessing Facility (Cleanroom and High Pressure Rinse (HPR)) has been commissioned at the UKRI STFC Daresbury Laboratory. The facility is currently undertaking a 2-year program to qualify high-β cavities for the European Spallation Source (ESS).

The VTF supports 2 K characterisation of three jacketed SRF cavities in a single cool-down run. Measurements of HOMs and passband modes are made at low power. Q vs E field measurements are made at high power levels (up to 200 W). A novel cryogenic architecture is used to significantly reduce the liquid helium (LHe) consumption compared with conventional facilities.

The HPR system has been developed to reprocess cavities that do not meet specification following their first vertical test; this system is currently in its commissioning phase.

VTF CRYOSTAT DESIGN

The conventional method for VTF SRF cavity testing is to fully immerse the cavities in a large LHe bath, and then cool to 2 K using a cold compressor/vacuum pump to reduce the vapour pressure over the bath. RF testing is then carried out with the cavities at 2 K. This approach has been used successfully for many programs, including XFEL cavity testing at DESY [1]. Whilst well-proven, this technique requires both a large cryoplant and, for this activity, would require ~8500 L of LHe per test cycle.

Given the diminishing global supply of He, and associated rise in cost, an alternative cryostat architecture has been developed for vertical testing of jacketed SRF cavities which requires significantly less LHe and a much smaller cryoplant throughput [2]. The cryostat is based on a cavity support insert (CSI) where three cavities are mounted horizontally inside LHe jackets below a header tank, each fed by a common fill/pumping line; this may be seen in Fig. 1 which shows a photograph of an assembled insert. By using this design approach, far less LHe is required per testing run (~1500 L, all of which is recovered) compared with the conventional designs.

Figure 1: Photograph of CSI on stand with three jacketed cavities installed (top and middle cavities dressed in MLI jackets)

The insert is mounted into a cryostat vessel which comprises the outer vacuum chamber, magnetic shielding (see

* mark.pendleton@stfc.ac.uk

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJ015

below), and thermal radiation shields. The cryostat was manufactured by Criotec[1].

An ALAT[2] Hélial ML cryoplant, commissioned in 2018, supplies 50 K gaseous helium (GHe, produced by the first heat exchanger stage of the liquefier) and 4.2 K LHe. Sub-atmospheric pumps provide cooldown of the liquid to 2 K. Helium is recovered from the shield and CSI cooling circuits, stored at high pressure, purified, and then reliquefied, providing a completely closed-loop system.

The cryogenic systems are described in greater detail in a companion paper to this conference [3].

CAVITY TESTING PROGRAM

As part of the UK's in-kind contribution to the European Spallation Source (ESS), STFC is responsible for the procurement, qualification testing, and delivery to CEA Saclay of 84 high-β Nb cavities. The high-β cavities, which accelerate the beam from 571 MeV to 2000 MeV, are a five-cell bulk Nb design operating at 704.42 MHz, designed at CEA Saclay. 2 K RF qualification of cavities with $Q \geqslant 5 \times 10^9$ at 19.9 MV/m will be required [4].

In total, 115 tests were anticipated; given the project timeline and a 2 week testing duration, this required the infrastructure and work flow to be developed for testing 3 cavities simultaneously. To facilitate this, two CSIs have been manufactured and commisioned which can be used alternately in a single vacuum vessel. This allows simultaneous testing of three cavities and preparation of the following three on the other insert, reducing down time between runs.

Following the completion of the ESS high-β testing program, the facility will be used for testing of HB650 cavities for the PIP-II project. Work is currently ongoing to study the modifications to the facility that will be necessary to support the requirements of this new project.

RF TESTING

Measurements of HOMs and passband modes are made at low power. Q vs E field measurements are made at high power levels (up to 200 W). The RF systems that have been developed for the facility are described in detail in a companion paper to this conference [5]. In this system, the input flange, where RF power is applied, tends to warm at the highest power levels. This is because such flanges are typically stainless steel and there were some conductor losses on the metal. During operation in the accelerator, the RF input coupler is cooled directly by LHe; in this setup however, copper straps were used to thermally anchor the input flange.

