PROGRESS ON SUPERCONDUCTING RF CAVITY DEVELOPMENT WITH UK INDUSTRY

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Abstract

As part of a STFC Industrial Programme Support (IPS) Scheme grant, Daresbury Laboratory and Shakespeare Engineering Ltd have been developing the capability to fabricate, process, and test a 9-cell, 1.3 GHz superconducting RF cavity. The objective of the programme of work is to achieve an accelerating gradient of greater than 20 MV/m at an unloaded quality factor of 1.0 x 10^{10} or better. Processes such as the high pressure rinsing and the buffer chemical polishing are being developed at Daresbury Laboratory and the manufacturing of the cavity half-cells and beam-pipes are being optimised by Shakespeare Engineering to enable this target to be achieved. These are discussed in this paper.

INTRODUCTION

ASTeC (Accelerator Science and Technology Center) Department at Daresbury Laboratory and Shakespeare Engineering Ltd [1] are developing the capabilities to produce and test a 9-cell, 1.3 GHz Tesla style superconducting RF (SRF) cavity as part of a 3-year Industrial Programme Support (IPS) Scheme grant [2].

The IPS grant is a follow-up grant from a MINI-IPS [3], in which 3 single-cell 1.3 GHz niobium SRF cavities were successfully produced. The aim of the MINI-IPS was to set the foundations for the development of 9-cell cavity and with a target objective of 15 MV/m at 1.0 x 10^{10} at 2 K, initial tests performed on the first single-cell cavity in collaboration with Jefferson Laboratory, PIPSS #01 achieved a gradient of 15.7 MV/m at 2K prior to processing. After processing, buffer chemical polishing (BCP) and high pressure rinsing (HPR), a gradient of 22.9 MV/m with a Q_0 of 1.06 x 10^{10} at 2K was achieved, as shown in Fig. 1. Qualification tests performed at FermiLab on PIPSS #03 an accelerating 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, as shown in Fig. 2.

These results provided great confidence in the forming of the cell shape and the techniques developed, to progress the knowledge gained toward the manufacture of a 9-cell cavity. Thus expanding on this original programme of work, the aim of the IPS is to develop the ability to produce and test a 9-cell, 1.3 GHz Tesla style SRF cavity. The programme of work is being progressed in a number of stages:

- Development of the design and the drawings
- Fabrication of a prototype 2-cell copper cavity
- Fabrication and vertical testing of a 2-cell niobium cavity
- Fabrication and vertical testing of a 9-cell niobium cavity.

It is planned to firstly perform BCP processing and then electro-polishing processing (EP) on the 9-cell cavity. To verify the quality of the design and the fabrication an accelerating gradient of greater than 20 MV/m at an unloaded quality factor, Q_o better than 1.0 x 10^{10} after BCP is targeted and a gradient greater than 30 MV/m after EP.

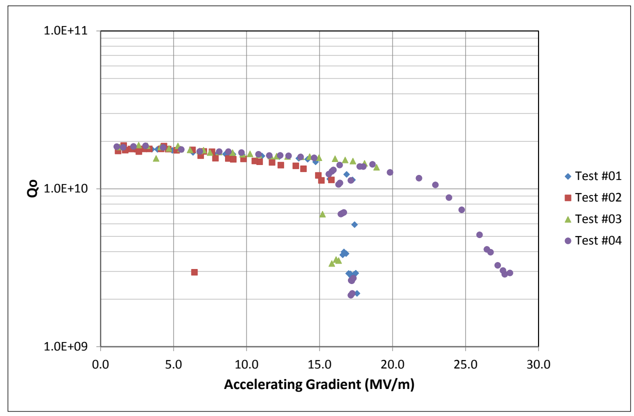

Figure 1: Performance results for PIPSS cavity #01 tested in the vertical test stand at Jefferson Laboratory after BCP processing.

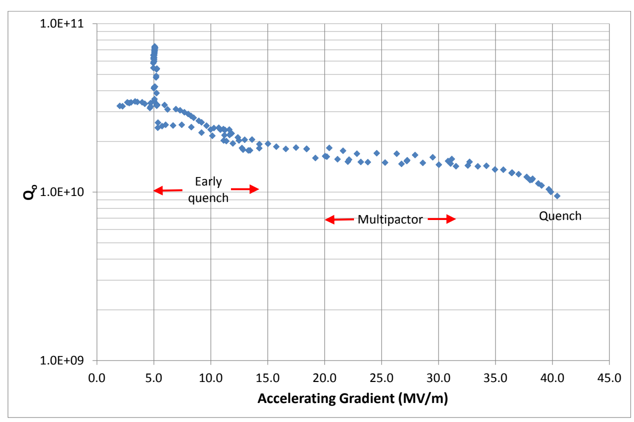

Figure 2: Performance results for PIPSS #03 tested at Fermilab after CBP and a 120ºC vacuum bake.

