ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB075

PROVISION OF HIGH BETA CAVITIES FOR EUROPEAN SPALLATION SOURCE BY UKRI-STFC DARESBURY LABORATORY

A. E. Wheelhouse†, A. E. T. Akintola, A. J. Blackett-May, M. Ellis, S. Hitchen, P. C. Hornickel, C. Jenkins, M. Lowe, D. A. Mason, P. McIntosh, K. Middleman, G. Miller, J. Mutch, A. Oates, S. Pattalwar, M.D. Pendleton, J. O. W. Poynton, I. Skachko, P. A. Smith, N. Templeton, S. Wilde, J. T. G. Wilson, UKRI-STFC, Daresbury Laboratory, UK
D. Reschke, L. Steder, M. Wiencek, Deutsches Elektronen-Synchrotron, Hamburg, Germany

Abstract

As part of the requirement for the European Spallation Source (ESS) facility in Lund, Sweden, a project has been undertaken by Accelerator Science and Technology Centre (ASTeC) as part of a UK In Kind Contribution to provide 84 704 MHz High-Beta superconducting RF cavities. The project has included the procurement of niobium and the testing of cavities at Daresbury Laboratory and Deutsches Elektronen-Synchrotron, in preparation for integration into the cryomodules which is being performed at Commissariat à l'Energie Atomique et aux Energies Alternatives, Saclay, France. To date all the cavities have been manufactured in industry apart from the final cavity and 3 cavities remain to be tested. An overview of the experiences for the provision of these cavities is described.

INTRODUCTION

Testing of 704 MHz high-beta superconducting RF cavities for the European Spallation Source (ESS) [1] facility in Lund, Sweden started in 2019 with the aim to deliver 84 cavities to Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) Saclay, France for their integration into 21 cryomodules. The requirements for the cavity have an accelerating gradient of 19.9 MV/m at a quality factor (Qo) of 5 x 10^9 (see Table 1).

Table 1: ESS High-beta 704 MHz Cavity

Parameter	Value
Geometrical β	0.86
Frequency (MHz)	704.42
No. of cryomodules	21
No. of cavities per cryomodule	4
Cryomodule length (m)	6.584
Nominal accelerating gradient (MV/m	19.9
Nominal accelerating voltage (MV)	18.2
Q_o at nominal gradient	5 x 10^9

At the beginning of the project for the testing of the ESS high-beta cavities it was estimated that the failure rate of cavities undergoing test would be of the order of 30% and as such that between 115 and 120 cavity tests would be required. To date 88 out of 89 ESS high-beta cavities (Figure 1) have been fabricated in industry by Research Instruments (RI) in Germany and have been delivered to Daresbury Laboratory and Deutsches Elektronen-Synchrotron (DESY) for qualification testing.

The cavity test set-ups at the 2 facilities are different; DESY test system uses the conventional complete bath immersion and is able to test two 704 MHz cavities in a single run. Whereas in the STFC system the cavities are tested horizontally [2] with the cavities cooled by filling the liquid helium jackets, with the capability of testing three cavities in a single run. Additionally, the setups for the measurement of radiation from the cavities are different; DESY's facility has monitors positioned at the top and bottom of the test bunker approximately 2 m from the cavities on the vertical centre line, whereas at Daresbury Laboratory radiation detectors are located at either end of each cavity along the beam axis of the cavity approximately 25 – 30 cm from the cavity. As such the radiation measurements at Daresbury Laboratory are much more sensitive, around a factor of 300.

Figure 1: ESS high-beta 704 MHz cavity.

† Alan.Wheelhouse@stfc.ac.uk

ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB075

CAVITY PERFORMANCE

Pre-Series Cavity Performance

Qualification testing of the 4 pre-series cavities, H001 – H004, was performed at DESY, initially with the cavities un-jacketed and then tested jacketed. This was a fundamental part of verifying the industrial cavity manufacturing process. Manufacturing hold points were used to evaluate the readiness to proceed to cavity production manufacturing. This allowed the buffered chemical processing (BCP) niobium removal rate to be determined, the high-pressure rinse (HPR) process to be validated and ensure that the final light BCP etch of 20 µm and the tank integration process did not have a detrimental effect on the performance quality of the cavity.

