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PRODUCTION OF 325 MHZ SINGLE SPOKE RESONATORS AT FNAL[*]

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Abstract

The High Intensity Neutrino Source (HINS) project represents the current effort at Fermi National Accelerator Laboratory to produce an 8-GeV proton linac based on about 400 independently phased superconducting resonators. Eighteen $\beta = 0.21$ single spoke resonators, operating at 325 MHz, comprise the first stage of the linac cold section. We present the production status of the first two of these resonators along with progress on the slow tuning prototyping. In particular, we report on the construction phases, the pre-weld tuning process and the comparison of low power RF measurements with calculations.

Index Terms – cavity, power coupler, slow tuner, spoke resonator, superconducting, superconductivity.

INTRODUCTION

The FNAL High Intensity Neutrino Source (HINS) is a proposed 8 GeV superconducting H^- linac. Its primary mission is to enable a 2 MW beam power at 120 GeV for the Fermilab Main Injector neutrino program. Fermilab has aligned this effort with the laboratory's International Linear Collider (ILC) strategy [1].

Originally developed for the electron-positron linear collider, superconducting (SC) cavities operating at 1300 MHz can be directly applied for acceleration of H^- or proton beams above 1.2 GeV. Squeezed ILC-style cavities designed for $\beta = 0.81$ can be used in the energy range from ~400 MeV to 1.2 GeV [2].

The Front End linac, operating at 325 MHz, uses a mixture of warm copper structures and superconducting spoke resonators. After a standard RFQ, room-temperature crossbar H-type resonators are used to accelerate the beam from 2.5 to 10 MeV [3]. The use of short normal conducting resonators up to ~10 MeV reduces the number of different types of SC cavities and provides adiabatic beam matching. Three types of superconducting spoke resonators, two single spoke resonators, SSR1 at $\beta = 0.21$ and SSR2 at $\beta = 0.4$, and a triple spoke resonator, TSR at $\beta = 0.62$, are used to accelerate protons from 10 MeV to 400 MeV.

Within the framework of the HINS program, the plan is to build and operate a portion of the Front End (up to energies of 90 MeV) as a technical feasibility proof of the proposal. A very important part of the test facility experience will be to operate the superconducting spoke resonators in pulsed mode.

The RF and technical design of the SC spoke resonators, including simulations made using ANSYS® [4] and CST Microwave Studio® (MWS) [5], have been performed at FNAL [6, 7]. Following an established approach typical in the construction of large-scale modern accelerators, the SC spoke resonators (as well as almost all other equipment) will be manufactured in industry. The first SSR1 prototype (SSR1-001) was recently completed at Ettore Zanon S.p.A (see Figure 1). A second cavity (SSR1-002) is currently being fabricated at Roark Welding & Engineering Inc.. The construction phases, the pre-weld tuning process, and the comparison of low power RF measurements with simulations made using ANSYS and MWS are described in this note. In addition, some aspects of future high power testing and the status of the tuner mechanism design are discussed.

Figure 1: The first completed SSR1.

FABRICATION

An exploded view of the SSR1 is shown in Figure 2. The electromagnetic volume of the SSR1 is enclosed by a high RRR niobium wall that after all chemical etching and polishing has an average thickness of ~ 2.8 mm. The SSR1 structural integrity is improved by three systems of reactor grade niobium ribs: a tubular rib with elliptical section near the outer diameter of each end wall, six radial daisy-like ribs between the beam pipe and inner (conical) section of each end wall, and four circumferential ribs on the outer shell. All parts have been formed and then electro beam (EB) welded.

The end wall, with its protruding cone (nose), has been constructed following two different approaches. Zanon (Figure 1) built it in two parts, forming the nose by spinning and welding it to the stamped outer end wall portion. Roark (Figure 3) used a single sheet to produce the part by two-step stamping. The latter approach, although requiring more extensive die development, has proven to be preferable.

