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ANALYSIS OF A QUASI-WAVEGUIDE MULTICELL RESONATOR FOR SPX *

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Abstract

A compact deflecting cavity is needed for the Short Pulse X-rays (SPX) at the Advanced Photon Source (APS) of Argonne national laboratory. The deflecting cavity has to be quite efficient, providing a 2 MV kick voltage and satisfying stringent requirements on aperture size and total cavity length. Meanwhile, the cavity should allow operation up to 100 mT peak surface magnetic field before quenching. In this paper, we report on the latest analysis carried out on the cavity structure to investigate frequency sensitivity to pressure fluctuations, frequency sensitivity to tuning forces, mechanical resonances, and wakefield losses.

INTRODUCTION

A compact deflecting cavity was under development in a collaboration effort between Fermi and Argonne national laboratories to produce an efficient deflecting structure to be used in the Short Pulse X-rays (SPX) at the Advanced Proton Source (APS) of Argonne national laboratory. Using a deflecting cavity for SPX was initially suggested by Zholents, et al. in [1].

The cavity was designed to meet stringent requirements on both electromagnetic and mechanical performances. Table 1 lists the design parameters of the APS deflecting cavity, which operates at 2.815 GHz with an optimal group velocity of 1. The cavity should produce a nominal kick voltage of 2 MV, while keeping the peak surface electric field below 55 MV/m to avoid surface emission and the peak surface magnetic field below 80 mT to avoid thermal quench. Based on beam dynamics, the aperture of the cavity was required to be 12 mm x 30 mm.

Cavity design underwent several iterations to meet the specified design goals and in addition lower the higher order modes losses and simplify the fabrication process. Final electromagnetic design was reported in [2] with detailed higher order mode analysis. The cavity design named Quasi-waveguide Multicell Resonator (QMiR) is shown in Fig. 1. The proposed design meets the requirements and sustains a peak surface electric field of 54 MV/m and a peak surface magnetic field of 75 mT at the nominal operating kick of 2 MV. The designed cavity has a G-factor of 130 Ω.

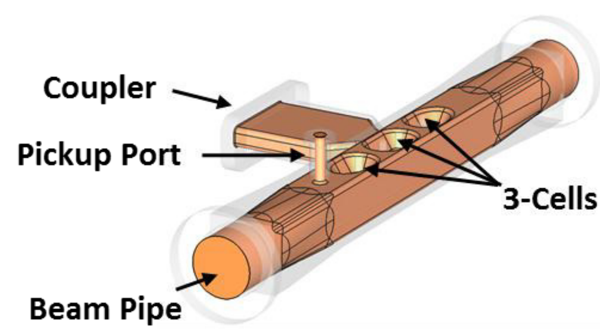
Argonne successfully constructed a cavity prototype for the QMiR structure and initial testing results were reported in [3].

In this paper, we present the analysis carried out on the QMiR structure to examine the frequency sensitivity to pressure fluctuations and tuning forces. In addition modal and wakefield analyses are also reported.

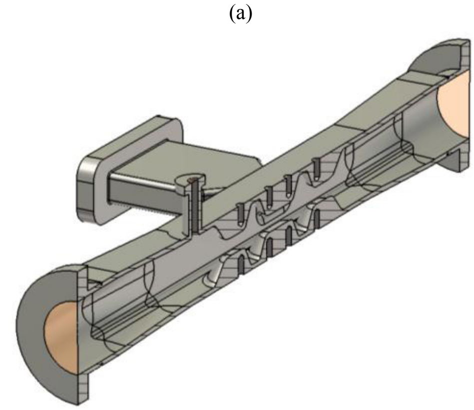
QMIR DEFLECTING CAVITY

Figure 1 shows the geometry of the QMiR cavity. The cavity consist of 3-cells. Each cell shape was optimized to lower the surface fields as explained in [2]. The cavity operates at 2.815 GHz in the transverse electric TE dipole mode, which is needed to produce the required transverse kick. The power coupler is located on the side of the cavity and its position was optimized to lower the external quality factor of higher order modes (HOM).

