DEVELOPMENT OF 325 MHz SINGLE SPOKE RESONATORS FOR HINS AT FERMILAB: RECENT RESULTS*

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Abstract

Progress on the R&D efforts for the HINS $\beta = 0.21$, 325 MHz Superconducting Spoke Resonator, SSR1 is reported. Results from the most recent continuous wave cold test of the first unjacketed prototype are shown, and they include evidence of Q disease. The buffered chemical polishing, high pressure rinse, and first continuous wave cold test of the second unjacketed prototype are also described. This cavity achieved an accelerating gradient of 33 MV/m at 2 K. Inelastic tuning was performed on the first prototype. During this operation, the spring constant and the frequency sensitivity of the end walls were also measured. The design of the helium vessel that will jacket SSR1 resonators is presented.

INTRODUCTION

The Fermilab High Intensity Neutrino Source (HINS) Linac R&D program is building a 30 MeV superconducting (SC) H^- linac. The linac incorporates SC solenoids, high power radio-frequency vector modulators and SC spoke-type accelerating cavities starting at 10 MeV. This will be the first application and demonstration of any of these technologies in a low-energy, high-intensity proton/H^- linac.

Table 1: Geometric and RF properties of the SSR1

Operating temperature in HINS	4.4 K
HINS accelerating gradient, E_{acc} [1]	10 MV/m
Q_0 at accelerating gradient	$> 0.5\times10^9$
Beam pipe, Shell ID	30 mm, 492 mm
Lorenz force detuning coefficient [2]	3.8 Hz/(MV/m)^2
E_{peak}/E_{acc} [1]	2.56
B_{peak}/E_{acc} [1]	3.87 mT/(MV/m)
G	84 Ω
R/Q_0	242 Ω
Geometrical Beta, β_g	0.21

[1] With helium vessel.
[2] See section SSR1-01 High gradient measurements and baking for the definition of E_{acc}.

Some important geometric and RF properties of the SSR1 are given in Table 1. The HINS linac includes two cryomodules containing nine SSR1 resonators each.

Earlier papers [1][2] described the Buffered Chemical Polishing (BCP), High Pressure Rinse (HPR), and the first three Continuous Wave (CW) cold tests of the first unjacketed prototype, SSR1-01, manufactured by Zanon [4]. This paper describes the fourth cold test and the inelastic tuning operations performed on this prototype before the helium vessel was attached. A second unjacketed prototype, SSR1-02, manufactured by Roark Welding & Engineering [5], has undergone BCP and HPR, and has had its initial CW cold test. We will briefly describe and update the BCP and HPR procedure and give the results of that cold test. The design of the helium vessel that will jacket SSR1 resonators is presented.

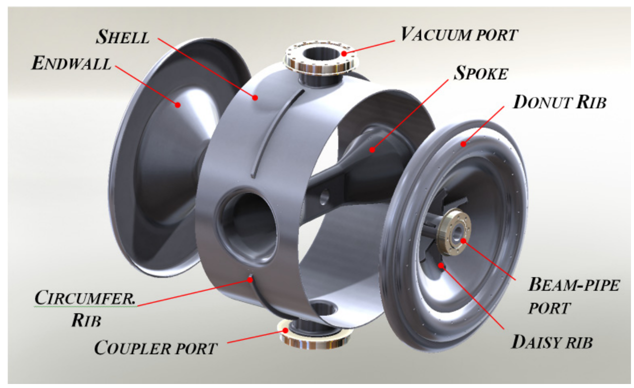

Figure 1: Exploded view of the SSR1 resonator showing the three major sub-assemblies.

SSR1-01

High Gradient Measurements and Baking

SSR1-01 previously reached $E_{acc} = 18$ MV/m at 4.4 K when tested without a helium vessel in the Vertical Test Stand (VTS) at Fermilab [2]. Here E_{acc} is the total accelerating voltage divided by L_{eff}, where $L_{eff} = (2/3)\beta\lambda = 135$ mm, the distance between the edges of the accelerating gaps at the two endwalls. A planned specific test for Q disease, a decrease in Q_0 due to hydrogen in the niobium [3], was not performed due to a leak that developed in the feed-through for the RF input antenna. After the feed-through was replaced, a fourth VTS test was performed, and the resulting Q_0 vs. E_{acc} curves are shown in Figure 2.

The upper Q_0 vs. E_{acc} curves at 2.0 K and 4.4 K were taken after the usual fast cool-down (~15 minutes from 150 K to 75 K) of the VTS. They exhibit a large slope as in earlier tests (except for the first), which prompted the concern for Q disease. The bottom curve was taken after warming up and cooling down again with a seven hour hold at 100 K to explicitly test for Q disease. The large drop in Q_0 clearly indicates the need for hydrogen degassing, and the cavity has subsequently undergone a 10 hour, 600 °C vacuum bake at Thomas Jefferson National Accelerator Facility. In all cases the maximum

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accelerating field (e. g., 20 MV/m at 2 K) was limited by the 200 W RF power supply.

