ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-MOPORI18

# OVERVIEW OF STFC DARESBURY LABORATORY VACUUM OPERATIONS FOR THE TESTING OF ESS HIGH BETA CAVITIES*

S. Wilde[1,2], K. Middleman[1,2], O, Poynton[1,2], M. Pendleton[3], D. Mason[3], J. Mutch[3], G. Miller[3]
[1]ASTeC, STFC Daresbury Laboratory, Warrington, UK
[2]Cockcroft Institute, STFC Daresbury Laboratory, Warrington, UK
[3] Technical Department, STFC Daresbury Laboratory, Warrington, UK

*Abstract*

This paper describes the vacuum systems and operations that are used at the STFC Daresbury Laboratory superconducting radio frequency (SuRF) lab during cold RF testing of European Spallation Source (ESS) high beta superconducting radiofrequency (SRF) accelerating cavities. Dedicated slow pump slow vent (SPSV) systems are used to perform vacuum acceptance testing of each cavity before, during and after cold RF testing. Details of the vacuum systems, acceptance criteria and test results will be discussed in detail.

## INTRODUCTION

The ESS will be the most powerful linear proton accelerator that has ever been built. The accelerated protons will impact a helium cooled tungsten target wheel and produce neutrons that can be used to analyse the nanostructure of materials at the atomic level. STFC will supply 84 high beta SRF accelerating cavities to ESS as part of the UK's in-kind contribution to the facility. The SuRF lab was purpose built to conduct acceptance testing of the ESS high beta cavities once they have been built by industry partners. A range of acceptance testing is performed, including mechanical, cleanroom, vacuum, and RF. However, this paper will concentrate on the vacuum acceptance testing.

## VACUUM ACCEPTANCE CRITERIA

Vacuum acceptance criteria have been developed so that each SRF accelerating cavity can be expected to work at optimal performance when installed into the ESS beamline. The acceptable helium leak rate is <1E-9 mbar l/s within the cavity beamline vacuum space and <2E-10 mbar l/s within the helium jacket vacuum space. The helium jacket vacuum space was given a more stringent helium leak rate acceptance criterion so that there is reduced risk of a cold superfluid helium leak once the cavity is installed within cryomodules. All helium leak rates are measured using a Leybold Phoenix Vario leak detector.

Cavities must be delivered to STFC with a total pressure of <1 mbar within the cavity beamline vacuum space. Cavities are at risk of particulate contamination if they are delivered with total pressure of >1 mbar as this puts the vacuum characteristics within the molecular flow regime [1].

The cavity beamline vacuum space must be measured using a residual gas analyser (RGA) and meet the specifications described in table 1. RGA measurements are performed using an MKS Microvision 2 and ensure that the cavity beamline vacuum space is within ultra-high vacuum (UHV) specification [2]. Each vacuum acceptance testing step is performed at pre-defined junctures within the overall process of testing the ESS SRF cavities for SRF performance. An overview of the testing procedure, including the vacuum acceptance testing schedule is described in Fig. 1. A full and detailed description of the SRF testing and setup is given in [3].

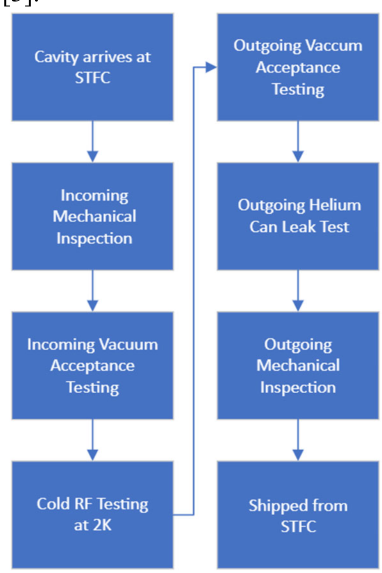


Figure 1: Simplification of the cavity testing process at STFC.

## VACUUM TESTING SYSTEMS

Purpose built slow pump slow vent (SPSV) vacuum systems have been designed and built to perform vacuum acceptance testing. Two SPSV systems, comprising three separate pumping lines, are used during cold RF testing of cavities. A schematic of the SPSV systems is shown in Fig. 2. Each of these two systems is housed on a test insert that can hold up to three cavities. The cavities are loaded onto the test insert, located at a parking stand, and incoming vacuum acceptance testing is performed. The incoming acceptance testing begins by making vacuum connections to the right-angle valve (RAV) of the cavity within an ISO 4 glovebox and recording particulate counts. The SPSV system is then slow pumped at a rate of 10 mbar / min and a helium leak test of the cavity connection and RGA analysis of the SPSV system is performed. If the SPSV is accepted, then the cavity RAV is opened and leak testing and RGA analysis of the cavity is performed. Valve V7, as described in Fig. 2, is closed when opening the cavity RAV, and protects the SPSV system from overpressure. So long

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Table 1: Summary of RGA Acceptance Criteria. Calculation to be Performed at $10^{-7}$ mbar or Below.

