SUPERCONDUCTING RF CAVITY DEVELOPMENT WITH UK INDUSTRY

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Abstract

As part of a continuing STFC Innovations Partnership Scheme (IPS) grant, in support of enabling UK industry to address the large potential market for superconducting RF structures, Daresbury Laboratory and Shakespeare Engineering Ltd are developing the capability to fabricate, process and test a niobium 9-cell 1.3 GHz superconducting RF cavity. A single-cell cavity fabricated under this grant was surface processed and tested at Fermilab, and achieved an accelerating gradient in excess of 40 MV/m at an unloaded quality factor in excess of 1.0 x 10^{10}. This paper presents the results of the single-cell cavity testing and discusses the progress made to date in the development of the design and manufacture of a 9-cell niobium cavity, which Shakespeare Engineering Ltd will fabricate and which is anticipated to be qualified in 2014.

INTRODUCTION

Previously as part of a STFC Industrial Programme Support Scheme (PIPSS) grant provided to ASTeC (Accelerator Science and Technology Center) Department at Daresbury Laboratory and Shakespeare Engineering Ltd [1] 3 single-cell 1.3 GHz niobium superconducting RF (SRF) cavities were fabricated in collaboration with Jefferson Laboratory [2]. The programme to support the development of the UK capability to fabricate, process and test SRF cavities has been further continued through a 3 year STFC Innovations Partnership Scheme (IPS) grant. The aim of the programme of work is to fully qualify the single cell cavities and to develop the capabilities to fabricate and test a 9-cell SRF cavity. Following on from the single-cell cavity a staged approach to the development is planned, thus initially a 2-cell cavity will be fabricated so as to verify the design of the cells (end and centre cells) and to gain experience in the fitting of stiffening rings, both longitudinally and radially in relation to the inner surface of the half-cell. The overall objective for the 9-cell cavity is to achieve an accelerating gradient of greater than 20 MV/m at an unloaded quality factor, Q_o better than 1.0 x 10^{10} and a gradient greater than 30 MV/m after performing electro-polishing (EP) chemical processing. The step from a single cell cavity to a 9-cell cavity also introduces additionally fabrication complications such as the cell to cell alignment, tuning robustness and uniformity, tolerance management, cleaning/processing compliance, and RF surface integrity management, which are to be investigated.

Additionally an automated Buffered Chemical Polish (BCP) etching system and a High Pressure Rinse (HPR) system are being installed and commissioned at Daresbury Laboratory to facilitate the fabrication of the cavities.

SINGLE CELL CAVITY EVALUATION

Previously reported [2] processing and qualification testing was performed at Jefferson Laboratory on PIPSS cavity #01. The cavity was initially BCP etched and HPR (Tests #01 and #02), followed by a vacuum bake at 600°C for 10 hours with an additional BCP etch and a HPR (Test #03), and finally with a further HPR (Test #04). The target was to achieve an accelerating gradient of 15 MV/m at a Q_o of 1.0 x 10^{10} at 2K, which was successfully managed during the first test with a gradient of 15.7 MV/m and subsequent processing enabled the cavity to reach 22.9 MV/m with a Q_0 of 1.06 x 10^{10} at 2K (Fig. 1). However, multipactor was present at around 16 MV/m.

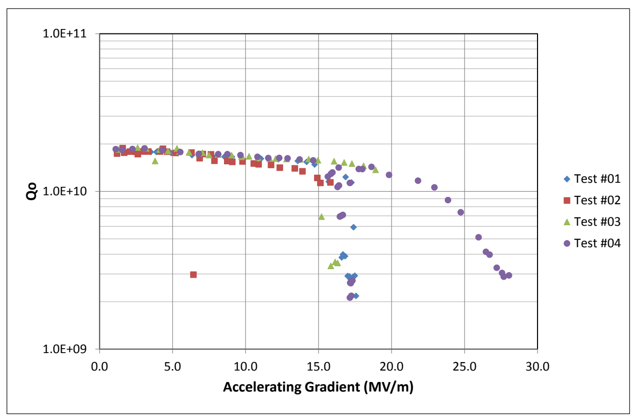

Figure 1: Performance results for PIPSS cavity #01 tested in the vertical test stand at Jefferson Laboratory after BCP processing.

Qualification tests on the single cell cavity PIPSS #03 has been performed by Fermilab in their vertical test facility as part of a collaboration agreement. An initial evaluation was performed after a bulk EP processing, followed by an 800°C hydrogen degas and a light EP process. As shown in Fig. 2 the cavity achieved a gradient of 25 MV/m with Q_o=1.5 x 10^{10} under 2K conditions and was limited by a quench at 25.5 MV/m, which would not process out. Some soft multipacting was noted in the typical 19 MV/m region for an ILC-shaped cavity which was processed away.