The plot in Fig. 2 shows the measured data for ESS high-β cavity H016. Two separate data sets were taken on separate days, showing very good repeatability. More extensive comparisons of cavity data across different cradle positions and comparison between different test facilities is given in the companion paper [5]. Measured radiation levels for H016 were very low. It may be seen that the cavity easily met the ESS requirement of $Q \geqslant 5 \times 10^9$ at 19.9 MV/m. Typical error values were on the order of 10 to 15% which is consistent with standard measurement errors found by other authors [6]. Further understanding of both the repeatability and accuracy of the data will be the subject of ongoing efforts throughout the testing program.

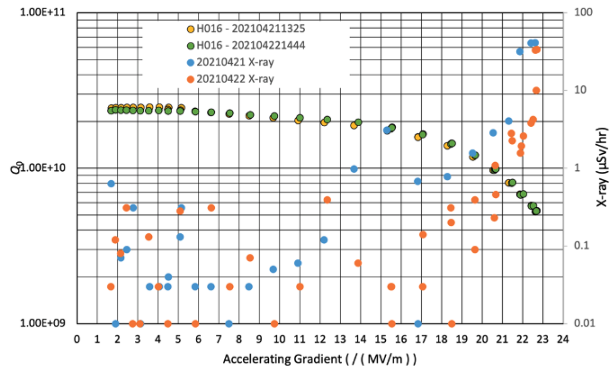

Figure 2: Measured Q and radiation levels against accelerating gradient for ESS high-β cavity H016

Measurements of Q against temperature (not shown) were also made by allowing the temperature of the LHe bath to drift and sampling the Q periodically at low power.

In this system, the radiation dose rate detectors were much closer to the ends of the cavities than in most other systems in use around the world. The separation was 20 to 30 cm. In most other laboratories, the distance is typically on the order of 2 to 3 m. This means that the dose rate measured at Daresbury was expected to be on the order of 100 times greater than that measured at other labs, purely from the effect of $1/r^2$. Work is ongoing to characterise this in greater detail, including both geometrical and instrumentation effects.

MAGNETIC SHIELDING

Stray field attenuation at the cavities to <1.4 µT is achieved by a static Mu-metal magnetic shield[3] surrounding the cryostat. Further attenuation to <1.0 µT is achieved through the use of two active coils located at the top and bottom of the cryostat. Coils are energised to ~5.8 A and ~6 A respectively to provide the desired attenuation. Field measurements in the centre of each cradle showed 0.399 µT for the top cavity position, 0.457 µT for the middle cavity position, and 0.647 µT for the bottom cavity position [7].

UHV SYSTEM

A custom slow pump slow vent (SPSV) ultra-high vacuum system has been designed and built as part of each CSI. Pumping through a SPSV system allows cavities to be actively pumped during RF testing to the level of $1e-7$ mbar with minimal risk of particulate transfer from the internal surfaces of the pumping system to cavity. All components used for the build were processed for cleanliness and particulate

[1] criotec.com
[2] advancedtech.airliquide.com
[3] magneticshields.co.uk

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO15

control before final assembly under ISO 4 cleanroom conditions. The SPSV system comprises three separate pumping lines, one for each cavity that can be tested on the CSI, and each pumping line can be linked if required to protect against hardware failures. The SPSV system is controlled remotely via PLC and each line comprises a number of control valves, Pirani gauges, cold cathode gauges, and RGAs that allow cavity acceptance data to be recorded before and after RF testing. All gauge and RGA data is logged and stored during RF testing.

CLEANROOM AND HIGH PRESSURE RINSE FACILITY

Data from previous cavity testing programs such as XFEL [8] suggest that ~30% of cavities may be expected to fail to meet specification on the first test. The standard approach to improve the performance to meet specification is for these cavities to undergo a high pressure rinse (HPR) of their RF surface. A bespoke cleanroom has been designed and commissioned, and houses the HPR facility which has now in the commissioning and validation phase.

The HPR machine was procured from an external supplier, with key design input from STFC technical staff, DESY technical staff, and a contracted SRF technical expert.

Cavities follow a staged cleaning process. First, they enter the ISO 7 area where they are cleaned and loaded onto an inspection table for the assembly of the bespoke alignment cradle, giving concentricity along the full length of the cavity (~1300 mm) of ≤1 mm. They then undergo additional cleaning procedures where they are finally prepared in the main cleanroom (operating under ISO 4 conditions) and vented via a SPSV system with qualifying residual gas analysis (RGA) scans. UHV beam line flanges are then removed and capped, before cavities are connected to the TORROS 500 lifter[4] where they can be rotated into a vertical position in preparation for loading on the HPR machine for treatment in the wet cleanroom. Following the HPR cycle, a designated drying room is utilised.