| Pressure Region | General Contaminants (%) | Perfluoropolyphenylethers (Sum of peak at 69 and 77 amu) (%) | Chlorinated species (Sum of peak at 69 and 77 amu) (%) | Comment |
|---|---|---|---|---|
| HV – UHV | 0.75 | 0.075 | 0.075 | Assuming unbaked system |

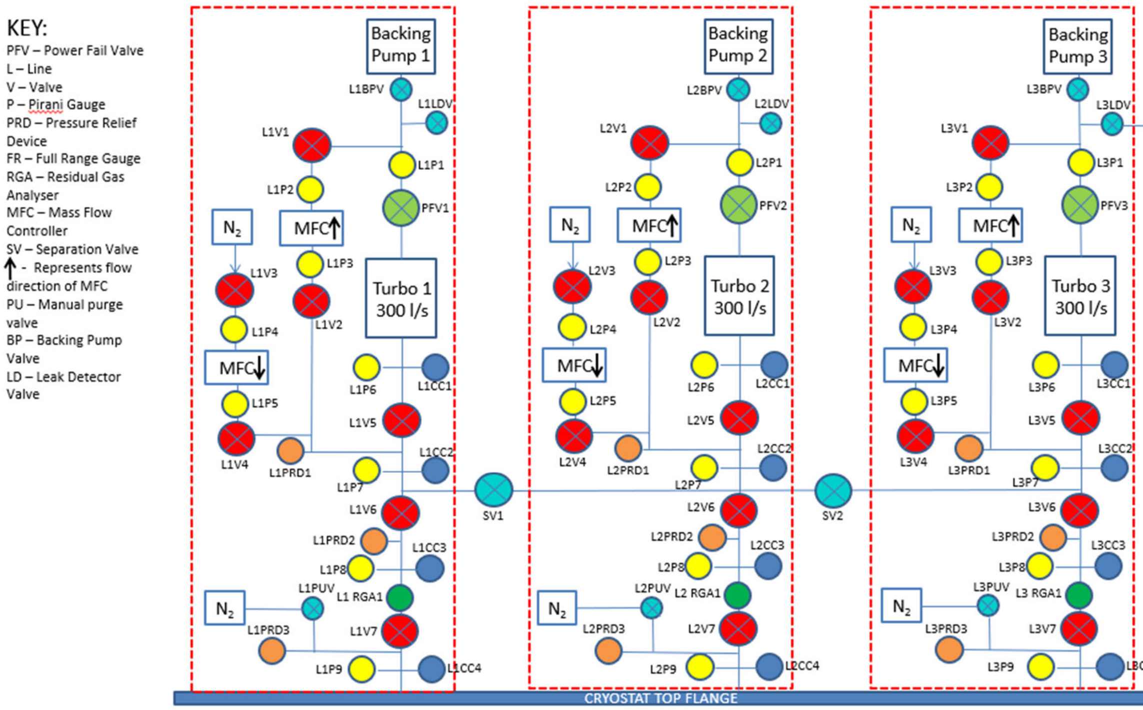

Figure 2: Schematic of SPSV system.

as the cavity pressure is <1 mbar then testing can continue. If Cavity pressure is ≥1 mbar, then cavity is slow pumped and rejected.

If the cavity passes incoming vacuum acceptance, then the test insert is moved to a bunker area for cold RF testing to take place. The test insert is moved back to the parking stand after cold RF testing is complete and the outgoing vacuum acceptance testing is performed and cavity RAV closed.

## RGA ACCEPTANCE TESTING RESULTS

Sixty-six cavities have been tested so far using RGA analysis and all have been within specification. A typical outgoing RGA scan is shown in Fig 3.

Repeated RGA testing has shown that there is a process bottleneck whilst waiting for RGA filaments to degas and therefore meet the required acceptance criteria i.e. the cavity RAV is still closed but SPSV is awaiting acceptance.

This has meant that each SPSV system is to be upgraded so that RGA's can be isolated and kept under vacuum using an ion pump. Thus, the RGA does not need to be vented when changing cavities on the insert and the RGA filaments can always remain on (except during transfer from parking stand to bunker). This change will save approximately one day per testing run.

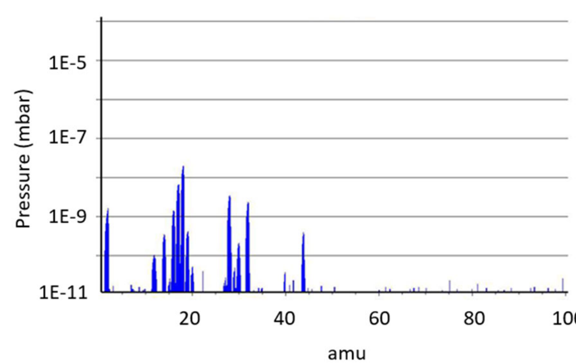

Figure 3: Typical accepted RGA spectrum of ESS SRF cavity.