The cavity prototype was machined from a solid brick of Niobium. Fig. 1(b) shows a section of the cavity with the Niobium walls highlighted. Series of blind holes is to be used for cooling the high magnetic field areas at the cell centers.



(a)



(b)

Figure 1: Geometry of the quasi multimode resonator. (a) RF domain is highlighted. (b) Section of the cavity with the Niobium walls highlighted.

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Table 1:Design Parameters for the APS Deflecting Cavity

Parameter	Value
Frequency	2.815 GHz
Optimal beta	1.00
Nominal Kick Voltage	2 MV
Beam aperture	12 mm x 30 mm
Max surface E_{pk}	54, (< 55) MV/m
Max surface B_{pk}	75, (< 80) mT
G-Factor	130 Ω

FREQUENCY SENSTIVITY ANALYSIS

Superconducting radio frequency (SRF) cavities are vulnerable to frequency detuning that is caused by fluctuation in the Helium path pressure. Because of the extremely high quality factors of SRF cavities, their bandwidth is relatively very narrow. Thus the cavity can be seriously detuned even by fluctuations in the Helium path pressure, especially if the cavity is barely over-coupled.

QMiR cavity was analyzed using Comsol Multipysics [4] to investigate the frequency sensitivity of the cavity to pressure fluctuations *df/dP*. Computation of *df/dP* requires coupling the electromagnetic and mechanical aspects of the problem in order to capture the cavity's resonance frequency before and after applying the pressure load.

For the QMiR cavity geometry *df/dP* was computed under the mechanical boundary conditions shown in Figure 2(a), where the beam pipe ports are fixed, and cavity outside surface (shown in blue) is subject to 2 bar pressure load. Figures 2(b) and (c) show the amount of displacement in µm and Von Mises stresses in MPa, respectively under the 2 bars of pressure load. The calculated frequency change under this pressure load is -3 kHz, which translates to *df/dp* of -1.5 Hz/mbar. The maximum stress in this case is 55.9 MPa. In case the beam pipe left free *df/dp* was found to be -3 Hz/mbar.

On the other hand, it was essential to investigate the cavity sensitivity to a tuning force as RF tuning is an essential step in preparing the cavity for final assembly. Typically, the RF tuning is done by plastically deforming the cavity. Plastic deformation will perturb the cavity's resonance frequency to the designed vlaue.

We have studied how the QMiR cavity can be tuned. We recommend tuning the cavity under the mechanical boundary conditions shown in Figure 3(a), where beam pipe ports are fixed and the bottom surface of the cavity is fixed in vertical direction. Then by pushing with a force up to 15kN on the middle cell against the fixed bottom surface, we could plastically deform the cavity and attain -39.5 kHz frequency shift per each µm of deformation. Figures 3(b) and (c) demonstrate the resultant displacement in µm and the Von Mises Stresses in MPa for a 15 kN force applied on the middle cell as shown in Figure 3(a). The cavity frequency sensitivity to deformation *df/dl* is satisfactory and indicates that RF tuning of the cavity can be easily attained.