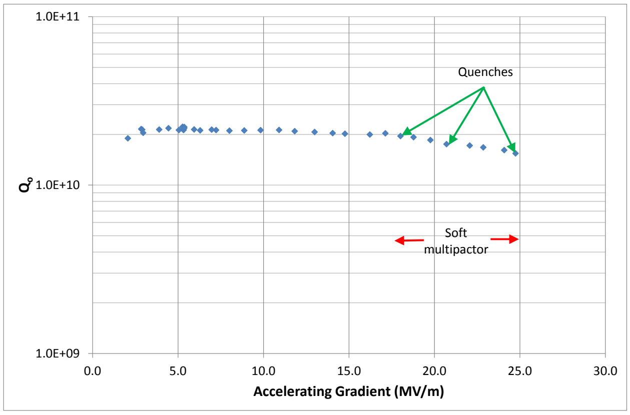

Figure 2: Performance results for PIPSS #03 tested at Fermilab after EP processing.

At Fermilab a programme of work to develop the capability Centrifugal Barrel Polishing (CBP) [3], is on-going with one of the aims being to potentially remove the need for acid processing of cavities [4]. Thus the next stage of processing performed on the cavity was a CBP, followed by a light 30 µm EP process, an 800°C vacuum bake for 3 hours and a HPR. An increased accelerating gradient of 25 MV/m at Q_o of 2.0 x 10^{10} was achieved at 2K. Once again it was necessary to process through a region of multipactor, with the onset occurring at 16 MV/m. However, this time X-rays were observed with maximum level of 5 µSv/hr being observed at a gradient of 16.5 MV/m. The cavity then received a 120°C vacuum bake and was retested at 2K (Fig. 3). Initially multipactor was observed at gradients between 20 and 30 MV/m with X-ray levels of up to 0.3 µSv/hr. After conditioning an increased gradient of 40 MV/m with a Q_o of 1.0 x 10^{10} was achieved and was limited by a quench at 41 MV/m.

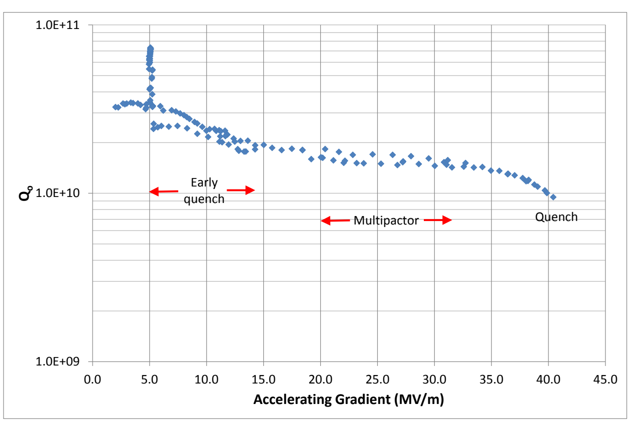

Figure 3: Performance results for PIPSS #03 tested at Fermilab after CBP and a 120ºC vacuum bake.

Further vertical tests incorporating a T-map facility are planned to enable analysis of the location of the multipactor.

FACILITIES

To enable the step from processing a single-cell cavity to that for a 9-cell cavity the facilities have been expended to include a fully automated BCP etching facility and an automated HPR stand.

The BCP cabinet (Fig. 4) has been manufactured by Engenda Process Design Ltd (formally S. J. Process Ltd) [5], based in the UK. The system is a fully enclosed within a walk-in type of fume cupboard and includes extraction system exhausted to an alkali scrubber to greatly reduce the risk to the operator of exposure to the hazardous chemical fumes. The cavity to be etched will placed in a chilled water jacket to control the temperature of the cavity inner surface during the exothermic reaction and the amount of material etched is to be determined by ultrasonic measurement. The system is controlled via a Siemens S7 PLC [6], for which the software has been fully implemented and tested.

Figure 4: Buffer Chemical Polishing cabinet.

Additionally a fully automated ultra-pure water HPR stand based on a similar design to the stand at Fermilab, has been manufactured and installed in a room next to the BCP facility. The stand is designed for a water pressure of 1350 PSI, and the water quality will be better than 18 MΩcm. It has 1.5 m linear rail and the rinse nozzle wand has a maximum speed of 2 RPM.