The BCP process on cavity H001 was performed in 3 steps; two approximately 45 µm removal runs followed by a 90 µm removal run. The first etch run was used to determine the etch rate and was measured by 3 methods, a sample piece, weighing the cavity before and after processing (most repeatable method) and an ultrasonic thickness measurement performed after the cavity has been dried. A removal rate of 1.1 – 1.2 µm/min was determined and was verified during the subsequent 2 etch runs. A total thickness of 180 µm of niobium was removed. After undergoing high pressure rinsing (HPR) the cavity was then successfully tested without its jacket at DESY, meeting Q, accelerating gradient and X-ray level performance. A second cavity test was then performed after the installation of the helium jacket, a 20 µm light BCP etch and a HPR for 12 hours. A slight degradation in the Q performance at high gradient after the jacket integration was noted as shown in Figure 2.

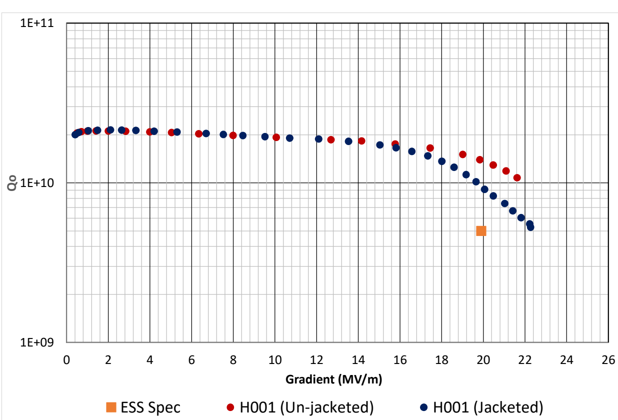

Figure 2: ESS high-beta unjacketed and jacketed cavity test performance for pre-series cavity H001.

Cavity H002 was then released for production which underwent 2 times 90 µm BCP etch removal runs. Similar tests were performed without and with the jacket and showed no degradation in the Q performance. Thus, H003 and H004 were released for processing following the same process as H002 and again no degradation in the performance was noted. The results for the jacketed performance are shown in Figure 3. All cavities met Q versus gradient performance, however, cavity H003 exhibited field emission above a gradient of 16 MV/m (H001, H002, and H004 radiation levels were all below the noise floor of the radiation detectors so are not shown below). An investigation of the cavity showed that it had a stain on the beam pipe, the root cause of which was not determined.

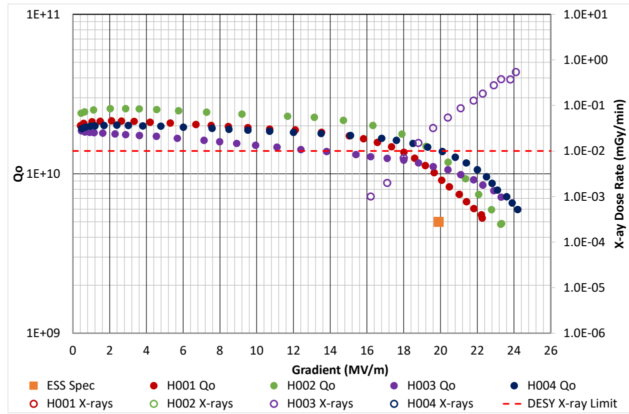

Figure 3: ESS high-beta jacketed cavity test performance for pre-series cavities, H001 - H004.

Overall, with good Q versus gradient performance achieved on all 4 cavities it was decided to proceed with the production cavities.

Additionally, H004 was also tested at STFC to perform a correlation test on the Q and gradient performance of the 2 facilities. Errors for Q and accelerating gradient are estimated to be around 10% and 20% [3], respectively. Here the results obtained showed excellent correlation and are well within the estimated errors as shown in Figure 4.

