SSR1 HOM ANALYSIS AND MEASUREMENTS*

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Abstract

Single spoke resonators (SSR1, β=0.22) are currently under development for Project X at Fermilab. In this paper, extensive Higher Order Mode (HOM) analysis carried out on SSR1 is reported including the simulated R/Q for monopoles, dipoles, and quadrupoles. HOM measurements carried out on several spoke cavities are also reported including the harmonic response and the bead pull measurements. Comparison between the measured R/Q values and the simulated ones are presented.

INTRODUCTION

Project X is a future high intensity proton accelerator to be built in Fermi National Accelerator Laboratory targeting the intensity frontier with focus on the study of rare subatomic processes and supporting neutrino experiments. Project X could reveal physics phenomena far beyond the energy reach of the Large Hadron Collider, but only in an indirect way [1-4]. Project X would provide, by a large margin, better neutrino, kaon and muon beams compared with existing facilities. The proposed facility would not only allow for numerous experiments at the intensity frontier, but also it would allow scientists to develop the technologies for a future machine at the energy frontier.

Project X consists of two superconducting linear accelerators; the first of them is a Continuous Wave (CW) machine to get the beam to 3 GeV, the second one is a pulsed machine, which will boost part of the beam from 3 to 8 GeV. The beam is finally cycled in the existing main injector of Fermilab to get to 120 GeV [3-4], as shown in Figure 1(a).

Spoke cavities play a major role, in the CW Linac frontend, in accelerating the H^- beam from 10 MeV to 160 MeV, as shown in Figure 1(b). Two stages of single spoke cavities namely; SSR1 of β=0.22, and SSR2 of β=0.47, are proposed in the reference design of Project X [5].

SSR1 cavities currently under production for Project X injection experiment PXIE. HOM analysis is needed for such high current cavity to make sure that the HOM losses are within the acceptable ranges. In this paper, an extensive HOM analysis, carried out on SSR1, is reported including the simulated R/Q for monopoles, dipoles, and quadrupoles. Higher order mode measurements carried out on several spoke cavities are also reported including the harmonic response and the bead pull measurements. Comparison between the measured R/Q values and the simulated ones are presented.

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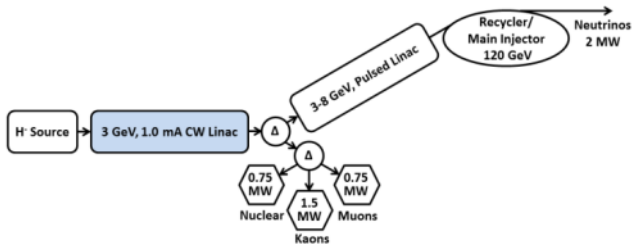
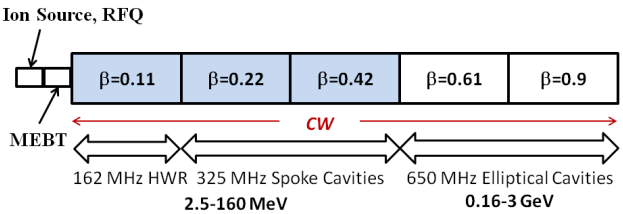


(a)



(b)

Figure 1: Project X. (a) Layout. (b) CW linac section showing the spoke cavities section.

HOM ANALYSIS

Utilizing the symmetry of the spoke cavity and by enforcing different boundary conditions (perfect electric conductor "PEC", and perfect magnetic conductor "PMC") on the symmetry planes, as shown in Figure 2, higher order modes have been calculated using Comsol mutliphysics (a finite element software) [6]. Three kinds of modes namely; monopoles, dipoles, and quadrupoles, have been calculated.