## HELIUM LEAK RATE MEASREMENTS

Helium leak rates have been measured using two different techniques. Measurement of the cavity beam line has been performed by spraying helium around flanged joints and welds whilst measuring the leak rate using a leak detector. Cavity helium jackets have been measured whilst pumping on the helium jacket vacuum space with a leak

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Table 2: Summary of Helium Jacket Leak Rates (*2E-12 after 24 hours).

| Cavity | Leak rate after 1 hour (mbar l/s) | Leak rate 1 hour after hot purge (mbar l/s) |
|---|---|---|
| H051 | 7E-8 | 2E-10 |
| H047 | 2E-10 | |
| H060 | 1E-9 | 4E-10* |
| H034 | 6E-10 | 9E-11 |
| H074 | 7E-10 | 1E-12 |
| H035 | 2E-10 | 1E-12 |
| H064 | 3E-9 | 1E-12 |
| H061 | 1E-12 | |
| H076 | 3E-10 | 1E-12 |
| H067 | 1E-12 | |
| H074 | 1E-12 | |
| H077 | 9E-11 | |
| H080 | 1E-12 | |
| H085 | 9E-11 | |
| H083 | 9E-11 | |
| H014 | 4E-11 | |
| H017 | 4E-11 | |
| H088 | 1E-10 | |
| H018 | 1E-12 | |
| H035 | 2E-10 | 2E-12 |
| H068 | 3E-11 | |
| H037 | 2E-11 | |

detector and then enclosing the entire cavity with a helium filled bag, the resulting leak rate is then measured. To date, sixty-six cavities have been tested for the beam line leak tightness and twenty-two have been tested for helium jacket leak tightness, all met the leak rate requirements. However, helium leak rate testing of the cavity helium jacket has proved to be complicated in some instances since the in-vacuum surfaces of the helium jacket will have recently been exposed to liquid helium during cold RF testing. After leak rate testing of several different cavities, we noticed that if the required leak rate was not reached within one hour of initial pump down, then it would take several days to reach the required rate of <2E-10 mbar l/s. Thus, a solution to speed up the outgassing of the adsorbed helium needed to be implemented so that the outgoing helium jacket leak test could be performed within a reasonable operational timeline.

The solution to the problem came in the form of a nitrogen purge using heated nitrogen gas. An Omega AHP-3741 in-line gas heater was used to heat the nitrogen gas to approximately 80˚C at the inlet to the helium jacket. The helium jacket itself did not heat above 30˚C. A thermal imaging camera was used to measure the temperature of both the helium jacket inlet and helium jacket, and the images are shown in Fig. 4.

It should be noted that not all cavities required the hot purge to reach the required helium leak rate. Thus, cavities are pumped for one hour, if a leak rate of <2E-10 mbar l/s is achieved in that time, then testing can continue. If the required leak rate is not achieved, then the hot purge is implemented. Table 2 highlights that all but one tested cavity requiring the hot purge subsequently reach the required leak rate within one hour of pumping after the purge, saving a potential of several days of operational time.

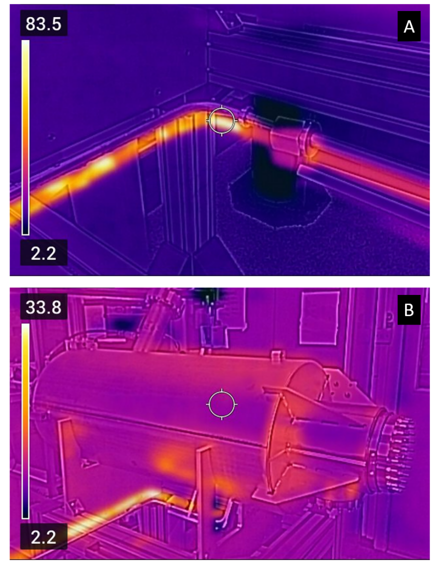


Figure 4: Thermal imaging of A, the helium jacket inlet, and B, the cavity helium jacket.

## INCOMING CAVITY PRESSURE MEASUREMENTS

Incoming cavity pressure typically ranges between E-5 to E-3 mbar. However, two cavities have been received with pressure of 1 mbar and were subsequently rejected as out of specification and sent back to the vendor for repair. Both instances of overpressure were a result of RAV which leaked though the closing face of the valve. Since each RAV was repurposed from XFEL cavity manufacture (but with incomplete history i.e. unknown how many times each RAV has been cooled to 2K), then it has been assumed that RAV can become damaged by repeated thermal cycling. Further testing is required before conclusions can be made as to whether there is a maximum number of times each RAV can be thermally cycled before they are no longer fit for purpose.

## CONCLUSIONS

To date, all ESS high beta cavities have achieved the required helium leak rates and RGA characteristics. Two failures have occurred due to faulty RAV. All data will be compiled once cavity testing is complete and further information will be reported at that time.

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