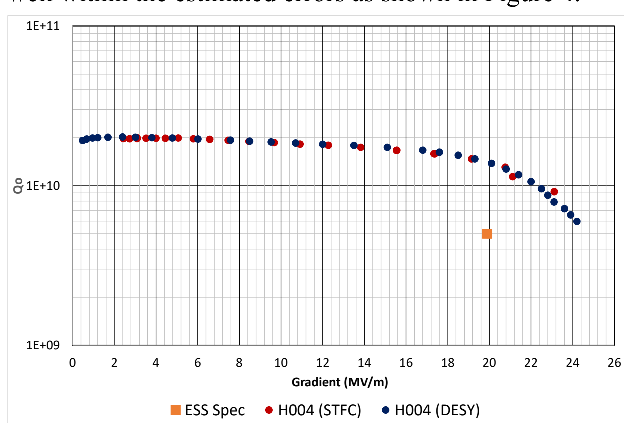

Figure 4: DESY and STFC cavity correlation test results for H004.

Production Cavity Performance

To date 142 jacketed cavity tests (including the pre-series cavities) have been performed either at Daresbury Laboratory or DESY, and 86 cavities have been tested at least once, with 45 (52.3%) cavities having successfully passed test first time. To date 73 (84.8%) cavities have successfully passed test either having passed test first time or having undergone reprocessing, either high pressure rinsing (HPR), or buffered chemical processing (BCP). The most recent cavity test performance is shown below in Figure 5 and Figure 6.

ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB075

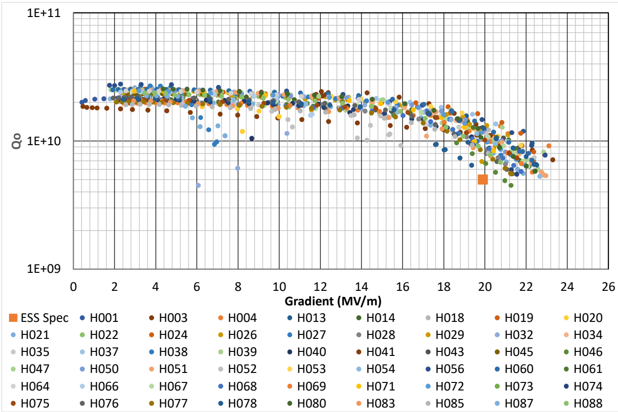

Figure 5: Most recent ESS high-beta cavity test performance for cavities tested at STFC.

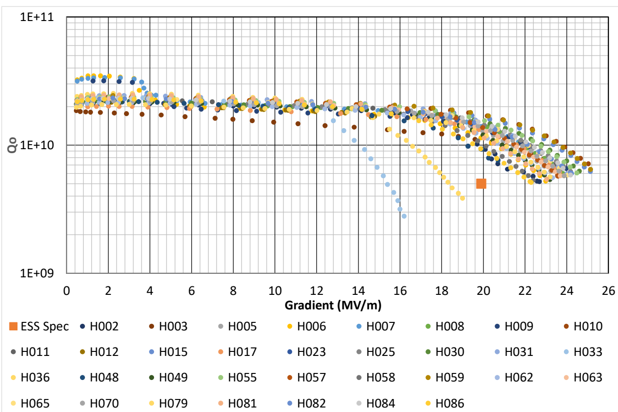

Figure 6: Most recent ESS high-beta cavity test performance for cavities tested at DESY.

An analysis of the cavity test performance to date is shown in Figure 7. It highlights that only 52.3% of cavities have passed test first time.

