FABRICATION AND TESTING OF SSR1 RESONATORS FOR PXIE*

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Abstract

Fermilab is in the process of constructing a proton linac to accelerate a 1 mA CW beam up to 30 MeV to serve as a test beam for the Project X Injector Experiment (PXIE) [1]. The major goals of PXIE are the validation of the Project X concept and mitigation of technical risks. The PXIE linac consists of an Ion source and Low Energy Beam Transport, a 162.5 MHz Radio Frequency Quadrupole, a Medium Energy Beam Transport, a 162.5 MHz Half-Wave Resonator cryomodule and a 325 MHZ Single Spoke Resonator of first type (SSR1). In this paper, we present the recent advances in the development of the SSR1 resonators at Fermilab, discuss the cavity processing and testing regimes, and report performance results of several bare SSR1 resonators that were successfully tested in the Fermilab Vertical Test Stand (VTS).

INTRODUCTION

The SSR1 cryomodule included in the PXIE linac contains 8 SSR1 cavities. Ten cavities were manufactured in US industry and delivered to FNAL in 2012. Manufacturing issues were observed during electron-beam welding resulting in the development of new welding parameters that lead to the successful completion of the cavity production. Where weld failures occurred, repairs were performed that did not diminish cavity performance. This production batch of cavities is nearing the completion of the high-gradient tests in the VTS at FNAL with results above the SSR1 Project X performance specifications.

MANUFACTURING ISSUES

SSR1 resonators are manufactured by forming, machining and electron-beam welding Niobium sheets having nominal thickness of ~ 3 mm. Some joints in the SSR1 resonator require full-penetration welding from the non-RF side. These welds are the most critical as they offer the least amount of forgiveness.

Weld samples of short length were produced to optimize the quality of the weld on the RF side of the cavity walls. Weld parameters were adjusted to obtain an acceptable result in terms of smoothness and consistency. The feed rate for these full-penetration welds (~ 6"/min) was considerably slower compared to similar SRF applications.

During the fabrication of the production batch, several issues were observed during full-penetration electron-beam welding. Minor changes and process improvements were implemented after these anomalies were observed. The anomalies that occurred included visible events such as increased sparking activity, and measurable events such as voltage and current instability. In most cases, such events produced minimal variations in the weld bead. Occasionally, the effects were apparent in the form of a ripple on the weld bead or a shallow crater from the non-RF side. After careful visual inspection, it was concluded that all these events caused acceptable deviations. In four cases spanning several months in the fabrication process, holes formed in the weld bead (see Figure **1**). The manufacturing was temporarily halted while the issues were addressed.

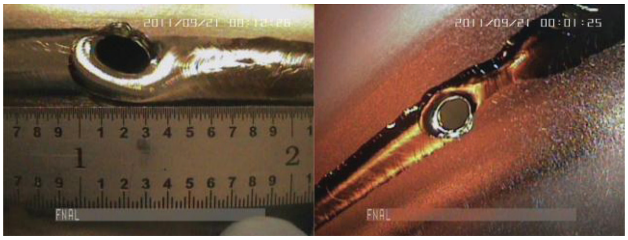

Figure 1: A typical blow-through viewed from the outside (left) and from the inside of the cavity (right).

Mitigation

Extensive EBW tests were performed on a cylindrical part (see Figure **2**). New parameters were developed that allowed increasing the feed rate and stabilizing the weld pool. Also, additional precautions were implemented such as interposing a vapor shield in front of the weld gun. Tests confirmed that the occurrence per unit length was reduced.

Figure 2: Baseline weld tests with original parameters, a hole is visible in the center of the image.

The remaining four cavities were welded with the new parameters. The recorded occurrence of weld anomalies was considerably smaller and the amplitude of measurable events was also smaller. No holes were

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* Operated by Fermi Research Alliance, LLC, under Contract DE-AC02-07CH11359 with the U.S. DOE

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generated in the tests with new parameters during the completion of the last four resonators.

Repairs

The typical plug-type repair plan for SRF cavities with blow-through holes was followed. This process occurs in several steps. First, the existing blow-through is machined to a known circular or race-track shape. Second, a niobium plug is machined to the same shape and carefully positioned in the hole (see Figure **3**). Finally, the plug is completely melted via electron-beam weld. The resulting weld bead depends on the size of the plug and is only slightly visible in the case of plugs having diameters smaller than the weld bead width.

Figure 3: Weld plug machined and positioned ready for welding.