Figure 3 shows the calculated R/Q values for the monopoles versus frequency. R/Q of the fundamental mode at 325 MHz frequency is 239 Ω, while all other HOM monopoles are less than 1 Ω in R/Q (at β=0.22) with the largest value being 0.61 Ω at 921 MHz. On the other hand, Figure 4 shows the simulated R/Q of the monopoles versus the relative beam velocity. All of the HOM monopoles are less than 15 Ω in R/Q over the β range from 0.14 to 0.3 except the zero mode at 375 MHz which reaches R/Q about 40 Ω at β=0.14.

Both kinds (polarizations) of dipoles and also quadrupoles were calculated using the simulation setup shown in Figure 2(b), (c), and (d), respectively. Figure 5 shows the calculated R/Q in Ω/cm^2 for the dipoles and quadrupoles. For the dipoles, all of them are less than 1 Ω/cm^2 in R/Q with the largest mode being dipole EM at 713 MHz with R/Q equals 0.6 Ω/cm^2. On the other hand, all of the HOM quadrupoles are less than 0.01 Ω/cm^2 in R/Q with the largest mode being at 1580 MHz with R/Q equals 0.0013 Ω/cm^2.

External quality factor for all the modes has been calculated assuming 50 ohm coupler port with inner

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conductor of 33.4 mm in diameter. The depth of the coupler probe antenna was adjusted to have Q_{ext} of the fundamental mode equal to 1e6. Figure 6 shows the simulated Q_{ext} values of all the HOMs versus frequency. Largest Q_{ext} is that of the dipole EM mode at 713 MHz being ~1e12.

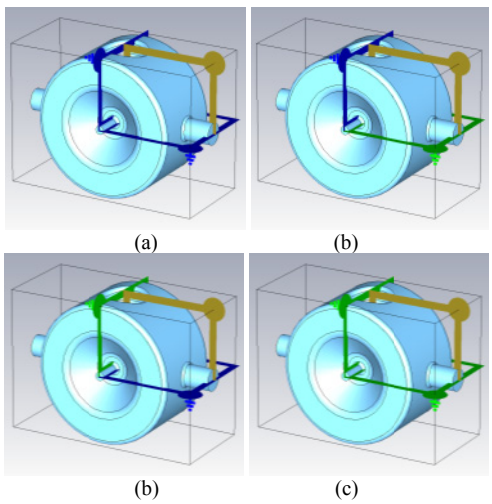

Figure 2: SSR1 simulation setup for HOM analysis with boundary conditions; (a) PMC-PMC for monopoles. (b) PMC-PEC for dipoles ME. (c) PEC-PMC for dipoles EM. (d) PEC-PEC for quadrupoles.

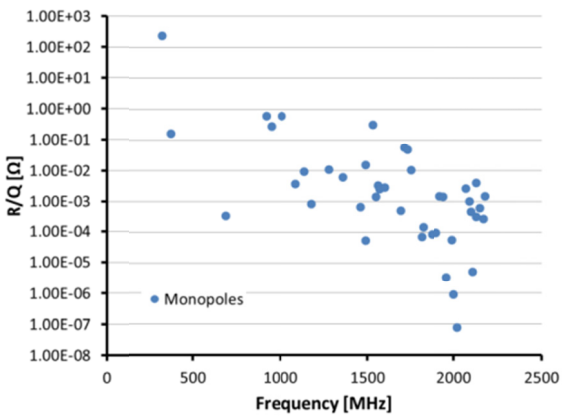

Figure 3: Simulated R/Q of the monopoles at β=0.22.

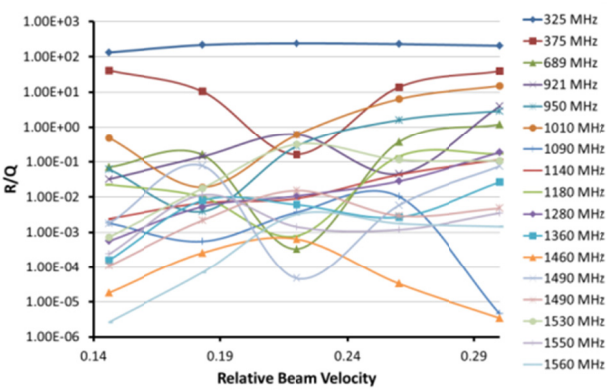

Figure 4: Simulated R/Q of the monopoles vs. relative beam velocity.

