RESULT OF COLD TESTS OF THE FERMILAB SSR1 CAVITIES

A. Sukhanov*, M. Awida, P. Berrutti, E. Cullerton, B. Hanna, A. Hocker, T. Khabiboulline, O. Melnychuk, D. Passarelli, R. Pilipenko, Yu. Pischalnikov, L. Ristori, A. Rowe, W. Schappert, D. A. Sergatskov
Fermilab†, Batavia, IL 60510, USA

Abstract

Fermilab is currently building the Project X Injector experiment (PXIE). The PXIE linac will accelerate a 1 mA H^- beam up to 30 MeV and serve as a testbed for validation of Project X concepts and mitigation of technical risks. A cryomodule of eight superconducting RF Single Spoke Resonators of type 1 (SSR1) cavities operating at 325 MHz is an integral part of PXIE. Ten SSR1 cavities were manufactured in industry and delivered to Fermilab. We discuss tests of nine bare SSR1 cavities at the Fermilab Vertical Test Stand (VTS). Recently, one of the SSR1 cavities was welded inside a helium jacket. Results of the test of this cavity in the Fermilab Spoke Test Cryostat (STC) are shown. We report on the measured performance parameters of SSR1 cavities achieved during the tests.

INTRODUCTION

The Proton Improvement Plan (PIP)-II project (essentially equivalent to Stage 1 of Project X) is under development at Fermilab [1]. In order to validate the concept of Project X and mitigate technical risks, Fermilab is designing and building the Project X Injector Experiment (PXIE), which will accelerate a 1 mA beam of H^- ions up to 30 MeV [2]. The final stage of acceleration in PXIE is performed by a cryomodule of eight superconducting RF Single Spoke Resonators of type 1 (SSR1) operating at 325 MHz [3]. For the PXIE application, SSR1 cavities are required to have 2.4 MeV maximum energy gain per cavity, corresponding to the accelerating gradient E_{acc} = 12 MV/m, and to have a quality factor $Q_0 \geq 5 \times 10^9$. The assembled cavity, jacketed in a helium vessel with tuner, is required to have a frequency sensitivity to LHe pressure variations of less than 25 Hz/Torr.

Results of high gradient tests of two prototype SSR1 cavities have been reported elsewhere [4]. Another ten SSR1 cavities have been recently manufactured by C.F. Roark [5] and delivered to Fermilab. Details of SSR1 design, manufacturing and mechanical measurements are reported in [6]. We present results of the cold tests of nine SSR1 bare cavities in VTS and one jacketed cavity in STC [7].

CAVITY TESTING AT VTS

The preparation of bare cavities for VTS tests including assembly and installation of instrumentation has been reported elsewhere [8].

The typical sequence for a VTS test is as follows. At the initial stage multipactor (MP) conditioning is performed at 4.4 K. With 150 W of RF power available at VTS, it usually takes from 3 to 8 hours to process most of the MP "barriers". The first production SSR1 cavity was not baked at 120 C before the cold test. Strong MP was observed, which did not completely process away even after 20 hours of conditioning. The cavity was warmed up and baked. In the subsequent cold test all MP was processed in just 3 hours. We incorporated a 48 hour-long 120 C bake as the final step of cavity preparation for cold test. Figure 1 shows the typical behavior of SSR1 cavity during MP conditioning. Strong multipactors were observed at 4.5 and 6.5 MV/m. It took 3.5 hours to clear MP in cavity S1H-NR-107, while in the first test of another cavity, S1H-NR-108, 6.5 MV/m MP was present even after 9 hours of processing. We also observed mild field emission during this test. The cavity was warmed up, re-rinsed and baked at 120 C and then re-tested. During the second test of this cavity all MP barriers were cleared after 4 hours of conditioning.

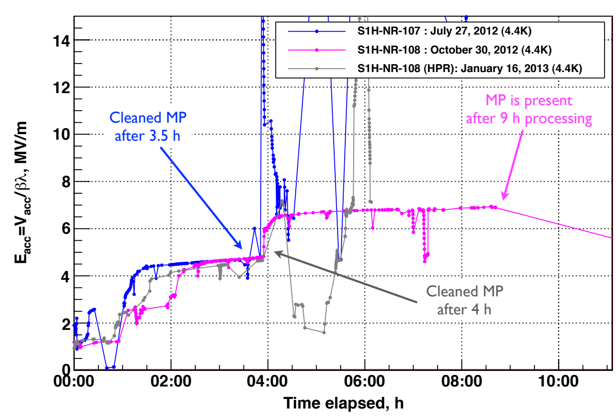

Figure 1: Multipactor processing.