CAVITY DESIGN

The design of the cavity is based on the Tesla cavity design, but does not include any coupling ports. The beampipe design is seamless, which reduces the need of performing an electron beam (EB) weld process. The design of the equator and iris interfaces incorporates a step joint to ensure the ease of parallelism, in particular

ISBN 978-3-95450-178-6

on the cell equator, thus providing greater repeatability. The size of the step has been minimised to a depth to 0.4 mm to reduce the risk of trapping contamination during the EB welding process, so as to minimise the likelihood of causing a hole.

FABRICATION

Beam-pipes

To produce a seamless beampipe it is necessary to spin a sheet of niobium (see Fig. 3). For the single-cell cavities 3 mm thick niobium was used, but for the fabrication for the 9-cell cavity, 4 mm thick niobium has been used to reduce the risk of material thinning during the process. Trials were initially were performed using copper, which has similar properties to niobium with respect to malleability, and was then successfully transferred to niobium, enabling the required beam-pipes to be produced.

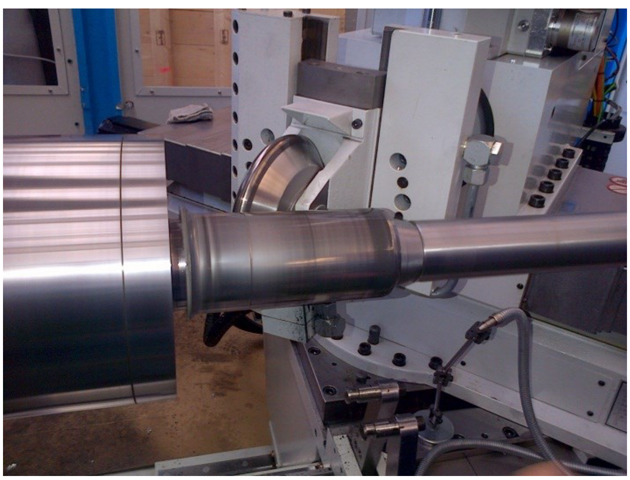

Figure 3: Niobium beam-pipe spinning.

Cavity

Deep-drawing tool dies have been manufactured from high carbon tool steel for each type of half-cell, and as part of the process particular care and attention was taken to minimise the wall thickness variability and spring-back, so as to maintain the roundness of the equator. Trials were initially performed with copper using a 60 tonne press. The shape of the pressed half-cells was validated via frequency measurements and measurements using a Coordinate Measurement Machine (CMM). Machining of the half-cells and dumbbells is performed using a modern CNC machine. Additionally to ensure the shape is maintained during the trimming of the dumbbells, and the machining of the equator and iris steps, additional jigs have been developed by Shakespeare Engineering which are combined with the pressing dies. These enable the half-cell/dumbbell to be self-located and importantly the repeatability of the datum points in terms of the accuracy of the axial and linear features. As such a copper 2-cell cavity was successfully fabricated to confirm these capabilities.

Following on from the copper cavity Shakespeare Engineering has formed the niobium half-cells for the 2-cell and 9-cell cavities (Fig. 4).

Figure 4: Pressed and partial machined 1.3GH SRF cavity.

Frequency measurements and some CMM measurements have been performed on these half-cells [4] prior to the machining of the steps and the forming of the dumbbells. The CMM measurements (Fig. 5) show that the half-cell profile is mainly within the 100 μm tolerance, apart from a deviation occurring near the iris. The results from the frequency measurements (Fig. 6) showed that the consistency of the fabrication of each type of half-cell has been determined to be within 5 MHz, which could be explained by the deviation seen at the iris.

Figure 5: CMM profile of niobium half-cells.

The half-cells are now ready for EB welding of the iris joints to form the dumbbells.

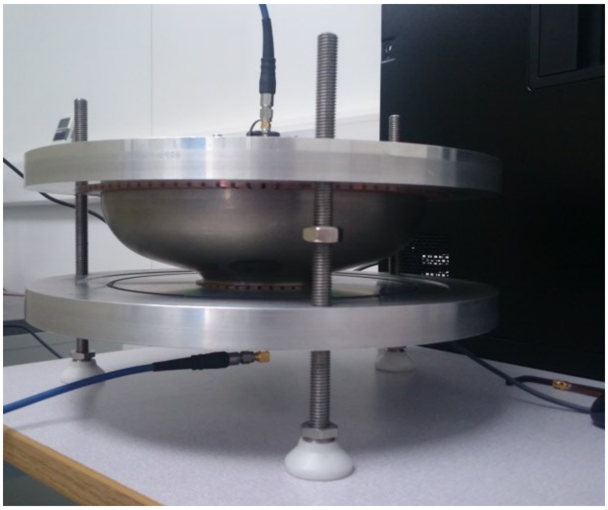

Figure 6: S21 frequency measurement of a half-cell.

