MICROPHONICS CONTROL FOR PROJECT X

W. Schappert#, S. Barbanotti, J. Branlard, G. Cancelo, R. Carcagno, B. Chase, M. Champion, I. Gonin, A. Klebaner, D. Orris, Y. Pischalnikov, T. Peterson, L. Ristori, N. Solyak, V. Yakovlev,

FNAL, Batavia, IL 60510, USA

Abstract

The proposed multi-MW Project X facility at Fermilab will employ cavities with bandwidths as narrow as 20 Hz. This combination of high RF power with narrow bandwidths combined requires careful attention to detuning control if these cavities are to be operated successfully. Detuning control for Projects X will require a coordinated effort between the groups responsible for various machine subsystems. Considerable progress in this area has been made over the past year.

INTRODUCTION

Project X is a multi-MW proton accelerator facility proposed for construction at Fermilab [1]. The facility would consist of a 3-GeV, 1mA superconducting CW linac followed by a 3-8 GeV pulsed linac. The pulsed linac would feed a modified version of the existing Recycler.

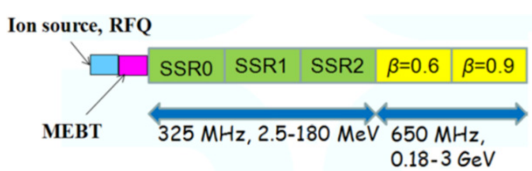

Figure 1: Schematic of the Project X linac.

The linac would employ a combination of three different types of spoke resonators and two different types of elliptical SCRF cavities. Design parameters for each cavity type are listed in Table 1 together with the number of cavities of each type required.

Table 1: Cavities for the Project X Linac

Section	Number of cavities/ c.modules	Max gain per cavity (MeV)	Minimum bandwidth (Hz)	Beam Power per cavity (kW)	RF Power (kW)
SSR0	18/1	1.0	35	1.0	1
SSR1	20/2	2.2	36	2.2	5
SSR2	44/4	3.9	24	3.9	6
LE650	42/7	11.6	21	11.6	30
HE650	152/19	17.4	24	17.3	30

*This manuscript has been authorized by Fermi Research Alliance, LLC under Contract N. DE-AC02-07CH11359 with U.S. Department of Energy.

#warren@fnal.gov

Optimal coupling to the planned 1 mA beam current would require relatively narrow cavity bandwidths. SCRF cavities are constructed from niobium sheet and the walls of the cavities are deliberately kept thin to maximize heat transfer to the surrounding helium bath. The thin walls of the cavities and the narrow operating bandwidths make them susceptible to detuning due to variations of the helium bath pressure or to mechanical vibrations.

As the cavities detune, additional RF power is required to maintain the accelerating gradient. If sufficient reserve RF power is not available to maintain the gradient, the beam can be lost. Sufficient reserve RF power must be provided to compensate for the peak detuning levels expected, not just for the mean detuning. For narrow bandwidth cavities, providing sufficient reserve RF power can significantly increase both the acquisition cost and the operational cost of the machine.

Specifically, detuning levels in the Low and High β 650 MHz elliptical cavities will have a significant impact on the overall cost of the project. The narrow bandwidths, and the high RF Power requirements, and the large number of these cavities mean that careful attention to detuning control will be needed if these cavities are to operate successfully.

SOURCES OF DETUNING

Cavity detuning can be driven by a variety of sources including:

- Pressure variations of the helium bath;
- Vibrations from external equipment such as pumps;
- Geophysical noise; and
- the Lorentz force.

In narrow bandwidth CW machines, cavity detuning is often dominated by variations in the bath pressure. In high gradient pulsed machines, mechanical distortions caused by the Lorentz force, the force exerted on the cavity walls by the RF pulse, can be more important.

DETUNING CONTROL STRATEGIES

Cavity detuning can be mitigated by taking some combination of any or all of the following measures:

- Reducing the sensitivity of the cavity resonant frequency to variations in the helium bath pressure.

- Improving the regulation of the bath pressure to minimize the magnitude of cyclic variations and transients.
- Minimizing the acoustic energy transmitted to the cavity by external vibration sources.
- Actively damping cavity vibrations using a fast mechanical or electromagnetic tuner driven by feedback from measurements of the cavity resonant frequency.
- Providing sufficient reserve RF power to compensate for the expected peak detuning levels.