After MP conditioning the cavity is cooled down from 4.4 to 2 K. During cool-down the cavity is usually kept on resonance at low field (2–3 MV/m) and measurements of the cavity frequency shift Δf *vs* LHe bath pressure and of Q_0 *vs* T are performed. Measurement of the slope parameter df/dp of the bare cavity is important for the validation of the computer model, used for the optimization of the sensitivity of the jacketed cavity to the LHe bath pressure variations. Data on the temperature dependence of Q_0 can be used to fine tune the cavity processing procedure.

Results of measurements of the resonance frequency shift Δf as a function of LHe bath pressure are shown in Fig. 2 for two cavities in four separate tests. The curve of Δf *vs*

* ais@fnal.gov
† Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.

ISBN 978-3-95450-142-7

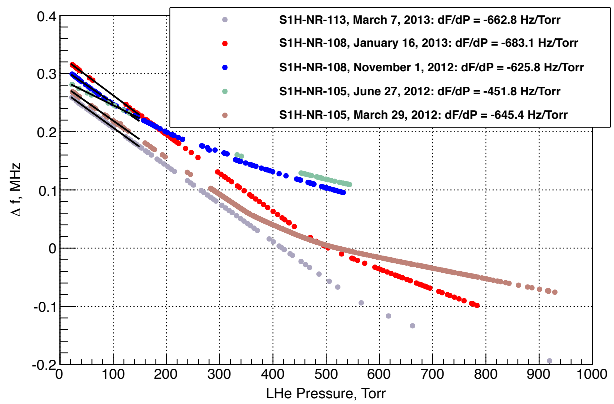

Figure 2: Measurement of the resonance frequency shift *vs* LHe bath pressure during cool-down from 4.4 K to 2 K.

pressure has two linear parts. The high pressure (4.4 K) regime with smaller slope df/dp corresponds to the cavity constrained by the Ti cage. At low pressure (2 K), the cavity becomes unconstrained and the df/dp slope increases. The measured value of df/dp of the unconstrained cavity is approximately 650 Hz/Torr and agrees well with simulation.

We determine surface resistance from the value of Q_0 using the following relation, $R_s = G/Q_0$, where the geometry factor for a SSR1 cavity is $G = 84\,\Omega$ [6]. We approximate the R_s *vs* T data with the expression $R_s(T) = R_0 + \frac{C}{T}\exp[-\Delta/T]$. Here R_0 is the temperature independent *residual* resistance, while the temperature dependent part describes the *BCS* resistance. At 2 K and 325 MHz of RF frequency, the *BCS* component is typically small ($\sim$ 1 nΩ) compared to $\sim$ 6 nΩ of residual resistance.

Cavity performance is evaluated at 2 K, and includes: measurements of Q_0 vs E_{acc}, maximum achievable field, Q_0 and radiation level at the maximum field. Onset field of field emission (FE) is recorded.

RESULTS OF VTS TESTS

Since March 2012 we have tested nine SSR1 cavities for a total of 15 cold cycles.

Three cavities (S1H-NR-107, 109 and 113) had very mild MP, which was completely conditioned within the first 3–9 hours of testing. These cavities demonstrated excellent performance, reaching requirements ($E_{acc} \geq 12$ MV/m and $Q_0 \geq 5 \times 10^9$) for PXIE and were qualified for cryomodule assembly. Requirements for SSR1 cavities in the PIP-II linac ($E_{acc} = 10$ MV/m and $Q_0 \geq 5 \times 10^9$) are less stringent. All qualified cavities for PXIE satisfy PIP-II requirements.

Four cavities (S1H-NR-105, 108, 110 and 114) showed performance limited by strong field emission during the initial tests. Two of these cavities (105 and 108) received additional HPR and 120 C baking before the second test. Additional light (20-30 μm) BCP was performed on two other cavities (110 and 114) before HPR and 120 C bake. All of these cavities were subsequently re-tested, showing improved performance and were qualified for the PXIE cryomodule.

Cavity S1H-NR-111 showed strong MP during its initial test. The cavity received an additional 48 hour bake at 120 C, has been re-tested and qualified for PXIE.