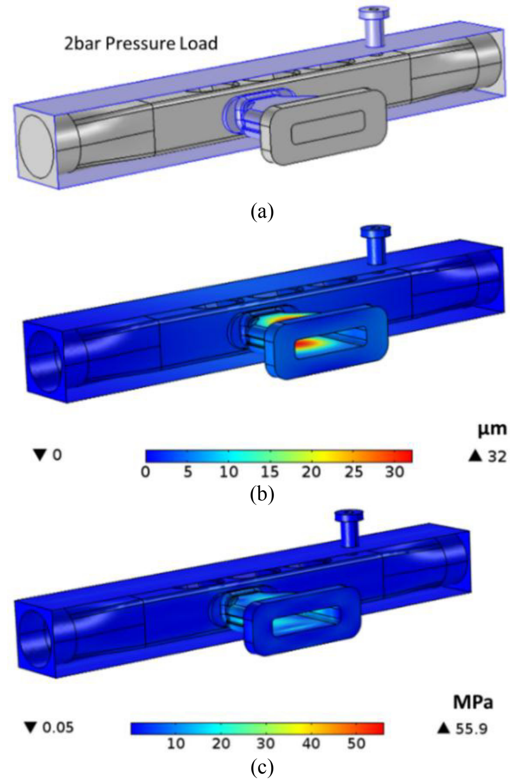

Figure 2: Frequency sensitivity to pressure fluctuation df/dP of the QMiR cavity. (a) Boundary conditions. b) Displacement in µm. (c) Von Mises stresses in MPa along the structure.

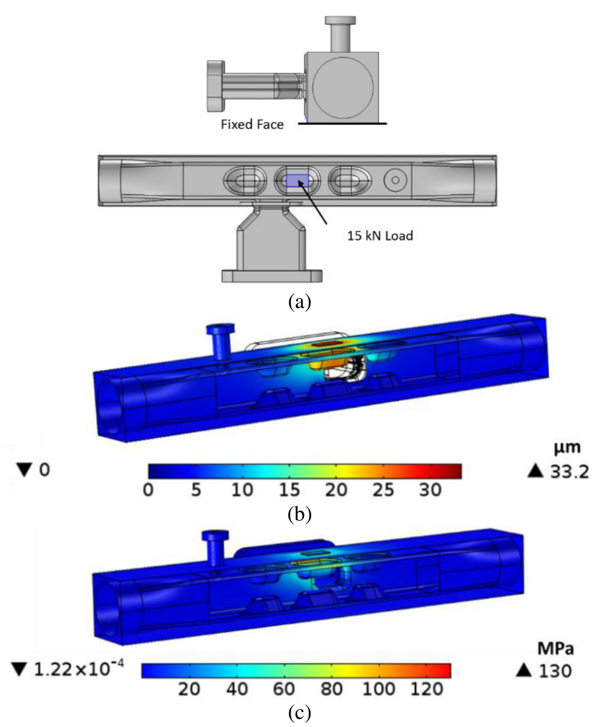

Figure 3: Investigation of frequency sensitivity to tuning forces for the QMiR structure. (a) Cavity with boundary load of 15 kN. (b) Resultant displacement in µm. (c) Resultant Von Mises stresses in MPa along the structure.

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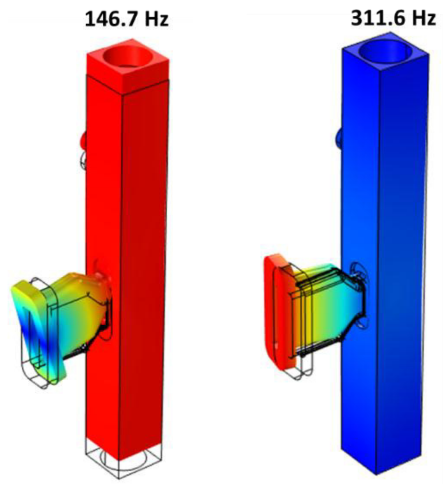
MECHANICAL RESONANCES

We have investigated the mechanical vibrations of the QMiR structure by running modal analysis using Comsol Multiphysics [4]. The lowest two mechanical modes of the structure are at 146.7 Hz and 311.6 Hz, as shown in Fig. 4. The calculated values of the mechanical modes are far from the 50 Hz electricity oscillation, which proves the structure immune to low frequency mechanical vibrations.



(a) (b)

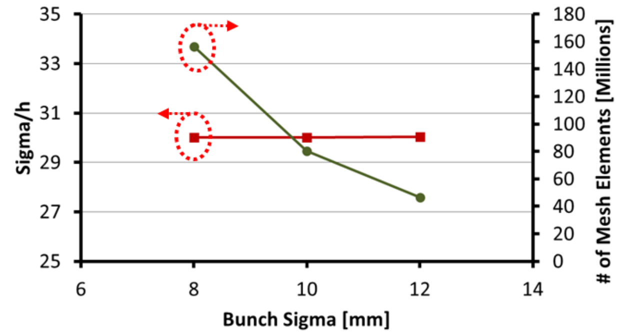
Figure 4: Modal analysis of the QMiR cavity showing lowest two mechanical resonances. (a) 146.7 Hz mode. (b) 311.6 Hz mode.