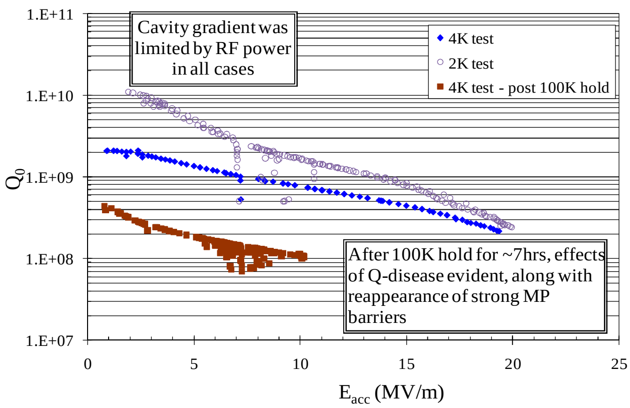

Figure 2: Q_0 vs. E_{acc} at 2.0 K and 4.4 K from the fourth cold test of SSR1-01.

Inelastic Tuning

SSR1-01 was placed in a fixture where its resonant frequency was adjusted by permanently deforming the two end walls. The fixture holds the resonator by its vacuum port and coupler port and allows pushing or pulling of the beam pipe flanges while measuring both the forces and the displacements. The initial frequency of the cavity in warm conditions at one atmosphere was 324.960 MHz. The target frequency being higher, the cavity had to be extended. The cavity was first stretched permanently to a frequency of 325.220 MHz by cycling between a load and the relaxed state, each time with a higher load. Later the cavity was compressed permanently following the same cycling method to a final frequency of 325.036 MHz as shown in Figure 3.

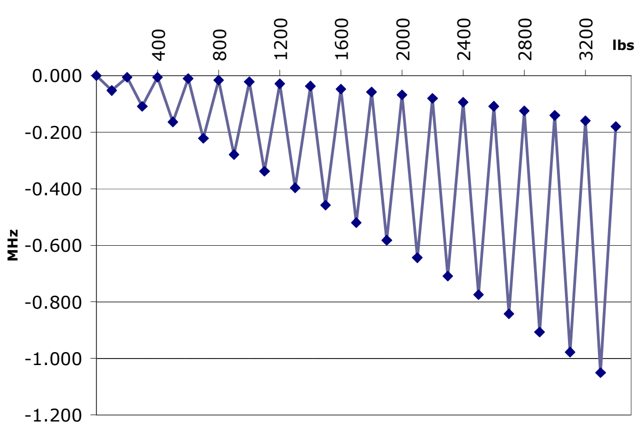

Figure 3: Cycling loads and frequency shifts of the cavity during the operation of inelastic tuning.

The tuning was performed in this manner because the cavity operates in a compressed state inside the cryomodule. Throughout the stretching operations, the elastic range increased expectedly due to work hardening. When the load was reversed to squeeze the cavity, the elastic range dropped with the first cycles and rose finally to about a factor of four larger than the initial value. This confirmed that the procedure had been effective. Table 2 shows other parameters extracted from the data collected during tuning. These measurements help to define the requirements for the active slow and fast tuning mechanism that will be installed on the helium vessel. The design of this mechanism is in progress.

Table 2: Measured parameters of SSR1-01

Spring constant of end wall	18.9 N/µm
Frequency sensitivity / total deformation	540 kHz/mm
Elastic range (0-3400 lbs, 0-0.783 mm)	871 kHz

SSR1-02

Chemistry and HPR

The BCP and HPR of SSR1-02 were performed at the G150 facility at Argonne National Laboratory, and the procedure was very similar to that for SSR1-01 [2]. An improvement to the BCP acid circulation was implemented. In addition to discharging acid at the beam pipes, it was also discharged near the power coupler port and the vacuum port. This was done to break up potential stagnant regions at the bottom and gas pockets at the top. The total etch time was 150 minutes with an average acid temperature of 14.4 °C. As with SSR1-01, the cavity was flipped top to bottom and the acid replaced with fresh about half way through the BCP. Compared to SSR1-01, the number of ultra-pure water rinses following BCP was increased from three to five. In addition, the cavity volume was kept filled with ultra-pure water much closer to the time when the HPR was started in order to avoid acid salts drying on the cavity surface.

The HPR was again performed with the wand entering the cavity in six different orientations to insure that high pressure jets would impact all interior surfaces for a reasonable time period. A new trunion mount was added for the SSR1-02 HPR in order to significantly reduce operator incursions into the clean area for reorienting the cavity. The total HPR time was two hours. After drying over a weekend in a good orientation for drainage in the class 10 clean area, the ports were sealed and the cavity was shipped to the Fermilab MP9 clean room for preparations for the first cold test in the VTS.