Cavity S1H-NR-112 had strong MP at 6.5 MV/m. The cavity temporarily reached 17 MV/m at 4.4 K, but when the input power level was decreased, the accelerating gradient dropped back to the 6.5 MV/m MP barrier. Subsequent conditioning at 100–120 W of input power for more than 10 hours did not clear MP and it was not possible to increase field in the cavity above 6.5 MV/m. At 2 K and $E_{acc} \leq 6.5$ MV/m we measured a quality factor $Q_0 = 1.3 \times 10^{10}$ comparable to the other qualified cavities at the same field level. We expect that the additional light BCP and HPR, which the cavity will receive during jacketing, will reduce the MP level. Since this cavity showed potentially good performance and we did not find any performance degradation associated with the manufacturing, we "conditionally" qualified this cavity for the PXIE cryomodule.

Figure 3 shows results from 2 K tests for all nine SSR1 cavities that were qualified for assembly in the PXIE cryomodule. The maximum achievable field in these cavities is in the range of 17–22 MV/m and is limited by quench in all cavities but S1H-NR-112. Oscillating Superleak second-sound Transducers (OST) [9] detected quench signals near the spoke to sidewall transition area in four cavities. In one test, OST signals were not detected during quench allowing us to conclude that the area of the quench in this case was on the cavity end-wall.

Five cavities (S1H-NR-105, 108, 112, 113 and 114) show very little radiation, while three other cavities (107, 109 and 110) have FE onset at 10, 13 and 17 MV/m, respectively. Cavities will receive additional light BCP (20–30 μm) and HPR after jacketing. We expect that additional processing and HPR will reduce the level of FE in cavities 107, 109 and 110.

RESULTS OF STC TESTS

Here we summarize results of the tests. For more details on STC upgrade and tests see [7].

Measured sensitivity of dressed cavity to pressure variations of LHe bath is $df/dp = 4$–5 Hz/Torr, which agrees well with room temperature measurements and simulation. Detuning of cavity frequency due to Lorentz force was found to decrease as square of the cavity field with the coefficient $-4\ \mathrm{Hz/(MV/m)^2}$. This value agrees with simulation.

Figure 4 shows Q_0 and radiation *vs* E_{acc} measured at STC (red markers). For comparison, also shown on this plot are the results of VTS measurements (black markers). Low field Q_0 at STC is $\sim$ 15 % lower. Since during this test cavity was over-coupled to RF source ($Q_0/Q_{ext} \sim 10$), systematic uncertainty in Q_0 measurements was quite large and both VTS and STC measurements may actually be consistent with one another. We plan a more through examination of systematic uncertainty later on. Dressed cavity quenches at $\sim$ 19 MV/m, which is about 3 MV/m lower than VTS results.