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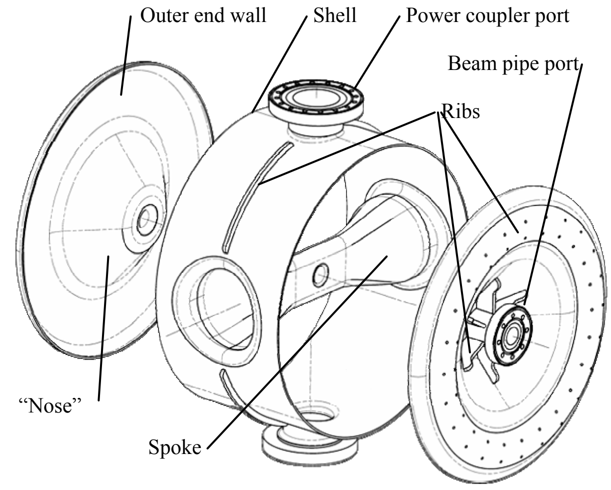

Figure 2: Exploded view of SSR1. For scale, the diameter of the Shell is 500 mm.

Figure 3: The SSR1 end wall stamped from a single sheet.

RESONANT FREQUENCY ANALYSYS

An analysis was performed to establish the target frequency for tuning the cavity at room temperature in air. The frequency shifts due to thermal shrinkage, vacuum load, dielectric constant and material loss from chemical etching have been determined and are shown in Table 1. As a result of the dielectric constant, the frequency of the cavity in air will be lower than in vacuum [8].

Table 1: Summary of physical phenomena effects on the tuning frequency in air

Target Operating Frequency	325.00 MHz
Vacuum to Air	-105 kHz
Vacuum Load	30 kHz
Thermal Shrinkage	-300kHz
BCP	-90kHz
Target Tuning Frequency	324.535MHz

The cavity distortions due to vacuum load and thermal shrinkage, taking into account constraints at the helium vessel and slow turner, have been predicted by finite element analysis. These distortions and the 200 μm material loss from buffered chemical polishing (BCP), approximated to be homogeneous on the RF side of the cavity, were modeled by a coupled ANSYS/MWS analysis to calculate the frequency shifts. The resulting target frequency at room temperature in air is 324.535 MHz.

PRE-WELD TUNING

The tuning of the SSR1-001 (see Figure 4) was done in four steps. Each step consisted of removing material from the two ends of the center body (shell). The shrinkage along the cavity axis due to EB welding of both end walls to the shell was 1.4 mm. Table 2 shows the results with the frequency normalized at 24ºC air temperature. The average sensitivity of 702.5 kHz per millimeter cut per side closely matches the theoretical estimate of 735 kHz/mm/side.

Table 2: Tuning of the SSR1-001. T_{air}=24˚C

Measure N°	**F [MHz]**	**ΔL cut [mm]**	**ΔF [kHz]**	**ΔF/mm/side [kHz]**	**Qo**
initial	328.606	-	-	-	3670
Cut #1	327.961	1.8	645	708.8	4362
Cut #2	326.625	3.8	1336	703.2	4490
Cut #3	326.0275	1.8	597	663.9	5412
Cut #4	325.0475	2.7	980	734.1	4025
final	324.728				6205

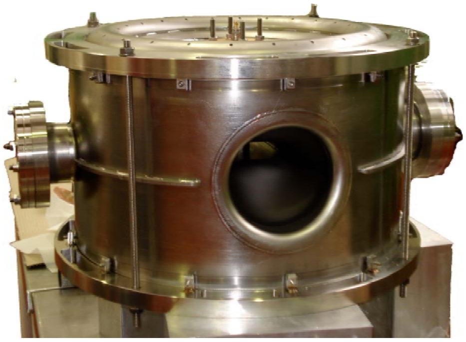

Figure 4: SSR1-001 in the "squirrel cage" that clamped the end walls to the outer shell during pre-weld tuning.

MEASUREMENTS

Low power RF measurements of the SSR1-001 were performed at Fermilab in part to reveal any possible damage the resonator might have incurred during transportation. The measured resonant frequency was 324.75 MHz, in agreement with that measured before shipping (324.73 MHz). As shown in Figure 5, the field strength balance between the two accelerating gaps is remarkably good (field flatness of 99.7%) and the field distribution is in excellent agreement with the MWS prediction. No additional tuning to balance the gaps was hence necessary at this point, and any frequency adjustment shall be done after bulk BCP.