An ultra-pure water system has been designed and has been fully commissioned, with the system having been demonstrated to meet the final resistivity specification ≥18 MΩ.cm. The full rinse cycle has a duration of 12 hours, including a 20 minute pre-rinse. The wand features a nozzle, manufactured to a DESY design, providing ultra-pure water at 100 bar, along with a nitrogen purge circuit. All cavities are mounted vertically, with the aforementioned concentricity allowing for a highly uniform spray pattern.

All processes are currently being verified and validated using series high-β cavities.

During initial testing of the HPR machine, it was found that the steel beraing was not fit for purpose and in fact was producing particulates. In order to mitigate this, a bespoke solution was developed in-house, utilising an AlTiN coating solution. Additionally, a new ceramic bearing has been procured and is currently being tested offline in readiness for installation during a future technical stop.

[4] torros.net

CONCLUSION

A new Superconducting Radio Frequency Lab (SuRF Lab) which includes a Vertical Test Facility (VTF) and Reprocessing Facility (Cleanroom and High Pressure Rinse) has been commissioned at the UKRI STFC Daresbury Laboratory.

The facility is now well underway on a 2-year testing program for the high-β cavities being provided by the UK as part of its in-kind contribution to the ESS project. Steady state operations are carried out on a 2-weekly basis.

Work is currently ongoing to study the modifications to the facility that will be necessary to support HB650 cavity testing for PIP-II.

ACKNOWLEDGEMENTS

The authors would like to thank collaborators from ESS, DESY, CEA, and INFN, as well as industrial partners. They also would like to thank A. Matheisen for sharing technical knowledge and expertise for the design and commissioning of the SuRF Lab infrastructure, and T. Powers for his help in designing the test system as well as the use of the LabVIEW software from JLab.

REFERENCES

[1] J. Schaffran, *et al.*, "Analysis of the Test Rate for European XFEL Series Cavities", in *17th Int. Conf. on RF Superconductivity (SRF2015)*, Whistler, BC, Canada, Sept. 13-18, pp. 316-318, 2015. doi:10.18429/JACoW-SRF2015-MOPB079

[2] A. J. May, *et al.*, "Commissioning and cryogenic performance of the UKRI STFC Daresbury Vertical Test Facility for jacketed SRF cavities", *IOP Conference Series: Materials Science and Engineering*, vol. 1240 no. 1, IOP Publishing, 2022. doi:10.1088/1757-899X/1240/1/012079

[3] A. J. May, *et al.*, "Steady-State Cryogenic Operations for the UKRI-STFC Daresbury SRF Vertical Test Facility", presented at LINAC'2022, Liverpool, UK, paper TUPOGE09, this conference.

[4] P. A. Smith, *et al.*, "ESS High-beta Cavity Test Preparations at Daresbury Laboratory", in *18th Int. Conf. on RF Superconductivity (SRF'17)*, Lanzhou, China, 17–21 July, 2017, pp. 137-140, 2018. doi:10.18429/JACoW-SRF2017-MOPB040

[5] P. A. Smith, *et al.*, "RF Measurement and Characterisation of European Spallation Source Cavities at UKRI-STFC Daresbury Laboratory and DESY", presented at LINAC'2022, Liverpool, UK, paper MOPOGE25, this conference.

[6] T. Powers, "Theory and practice of cavity RF test systems", Technical report JLAB-ACE-05-475; DOE/ER/40150-4011, Thomas Jefferson National Accelerator Facility, Newport News, VA, USA, 2006.

[7] A. Akintola, *et al.*, "Magnetic Field Measurements and Shielding at 2 K in the UKRI-STFC Daresbury Laboratory SRF Vertical Test Facility", presented at LINAC'2022, Liverpool, UK, paper TUPOGE07, this conference.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOJO15

[8] D. Reschke, *et al.*, "Performance in the vertical test of the 832 nine-cell 1.3 GHz cavities for the European X-ray Free Electron Laser", *Phys. Rev. Accel. Beams*, vol. 20, p. 042004, 2017. doi:10.1103/PhysRevAccelBeams.20.042004