CELL FABRICATION

The design of the 9-cell cavity is based on the TTC cavity design and incorporates steps at the equator and iris

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interfaces to ensure the ease of parallelism of the equator planes and repeatability of mating half-cells together. However, as the main purpose of the programme is to evaluate ability to fabricate and process the cells, the design does not incorporate any higher order mode coupling ports.

Deep-drawing tool dies have been manufactured from tool steel and trials have been performed on copper using a 60 tonne press. A number of centre and end cells have been formed in copper. Excellent interfacing between half-cells has been established, ensuring that there is maintenance of the roundness of the equator, along with control of spring-back and tolerance variability of thickness. As is standard additional length has been added to the equator of the half-cell design to allow for trimming to optimise the frequency and to allow for weld shrinkage. Resonant frequency measurements have been performed (Fig. 5 and Fig. 6) to assess the reproducibility of forming the shape of the half-cells. Good repeatability for 6 of the half-cells is seen and it needs to be understood the reason for the frequency variation on the other 2 half-cells. It is planned to trim the equators of the half-cells in their dumb-bell pairs in steps, to gain an understanding of the relationship to frequency.

Once these trials have been completed then the tooling ties will be re-polished to ensure that they are free from any contamination and niobium half-cells with be formed from niobium sheets with a residual resistivity ratio (RRR) of greater than 300, which has already been procured. A trial 2-cell cavity will be fabricated prior to fabrication of a full 9-cell cavity.

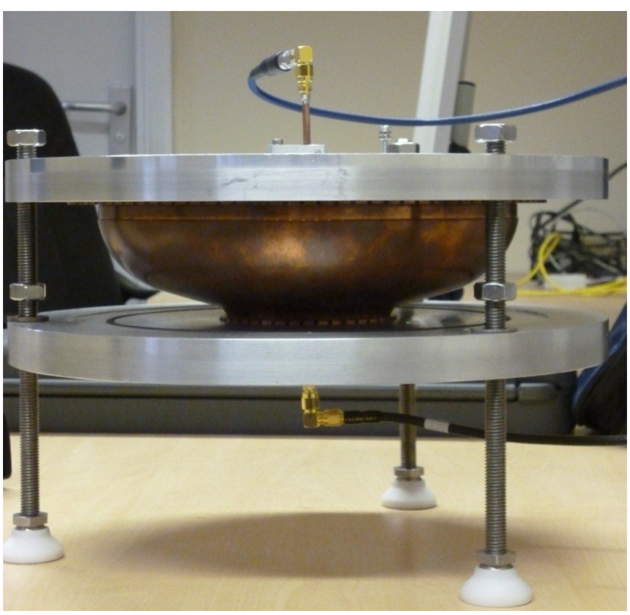

Figure 5: Frequency measurement of a copper half-cell.

SUMMARY

Qualification of single cell cavity PIPSS #03 is being performed at Fermilab, and has achieved a gradient of 40MV/m at a Q_o of 1.0 x 10^{10} after EP and CBP processing. Further characterisation of the cavity is to be performed to understand the location of soft multipactor which has been witnessed during the vertical tests performed. Previous qualification of a single cell cavity following BCP processing had achieved 22.9 MV/m. Thus, these recent tests further demonstrate that UK industry has the capability to fabricate world-class SRF components to the required standards.

Further developing SRF capabilities, facilities have been expanded to enable the processing of 9-cell cavities. Automated BCP and HPR facilities have been installed and are being commissioned at Daresbury Laboratory. Progress is also being made towards developing the techniques and controls to fabricate a 9-cell SRF structures.

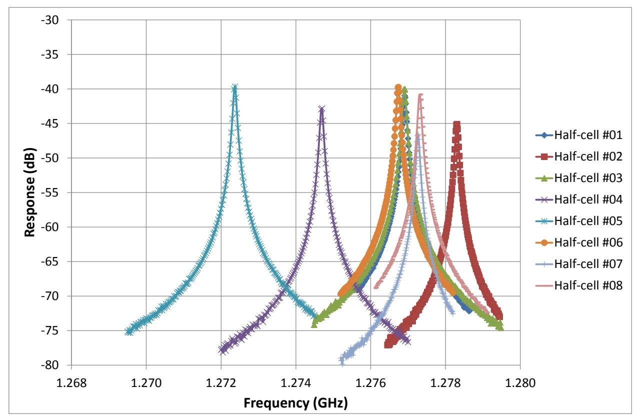

Figure 6: Frequency response for copper half-cells

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