CAVITY TESTS

Preparation of Cavities for Tests

Upon delivery, all cavities undergo incoming quality control/assurance (QC/QA) inspection, which includes visual inspection, coordinate machine measurements, RF QC and vacuum leak check. The cavities enter processing cycle at the FNAL/ANL cavity processing facility jointly operated by Fermilab and Argonne National Laboratories. The processing path is a typical buffered chemical processing sequence optimized for the SSR1 shape [2]. Following incoming QC/QA, the cavity is pre-cleaned for BCP utilizing ultrasonic (US) degreasing and ultra-pure water (UPW) rinsing. The cavity then receives 120 µm bulk internal material removal using a 1:1:2 (48%HF : 69%HNO_3 : 85%H_3PO_4) BCP mixture maintained at 12 C. The bulk BCP process is performed in two opposing orientations to minimize differential material removal. Following bulk BCP, the cavity is US degreased/UPW rinsed and receives a single-pass high pressure rinse (HPR) before Hydrogen degassing. The degassing cycle is performed with a 10 hour plateau in high vacuum at a pressure of 5.0 x 10^{-6} mbar and a temperature of 600 C. Then final RF tuning is done, followed by a third US degreasing/UPW rinse and subsequent light (20-30 µm) BCP. The cleanroom processing sequence starts with a final US/UPW rinse followed by an optimized HPR that introduces the wand in all ports in both the horizontal and vertical orientations. Inserting the wand in multiple orientations provides a nearly 100% internal HPR surface coverage that is otherwise impossible using only one orientation. Following HPR, the cavity is assembled in a class 10 cleanroom using particulate-free flange assembly techniques adapted from the ILC R&D program. Once the cavity is assembled, it is slowly evacuated and leak checked to a sensitivity of 10^{-10} mbar-l/s or better. In the final step of processing, cavities are degassed for 48 hours at 120 C while maintaining an internal cavity vacuum of 0.5 x 10^{-7} mbar or lower. During low temperature baking, an RGA is used to monitor the partial pressures of the evolving gases. Of critical importance is the reduction of the partial pressure of water which is typically reduced by a factor of 100 after 48 hours. The reduction of the water content on the internal surfaces of the cavity has dramatically reduced the multipacting processing time as detailed below.

Typical Test Sequence

Cold tests of bare SSR1 cavities (see Figure **4**) are performed in the Fermilab VTS cryostat where they are instrumented with the 2nd sound (SS) quench detection system. SS sensors are positioned close to the spoke and sidewall transition area near the maximum magnetic field region, where a quench is most likely to happen.

Figure 4: SSR1 resonator in the VTS staging area**.**

At the first stage of the test, multipactor (MP) conditioning is performed at 4.4 K. With 150 W of RF power available at VTS, MP processing usually takes 3 to 8 hours to pass through most barriers. The first production SSR1 cavity was not degassed at 120 C before it came for the cold test. The cavity exhibited strong MP which did not completely process away even after 20 hours of high power conditioning. The cavity was warmed up and baked at 120 C for 48 hours. In the subsequent cold test all MP was processed in just 3 hours. From this test forward, 120 C degassing was implemented as the final step of cavity preparation prior to cold testing.

After MP conditioning, the cavity is cooled down from 4.4 to 2 K. During cooldown, the cavity is kept on resonance at low field (2-3 MV/m) and data is collected for *df/dp* and Q_0 vs T measurements. Cavity performance is evaluated at 2 K, including measurements of Q_0 vs E_{acc}, maximum achievable field, Q_0 and radiation level at the maximum field, as well as onset field of field emission (FE).

Results

Six SSR1 cavities have been processed and tested since March 2012, when the first production run cavity was received. Three cavities (S1H-NR-105, S1H-NR-108 and S1H-NR-110) showed performance limited by strong field emission during the initial tests. These cavities received additional HPR and 120 C degassing and were re-tested. The cumulative results of tests are shown in Figure **5**.