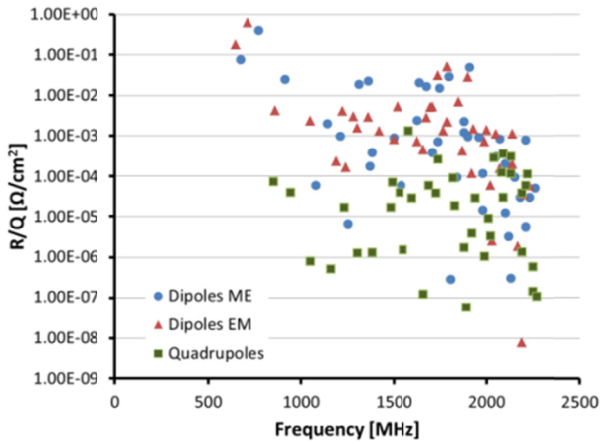

Figure 5: Simulated R/Q of the dipoles and quadrupoles at β=0.22.

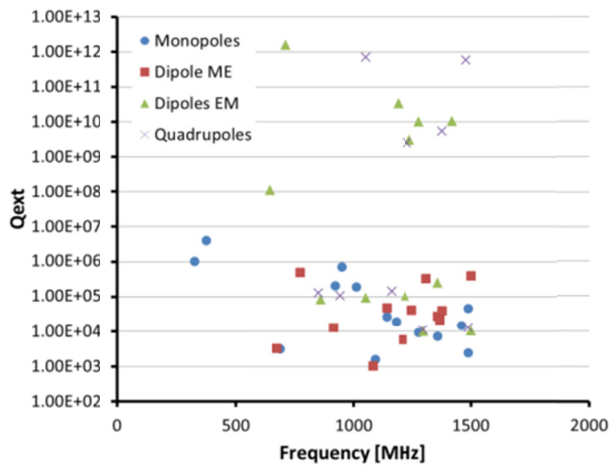

Figure 6: Simulated Qext of the HOMs.

HOM MEASUREMENTS

Six spoke cavities SSR1-105 to 110 have been fabricated and tested. Figure 7 depicts a picture of SSR1-109 in the test setup. Bead pull measurements were carried out on all the fabricated cavities measuring the monopoles up to 2 GHz.

The measured transmission response of one of the SSR1 cavities (SSR1-106) is shown in Figure 8, where the cavity was excited from the beam pipe to show mainly the monopoles. Figure 9 shows the measured R/Q of the monopoles for all the six cavities compared to the simulated values. R/Q of the fundamental mode for the different measured cavities is in good agreement with the simulated value. Relatively larger spread exists in the measured R/Q values for the HOMs, which is expected, as HOM fields are quite smaller near the cavity axes, thus closer to the noise level. The measured R/Q of the HOM monopoles is less than 1 Ω.

Figure 10 shows the measured frequency spread of the fabricated spoke cavities from their average values for monopole frequencies up to 2 GHz. Maximum frequency spread is about 7 MHz.