The optimal combination of measures may differ for different cavity types.

EXPECTED DETUNING LEVELS

To better understand the levels of detuning that might be expected for Project X and to understand the current state of the art in detuning control, surveys of the scientific literature were conducted with respect to cavity detuning due to microphonics and LFD for SCRF cavities.

The survey identified the following activities as most directly relevant to Project X:

- Microphonics control at BESSY using Tesla-style elliptical cavities operating in CW-mode [2];
- Design efforts at MSU [3] to minimize df/dP of cavities for the FRIB project; and
- Regulation of He pressure levels at SNS [4].

From the survey and from discussions with experts the projects listed above, at other laboratories, and at Fermilab, ranges for detuning that might be expected from each of the potential sources were established. These ranges were used to develop budgets for the component subsystems as listed in Table 2.

Table 2: Project X Detuning Budget

Parameter	Value	Units
dF/dP	25	Hz/torr
Pressure Stability	0.2	torr
RF Overhead	43	%
Maximum Detuning	20	Hz

Meeting the detuning budgets requires a coordinated effort between the multiple groups responsible for various component subsystems of the planned machine. Each of the groups involved has made considerable progress towards meeting these goals over the past year.

DESIGN OF LOW DF/DP CAVITIES

The cavity design group at Fermilab has made a concerted effort to reduce the pressure sensitivity of the both the spoke resonators and elliptical cavities.

Current cavity and helium vessel designs yield estimates for df/dP of better than 5 Hz/Torr for both the spoke resonators [5] and for the elliptical cavities [6].

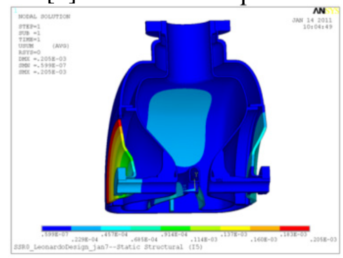

Figure 2: Optimization of the circular rib position of a spoke cavity to minimize df/dP.

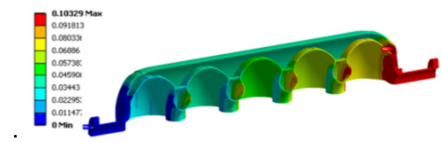

Figure 3: Longitudinal deformation of an elliptical cavity due to 1.0 bar internal pressure (units: mm).

CRYOMODULE DESIGN

The role of the cryomodule design on the frequency stability of the cavities is also being closely examined. “Open” helium vessels with large liquid-vapor surface interfaces such as those used at CEBAF and SNS can help buffer sudden pressure changes. “Closed” vessels of the TESLA type may not buffer such changes as well, depending on the magnitude and rate of the change.

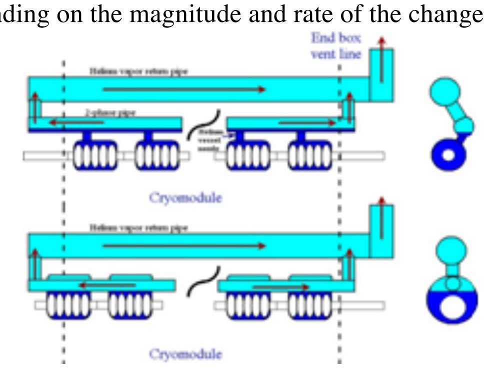

Figure 4: A comparison of open and closed cryomodule designs.

CRYOGENIC SYSTEM

Limiting pressure variations in the cryogenic system is a crucial element of any detuning control strategy. Based on the long term pressure stability measurements at SNS and JLab, a target for peak pressure excursions of 0.2 torr or less was established.

RF POWER OVERHEAD

Where RF power requirements are low, or where only a few cavities of any given type are required, cavities can be over-coupled to reduce their sensitivity to detuning.

In contrast, the low-β and high-β 650 MHz elliptical cavities not only constitute the majority of cavities required for the project; they also have the highest RF power requirements and the lowest bandwidths. With a planned 30 kW IOT delivering up to 17.3 kW of beam power per cavity while including an allowance for waveguide losses of 6%, a peak detuning of 20 Hz is the maximum that can be tolerated. The cost of over-coupling these cavities would be prohibitive so every effort must be made to limit peak detuning to this level or better.