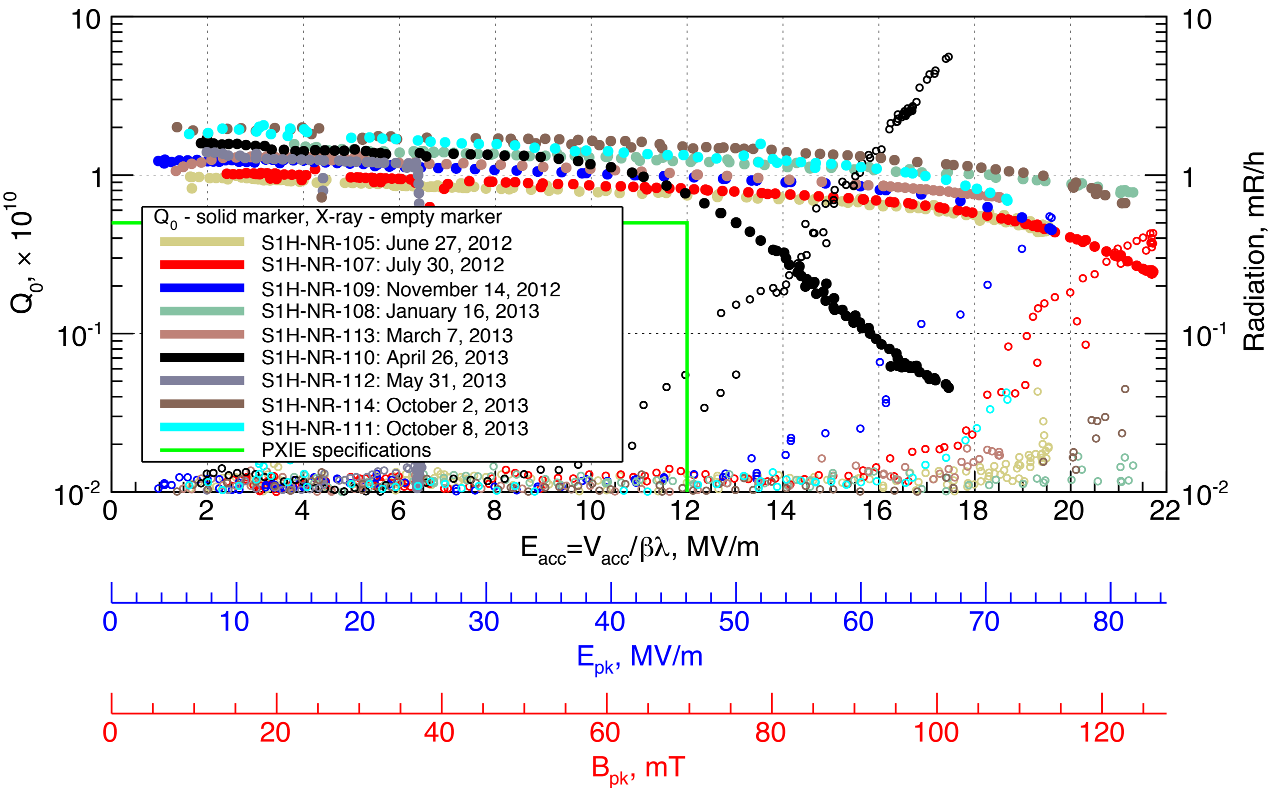

Figure 3: Summary of results of SSR1 cavity tests at 2K.

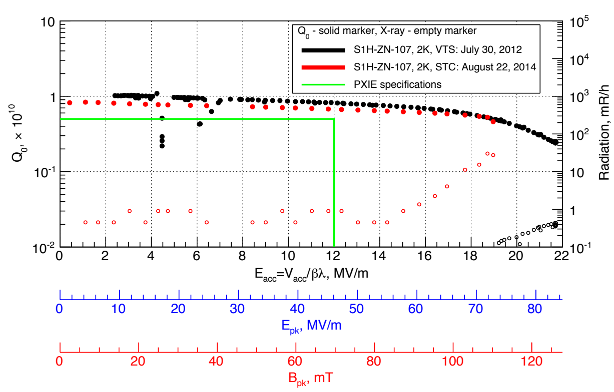

Figure 4: Q_0 and radiation *vs* E_{acc} measured at STC.

We declare that cavity performance is not degraded by jacketing and cavity is qualified for PXIE cryomodule.

SUMMARY

We have performed cold tests of nine bare SSR1 cavities in VTS. All cavities have been qualified for PXIE cryomodule assembly. One SSR1 cavity has been dressed in He vessel and subsequently tested in STC facility. No degradation of cavity performance has been found due to jacketing process.

ACKNOWLEDGMENT

Authors are grateful to the personnel of the Fermilab-Argonne joint processing facility and the Fermilab Technical Division SRF Development and Test&Instrumentation departments for their hard work on preparation of SSR1 cavities for cold tests in VTS. We also acknowledge the engineering and technical staff of the Fermilab's Accelerator and Technical Divisions for the successful upgrade of the STC to 2 K operation.

REFERENCES

[1] R. Alber *et al.* "Project X: Accelerator Reference Design, Physics Opportunities, Broader Impacts," `http://projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=776`

[2] A.V. Shemyakin *et al.*, "Project X Injector Experiment: Goals, Plan and Status", IPAC 2013, TUOAB102

[3] T.H. Nicol *et al.* "SSR1 Cryomodule Design for PXIE", NA-PAC 2013, THPMA09

[4] T. Khabiboulline *et al.* "High Gradient Tests of the Fermilab SSR1 Cavity", IPAC 2012, WEPPC052

[5] C.F. Roark Welding & Engineering co. Inc., Brownsburg, IN `http://www.roarkfab.com`

[6] L. Ristori *et al.* "Development and Performance of 325 Mhz Single Spoke Resonators for Project X", SRF 2013, FRIOB02

[7] A. Hocker *et al.* "RF Tests of Dressed 325 MHz Single-Spoke Resonators at 2K", LINAC 2014, MOPP055

[8] A. Sukhanov, "Cold Tests of SSR1 Resonators for PXIE", SRF 2013, MOP014

[9] Y. Maximenko, D. Sergatskov, "Quench Dynamics in SRF Cavities: Can We Locate the Quench Origin With 2nd Sound?", PAC 2011, TUP041