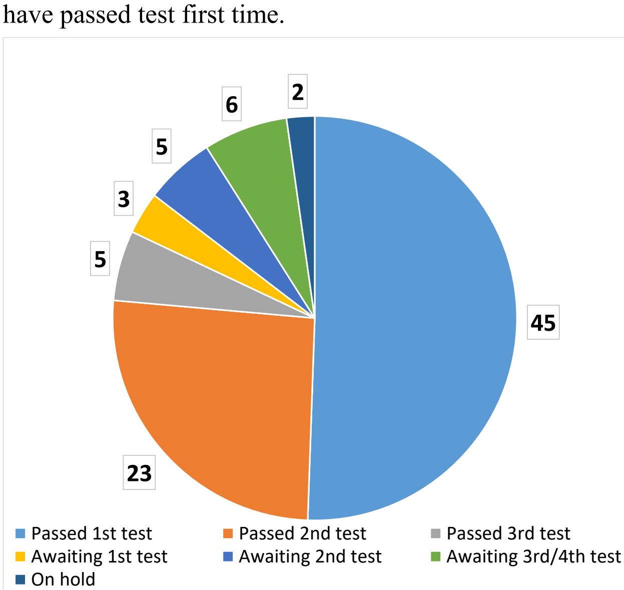

Figure 7: ESS high-beta cavity test performance.

However, for the first 18 cavities tested only 5 cavities passed, a pass rate of only 28% as previously reported [4]. The main failure reason for the 13 cavities was due to field emission, due to which a decision was taken to halt the production and testing of cavities whilst a review of the production processes was performed. During the initial production phase, it had not been possible to perform any quality assurance and control (QA/QC) reviews at RI due to the COVID lockdown, so the review had to be performed remotely and with the assistance of an external consultant, A Matheisen. The review identified several potential improvements; doubling the time for the final HPR to 24 hours, to take into account the cavity shape and surface area, and the inclusion of a Teflon disk on the bottom beampipe flange during coupler assembly to prevent the ingress of particulates. Production of cavities was recommenced and the cavities which had been awaiting test were given an additional 12-hour HPR at either RI or at Daresbury Laboratory.

These subsequent improvements resulted in an increase in the yield with the first-time pass rate for these cavities of 67%, a significant improvement. However, for the cavities that have failed the second tests further reprocessing has been required and to date 5 cavities have passed a third test and 6 cavities await additional processing having either failed the second or third tests. Currently H003 and H012 are on hold having both had additional BCP processing; H003 still exhibits similar field emission to that shown in Figure 3 and H012 has quenched on both tests at ~15 MV/m. Further BCP processing of these cavities would mean that the frequency would be outside the range of the cavity tuners therefore requiring an extensive rework of the cavity where the jacket needs to be removed to enable retuning for a higher frequency and field flatness.

SUMMARY AND FUTURE WORK

At the beginning of the project, it was estimated that between 115 and 120 cavity tests would be required as part of the delivery of 84 cavities to CEA Saclay, however to date 142 cavity tests have been performed and 86 cavities have been tested, with 73 cavities having successfully met performance requirements. Because of the field emission problems, it was necessary to revisit the manufacturing processes for the cavities and implement improvements to increase the testing yield to acceptable levels. This has identified the need for a more robust cavity qualification process as part of the pre-series evaluation and for a more stringent QA/QC monitoring for future similar SRF projects.

The project is continuing with the aim of completing the final cavity tests in October 2023 to enable delivery and cavity integration at CEA Saclay.

ACKNOWLEDGEMENTS

The authors would like to thank collaborators from ESS, DESY, CEA, and INFN, as well our industrial partner. They also would like to thank T. Powers (JLab) for his help in designing the test system as well as the use of the LabVIEW software, A. Matheisen for sharing technical knowledge, and Mrs S. Moeller (DESY) and Mr J. Diakun.

ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB075

REFERENCES

[1] https://europeanspallationsource.se/.

[2] A. J. May *et al.*, "Commissioning and cryogenic performance of the UKRI-STFC Daresbury vertical test facility for jacketed SRF cavities," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1240, p. 012079, 2022. doi:10.1088/1757-899X/1240/1/012079

[3] D. Reschke, "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, no. 4, p. 042004, 2017. doi:10.1103/PhysRevAccelBeams.20.042004

[4] P. A. Smith *et al.*, "RF measurement and characterisation of European spallation source cavities at UKRI-STFC Daresbury Laboratory and DESY", in *Proc. LINAC'22*, Liverpool, UK, Aug.-Sep. 2022, pp. 212-214. doi:10.18429/JACoW-LINAC2022-MOPOGE2