FAST AND SLOW TUNER DEVELOPMENT

Design and development of tuners for the various cavity types proposed for Project X is ongoing. Designing a suitable tuner for spoke resonators can be challenging because of the limited space available and the because of the stiffness of the cavities. A prototype lever tuner developed for the SSR1 cavity has been successfully cold tested [7].

LORENTZ FORCE COMPENSATION

During recent pulsed-RF cold tests of the 325 MHz SSR1-0 cavity, techniques developed at Fermilab for 1.3 GHz ILC-style elliptical cavities [8] were successfully used to compensate for LFD at gradients of up to 31 MV/m. Compensation reduced the detuning from 3 kHz to less than 100 Hz [7].

ACTIVE MICROPHONICS COMPENSATION

Active control of microphonics has been studied extensively elsewhere [2]. An effort to develop that capability in preparation for Project X is now underway. As part of that initiative, two prototype active detuning control systems were deployed during the first cold tests of the SSR1-0 cavity.

The first prototype system used a frequency locked loop to stabilize the resonant frequency of SSR1-0 against variations in the pressure of the 4.5 K He bath while the cavity was equipped with a 1.5 Hz bandwidth coupler. To maintain a constant gradient with such a narrow bandwidth, the frequency of the RF drive tracked the resonant frequency. The detuning control system measured the cavity frequency and used it to drive the fast tuner in a closed loop. As shown in Figure 8, the system was able to reduce pressure related variations in the resonant frequency from several hundreds of Hz to 1.3 Hz RMS/8 Hz peak.

The second system stabilized the frequency using a phase locked loop while SSR1-0 was driven with a fixed RF frequency of 325 MHz through a 100 Hz bandwidth coupler. This system was able to limit excursions in the cavity gradient to <=0.2% RMS and excursions in the phase to <=1.2°.

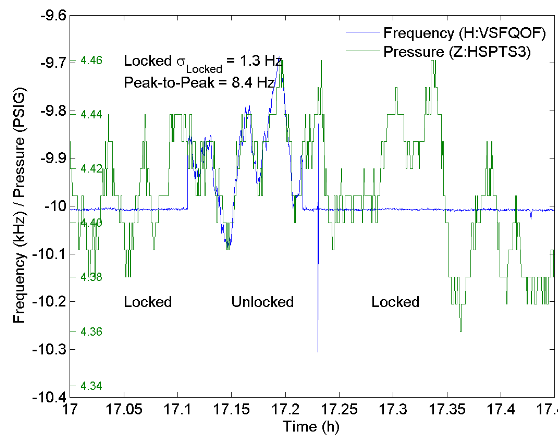

Figure 5: Active compensation for He pressure variations.

CONCLUSION

Detuning levels in the Project X cavities, specifically the Low and High β 650 MHz elliptical types, can have a significant impact on the overall cost of the project. The narrow bandwidths, and the high RF power requirements, and the large number of these cavities mean that careful attention to detuning control will be required if these cavities are to operate successfully. Limiting cavity detuning in Project X will require a coordinated effort between the groups responsible for various subsystems of the planned machine. Considerable progress towards this goal has been made by each of these groups over the past year.

REFERENCES

[1] S. Nagaitsev, "Project X, new multi megawatt proton source at Fermilab", these Proceedings.
[2] A. Neumann et al., "Phys. Rev. S T Accel. Beams 13, 08, 2001 (2010) .
[3] J. Popielarski et al., "Development of a Superconducting Half Wave Resonator for Beta 0.53", SRF 2003, DESY, September 2003.
[4] S.Kim et al., "Commisioning of the Superconducting Linac at the Spallation Neutron Source (SNS)", IEEE Trans. Appl. Superconducitivity, 17 2, 1299 (2007).
[5] I. Gonin et al., "Design of Single Spoke Resonantors for Project X", these Proceedings.
[6] S. Barbanotti et al., "Status of the Mechanical Design of the 650 MHz Cavities for Project X", PAC 2011, New York, US.
[7] Y. Pischalnikov et al., "Test of a tuner for 325 SRF spoke resonator", these Proceedings.
[8] W. Schappert, Y. Pischalnikov, "Resonance Control in SRF cavities at FNAL", these Proceedings..