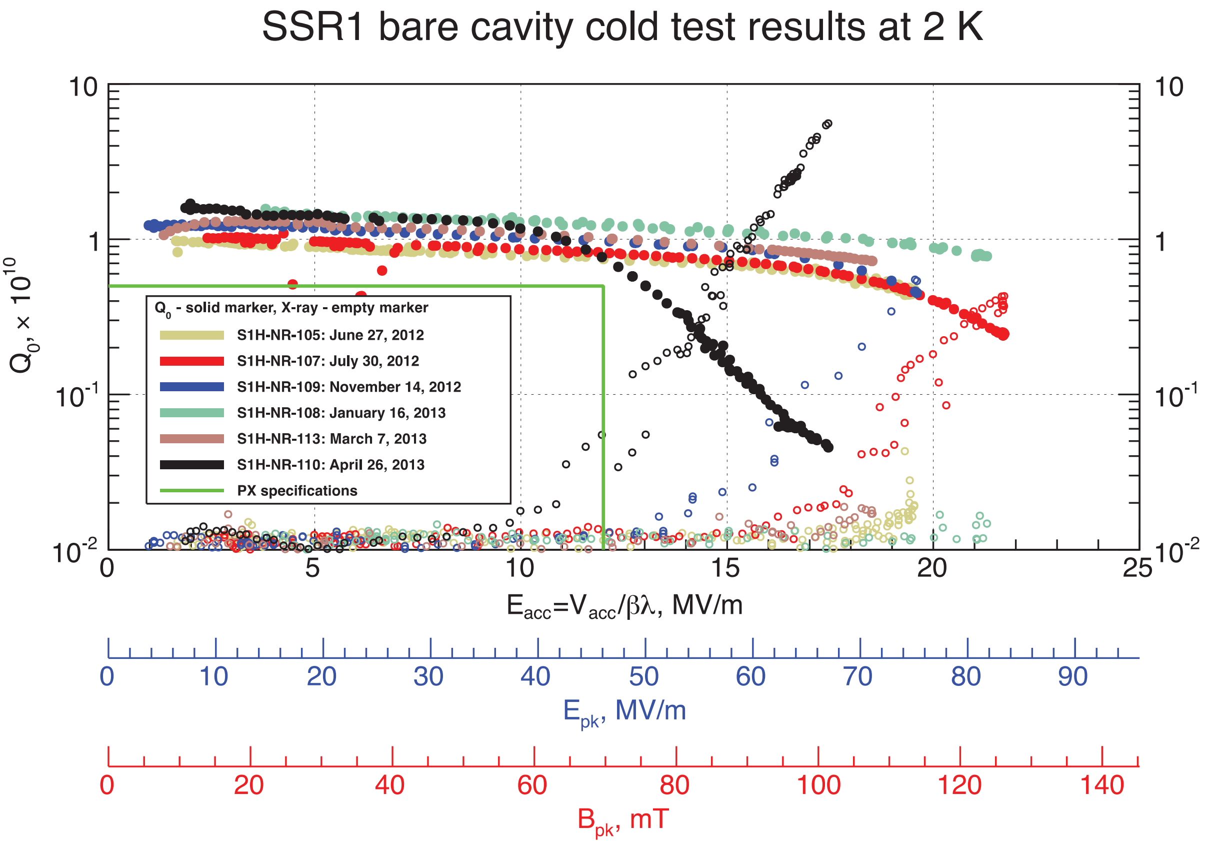

Figure 5: Results of cold tests of SSR1 cavities.

Maximum achievable field is in the range from 18 to 22 MV/m and is limited by quench in all cavities. SS system detected quench signals near the spoke-to-sidewall transition area in four cavities. In one test, SS signals were not detected during quench, so it was concluded that the end-wall contained the quench location.

Three cavities showed very little radiation, while three other cavities have FE onset at 10, 13 and 17 MV/m. During jacketing, all cavities will receive additional light (20-30 µm) BCP and HPR as part of the production processing sequence. The current FE signature in all cavities may improve with this additional processing. All six cavities, including the one that was repaired on the weld, satisfy requirements of PIXE (E_{acc} = 12 MV/m and Q_0 = 5x10^9) and will be used to build the SSR1 cryomodule. The remaining cavities will make up the rest of the SSR1 CM for PXIE once processed and tested.

CONCLUSION

With all 10 resonators manufactured and 6 resonators qualified, including a repaired resonator, the development efforts for the SSR1 cryomodule are progressing well. Though some difficulties arose during fabrication, weld repairs were successful and new weld parameter development mitigated blow-throughs. Successful processing and testing regeimes have been developed for these cavities and are promising for a future larger SSR1 production run for Project X.

REFERENCES

[1] S. Nagaitsev et al., “PXIE: Project X Injector Experiment”, IPAC2012, New Orleans, Louisiana, 2012, THPPP058.

[2] R. Wagner et al,. “High Gradient Tests of the HINS SSR1 Single Spoke Resonator”, Hadron Beams 2008, Nashville, USA.