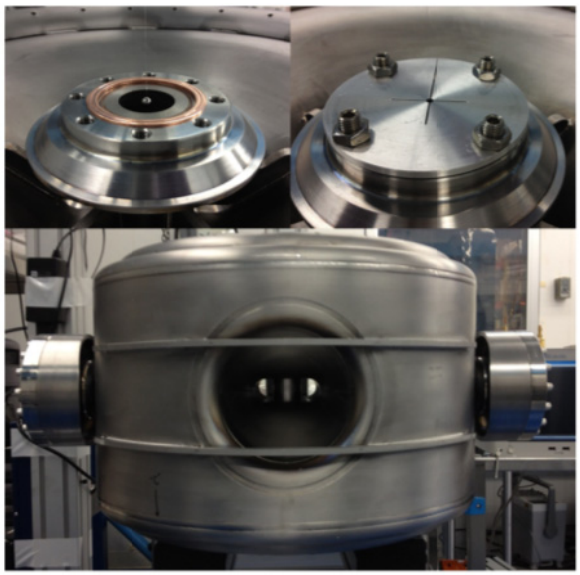

Figure 7: Bead-pull measurement test setup for an SSR1 cavity prototype.

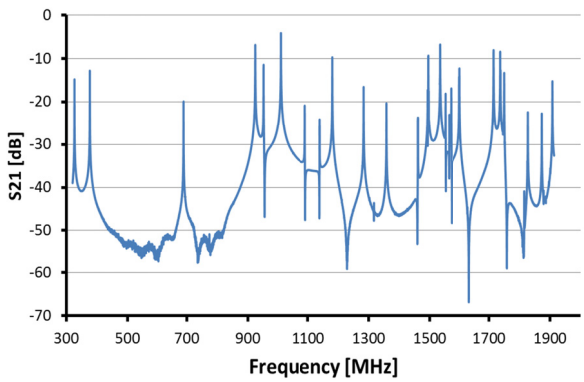

Figure 8: Measured transmission response of SSR1-106

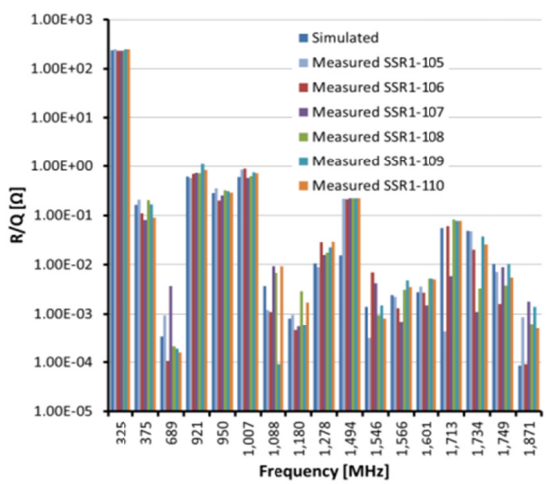

Figure 9: Measured monopoles R/Q for the fabricated SSR1 cavities.

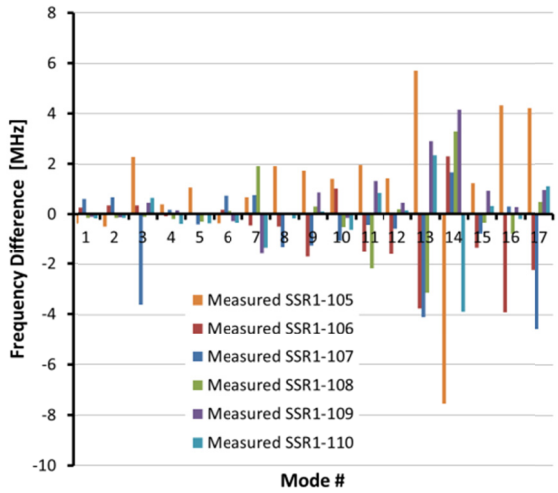

Figure 10: Measured frequency spread on the fabricated SSR1 cavities.

CONCLUSION

Higher order modes have been investigated for SSR1 carrying out a thorough simulation study. Monopole, dipole, and quadruple modes have been simulated and R over Q for each mode has been calculated. Simulated R over Q values show no worries about HOMs and no need for any HOM dampers.

Six cavities have been fabricated and tested. Bead pull measurements were carried out for all the HOM monopoles up to 2 GHz. Simulated and measured R over Q values are in good agreement. HOMs frequency spread of the six fabricated values is within 7 MHz.

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