Electron Beam Welding

EB welding trials have been performed at Bodycote PLC [5], using a 150 kV 160 mA EB welder. To facilitate the process, the welding bay was thoroughly cleaned to ensure the target welding pressure of 2 x 10^{-5} mbar could be achieved. Initial trials have been performed on niobium samples to develop the welding parameters. To optimise the process further trials are to being performed on both flat plate samples as well as beam-pipes. Jigs have been designed and produced to enable the EB welding to be performed.

FACILITY DEVELOPMENT

Following on from the MINI-IPS the facilities have been developed and expanded to meet the requirements for the fabrication of the 9-cell cavity. The BCP and high pressure rinse (HPR) stand have been automated.

Buffer Chemical Processing Facility

An automated BCP cabinet (Fig. 7), incorporating a walk-in type of fume cupboard with an extraction system exhausted to an alkali scrubber, so as to minimise the risk to the operator of exposure to the hazardous chemical fumes has been designed and manufactured by Engenda Process Design Ltd [6] (formally S. J. Process Ltd). The system has been installed and commissioned at Daresbury Laboratory. Even flow of the acid over the inner cavity surface to ensure a greater potential of more even etch rate, has been obtained by the inclusion of an inner narrow diameter shell within the cavity. To control the temperature of the exothermic reaction, the system has a chilled water jacket surrounding the cavity. The amount of material etched is to be measured ultrasonically. The overall system is controlled using a Siemens S7 PLC [7], for which the software has been fully implemented and tested.

Figure 7: Buffer Chemical Polishing cabinet.

High Pressure Rinse Facility

A fully automated ultra-pure water HPR stand (18 MΩ) based on a stand at Fermilab, has been located in a room next to the BCP facility. The system is capable of operating at a water pressure of 1350 psi and has a rinse nozzle wand with a maximum speed of 2 RPM along with a 1.5 m linear rail.

Mechanical Cavity Tuning

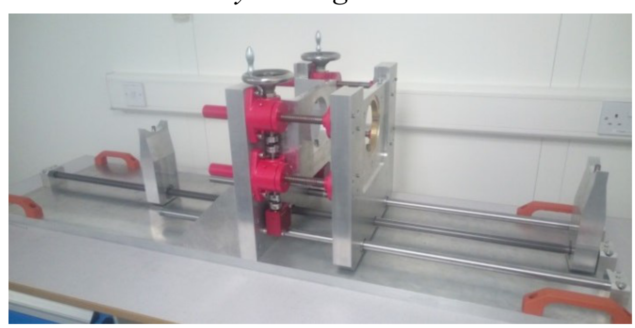

Figure 8: Mechanical cavity tuning fixture.

A manual mechanical cavity tuning fixture (Fig. 8) has been designed and procured. The system has been designed to provide a maximum tuning range of 4.5 mm and consists of 2 yokes, one of which is fixed and the other is floating. The cavity is held in place by split tuning plates which slot into the yokes and clamp around the iris. The floating yoke is supported by 2 precision linear bearings and cell tuning is performed by adjusting the position of this floating yoke with respect to the fixed yoke. The mechanism for the tuner contains inter-connecting actuators, which ensure equal and opposite rotation therefore providing even tuning. The positions of the cavity supports are adjustable to enable the tuning of the different cells. Measurements of the frequency of the cells and cavity flatness will be performed via bead-pull.

SUMMARY

As part of the initial MINI-IPS programme a gradient of 40MV/m at a Q_o of 1.0 x 10^{10} after EP and CBP has been achieved on a single cell cavity, PIPSS #03.

ISBN 978-3-95450-178-6

For the IPS programme the SRF capabilities, facilities have been developed to enable the processing of 9-cell cavities, with installation at Daresbury Laboratory of an automated BCP and HPR systems, along with a mechanical tuning facility.

A prototype 2-cell copper cavity has been fabricated, which has confirmed the capability of the pressing process of the dies showing that they can produce the required cell shapes for both the centre and end-cells. Niobium half-cells and spun niobium beam-pipes have been produced and characterised via frequency and CMM measurements. EB welding trials have been performed, and it is planned to progress the welding of the beam-pipes and half-cells in the near future.

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[6] Engenda Process Design Ltd, Dee House, Hampton Court, Manor Park, Runcorn, Cheshire, WA7 1TT, UK; www.engenda-group.com

[7] Siemens; www.siemens-automated.co.uk