First High Gradient Measurements

The first cold test should be free of the effects of Q disease [3]. Figure 4 shows the surface resistance, R_s, as a function of 1/T, indicating a residual resistance near 5 nΩ. Figure 5 contains the Q_0 vs. E_{acc} curves at 2 K and 4.4 K. As with SSR1-01, many multipacting barriers had to be processed when initially raising E_{acc}, and some are shown in the 2 K curve. Eventually the field reached 33 MV/m and was limited by quenching (from Table 1, B_{peak} = 128 mT at E_{acc} = 33 MV/m).

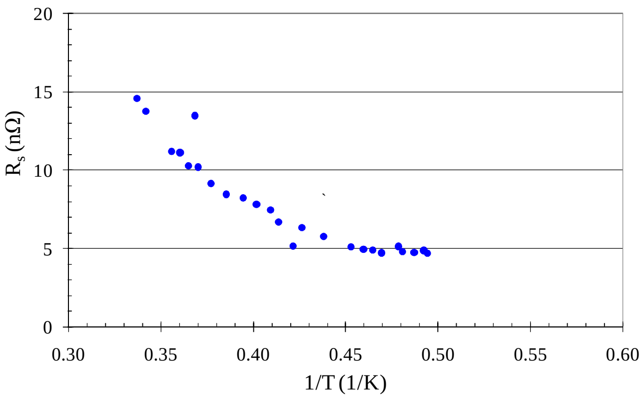

Figure 4: R_s vs. 1/T from the first cold test of SSR1-02.

The subsequent scan at 4.4 K reached 25 MV/m and was limited by the 200 W RF power supply. Also shown in Figure 5 is the X-ray intensity as measured by a sensor near the top of the VTS. During the 2 K scan, the intensity decreased after jumping through a multipacting barrier.

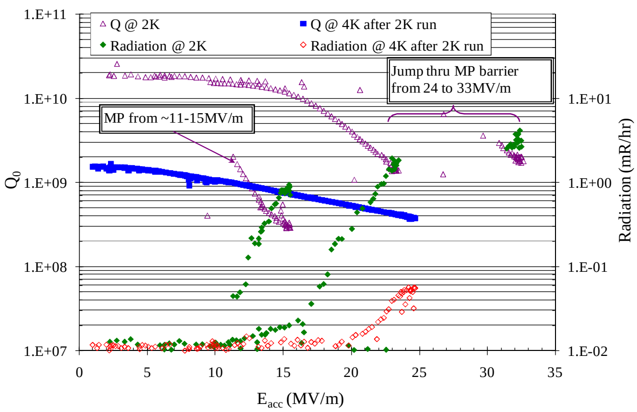

Figure 5: Q_0 vs. E_{acc} from the first cold test of SSR1-02.

HELIUM VESSEL

A cutaway view of the cavity and helium vessel assembly is shown in Figure 6. The helium vessel is constructed of 316L stainless steel. The four ports on the resonator are brazed to flanges also made of 316L allowing the use of conventional Tungsten Inert Gas (TIG) welding at the cavity-vessel interface. During welding, the cavity volume and the vessel volume are both purged with argon gas to maintain the oxygen particle count under 70 ppm and to provide some cooling. The frequency of the cavity is monitored regularly to assure that enough time is left for it to stabilize after each weld (this is a sign that the assembly has cooled sufficiently). A bellowed connection is present at the beam pipes of the resonator to allow for tuning. The jacketed assembly is estimated to weigh ~ 420 lbs. Eventually, nine jacketed resonators will be installed in a single cryomodule. Prior to the installation in the cryomodule, each jacketed cavity will be tested in both CW and pulsed mode in a test cryostat.

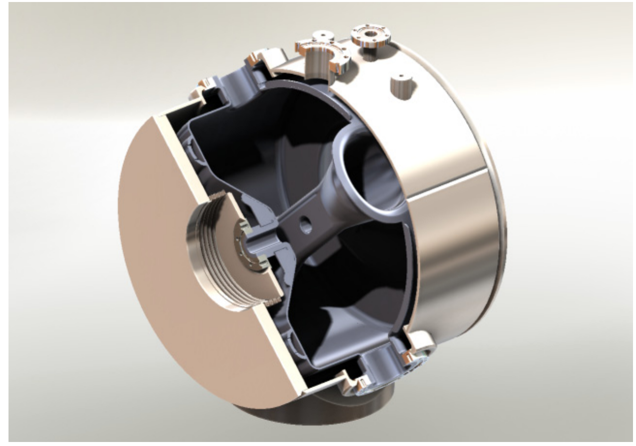

Figure 6: Sectioned view of the SSR1 resonator inside its helium vessel. The different materials are shown with different colors.

The results from the coupled structural-thermal analyses show that the jacketed assembly can be rated at a maximum allowable working pressure (MAWP) of 24.7 psi. This value is determined by the first buckling mode of the niobium cavity due to external pressure.

We are currently in the process of jacketing the first prototype.

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