The frequency shift caused by pressure variations was also measured in order to help understand the effects of the cooling helium on the cavity (see Figure 6). During the experiment the resonator was unconstrained and sitting on the test bench. The measured total frequency shift for the first resonant mode was -343 kHz for a 99.5 kPa pressure change. Correcting for the +105 kHz frequency change due to the air/vacuum dielectric constant difference, the pressure-induced mechanical deformations caused a frequency change of -448 kHz. Similar measurements are scheduled after the helium vessel is welded onto the cavity, and the plan is to cold test the SSR1 at high fields later this year.

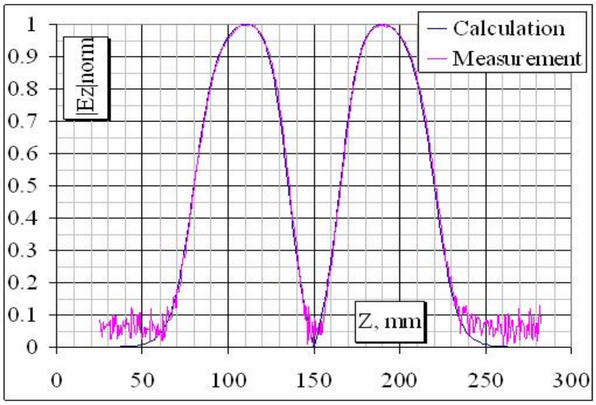

Figure 5: SSR1-001 field flatness measurement.

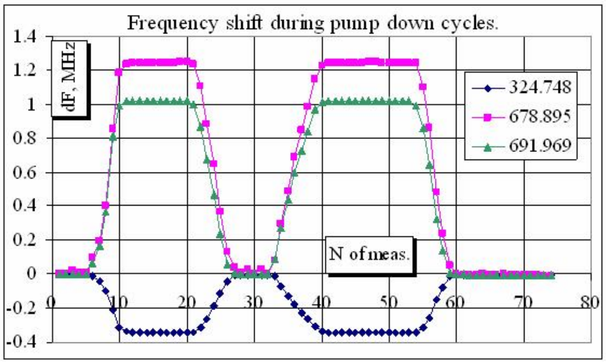

Figure 6: Frequency shift during two pump down cycles for the first three resonant modes.

SLOW TUNER MECHANISM

The cavity is constrained (welded) to the helium vessel at the two power coupler ports and at the two beam pipe ports (see Figure 2). A bellows connects the inner and outer end walls of the helium vessel, and three slow tuner arms (spaced by 120°) span the bellows on each end wall (see Figure 7). A stepping motor, via a roller screw, puts the slotted push/pull ring in rotation allowing for the motion of the three arms. According to the ring rotation, a compressive or extensive force is applied at the cavity beam pipe. All contact surfaces of the tuner have been coated with tungsten disulfide (WS_2) and Garlock® DU bearing surfaces [9] have been interposed where friction is more critical. The roller screw nut is lubricated with graphite and certified for operating under vacuum and cryogenic conditions.

A warm test was run to verify the accuracy of the mechanism. A central weight was placed at the center of the inner flange to simulate the vacuum load. The mechanism induces a 2.5 μm displacement per 1000 steps of the motor. For the SSR1, with a frequency sensitivity on the order of 300 Hz/μm, a single step of one motor translates into approximately $\Delta F = 0.75$ Hz. During testing, the mechanism repeatability, i.e. the capability of the tuner to return to the same position, was less than 3 μm.

Currently a fast tuner mechanism is being studied. Although locating the fast tuner on the inner end-wall under the slow tuner arms provides several advantages, the beam proximity might pose a serious threat to the survival of piezoelectric or magnetostrictive devices.

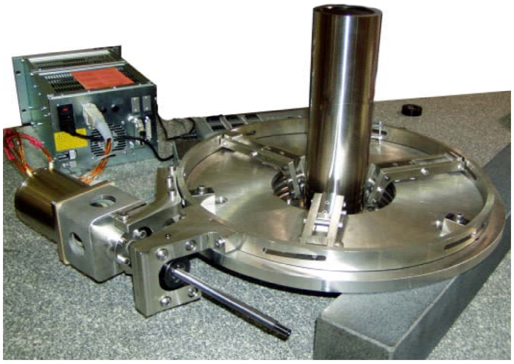

Figure 7: The first slow tuner prototype mounted on helium vessel end wall mockup. The stepping motor used in the tests is larger than planned for the cavity.

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