WAKEFIELD LOSSES

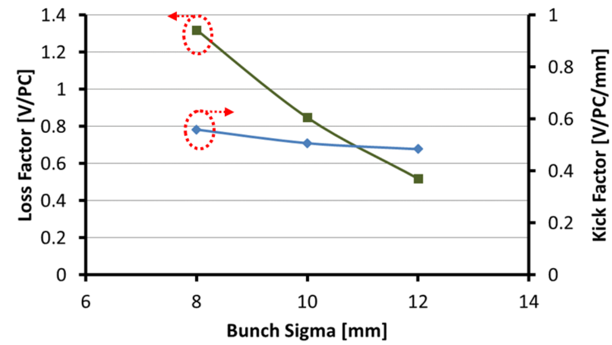
The wakefield losses inside the QMiR cavity due to bunch excitations were analyzed using CST microwave studio wakefield solver, where the structure is excited by a longitudinal line current [5]. For the loss factor calculations, the line current was placed on the beam axis, while for the kick factor the line is displaced off axis. In both cases, the line current ha a longitudinal Gaussian shaped charge distribution representing the beam.

Figure 5(a) demonstrates how we checked the accuracy of the analysis plotting *Sigma/h* versus and the number of mesh elements. Typically, the ratio between the bunch sigma (standard deviation of the Gaussian distribution) to the mesh step size in the longitudinal direction *Sigma/h* is used to check the accuracy of the analysis with conventionally using *Sigma/h* of 20 as a satisfactory level of mesh refinement. In this analysis, we have used a *Sigma/h* of 30. Mesh size of up to 160 million elements (per quarter of cavity) was needed for the relatively small bunch sigma of 8 mm.

Figure 5(b) shows the loss and kick factors of the QMiR cavity versus the bunch sigma for the range of interest for SPX from 8 to 12 mm. At 10 mm bunch sigma, the cavity would exhibit a loss factor of 0.85 V/PC, while the kick factor is 0.50 V/PC/mm.



(a)



(b)

Figure 5: Wakefield analysis the QMiR cavity. (a) Sigm/h (red) and number of mesh elements (green). (b) Loss (blue) and kick (green) factors.

CONCLUSION

Analysis of QMiR deflecting cavity indicates that the cavity would have a frequency sensitivity to pressure fluctuations *df/dP* of -1.5 Hz/mbar in case of fixed beam pipe ends and -3 in case of free ends. The RF tuning of the cavity can be attained by applying a force on the cells and the cavity exhibits a sensitivity of -39.5 Hz per every micron of change in the gap size (electrode to electrode distance). The lowest mechanical mode of the cavity was calculated to be 146.7 Hz, which is far from the common 50 Hz electricity oscillation. Finally, the cavity exhibits a wakefield loss factor of 0.85 V/PC and a kick factor of 0.50 V/PC/mm for a bunch sigma of 10mm.

REFERENCES

[1] A. Zholents, et al., “Generation of subpicosecond X-ray pulses using RF orbit deflection”, Nucl. Instrum. Methods Phys. Res., Sect. A, Vol. 425 (1999), p. 385.
[2] A. Lunin, et al., “Design of a quasi-waveguide multicell deflecting cavity for the advanced photon source”, LINAC14, THPP051, Geneva, Switzerland, 2014.
[3] Z. Conway, et al., “Development and test results of a quasi-waveguide multicell resonator”, IPAC14, WEPRI050, Dresden, Germany, 2014.
[4] Comsol Multipysics v4.4.
[5] CST Microwave Studio.