

SIMULATION RESULTS FOR A CAVITY BPM DESIGN FOR THE APS STORAGE RING*

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Abstract

A rectangular cavity BPM/tilt monitor for the APS storage ring has been designed to detect residual vertical-longitudinal tilt caused by the proposed short-pulse x-ray (SPX) project crab cavities. Electromagnetic simulations have been performed to verify the conceptual design and evaluate design alternatives. MAFIA and Microwave Studio have been applied to simulate the device in both time and frequency domain. The device geometry has been optimized to efficiently damp strongly driven lower- and higher-order modes while preserving the tilt-sensitive mode of interest. This mode is coupled out to the processing electronics using a waveguide geometry chosen to maximize isolation from the beam-driven modes.

INTRODUCTION

The SPX in the Advanced Photon Source upgrade (APS-U) presents challenges for the existing beam diagnostics. The ability to measure very small amounts of tilt will be essential to the success of the SPX project [1].

The X-band resonant cavity beam position monitor (BPM) has been designed, constructed, and operated in the Linac Coherent Light Source (LCLS) [2, 3]. It presents high sensitivity to both beam position and tilt [4, 5]. A cavity BPM is an efficient means to achieve beam tilt resolution at the level of tens of micro-radians, which is required for SPX.

The SPX crab cavities deflect the beam vertically, causing a longitudinal/vertical tilt on the beam. A rectangular cavity BPM geometry was chosen initially because all the modes are simple to compute analytically; it is the basis for the conceptual design studied here [6]. Simulation studies were performed on the structure shown in Figure 1.

The spectra and field patterns of the resonant modes in the cavity and coupler have been calculated using MAFIA and Microwave Studio [7] to further develop the design concept. The operating frequency was chosen to be 11.26 GHz (the fourth harmonic of the SPX frequency) to provide the highest practical resolution for beam position/tilt measurement. Different structures and materials were simulated to damp the unwanted beam-driven modes while leaving the vertical-beam-offset-driven mode of interest intact.

SIMULATION OF THE CAVITY BPM

The cavity dimensions (Table 1) were chosen to set the beam TM_{320} offset-sensitive mode frequency equal to

11.26GHz. During the simulation process, the stay-clear beam pipe aperture was determined by the need to have adequate room for injection.

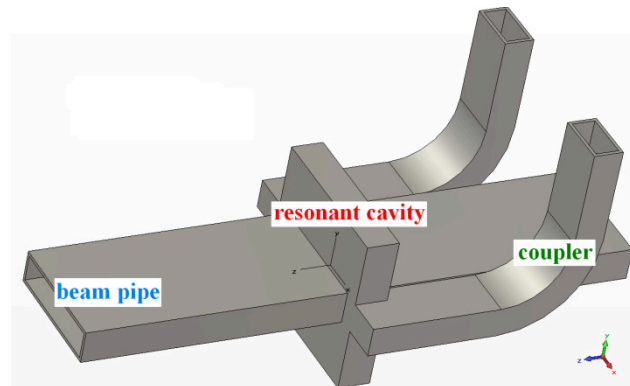


Figure 1: Layout of cavity BPM.

Table 1: Dimensions of the Cavity BPM

Dimension	Beam Pipe	Cavity	Coupler
Width	36 mm	46.09 mm	13.69 mm
Height	8 mm	46.09 mm	7.1 mm
Depth	NA	7.9 mm	NA

Field Patterns

The field patterns of the modes in a rectangular cavity are straightforward to calculate [6]. To check the simulation, the mode frequencies were verified using a very small beam pipe aperture with a vertically offset beam.

The magnetic field patterns of TM_{110} and TM_{320} are shown in Figure 2. The beam is offset vertically by 0.2 mm. Mode TM_{110} is the lowest beam-driven mode that must be damped. TM_{320} is sensitive to vertical beam offset / tilt and will be coupled out and measured.

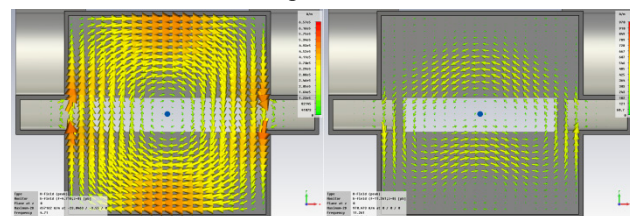


Figure 2: The magnetic field pattern of modes TM_{110} (left) and TM_{320} (right). Vertical beam offset is 0.2 mm.

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Spectrum of the Modes in the Cavity

Unless properly damped, many beam-driven modes will be trapped in the cavity, building up to very high levels that could result in locally high temperatures and possibly beam instability. The spectrum of the horizontal magnetic field H_x detected near the top of cavity is shown in Figure 3. The lowest modes TM_{110} , TM_{310} , and TM_{130} are strongly driven by the beam and must be coupled out or damped.

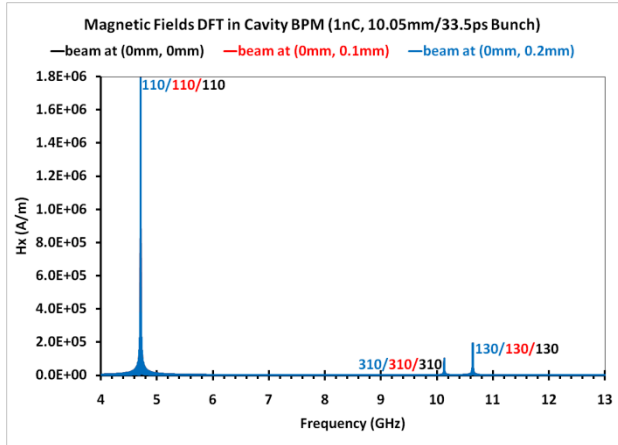


Figure 3: Spectrum of the modes in the top of the cavity.

Spectrum of the Modes in the Output Coupler

Modes that have horizontal magnetic fields in the mid-plane of cavity are coupled to the output coupler waveguide. The spectrum in the output coupler is shown in Figure 4. The magnitude of TM_{320} is proportional to the beam's vertical offset. The beam-driven modes will not couple to the output ports due to symmetry or because they fall below the waveguide cut-off frequency.

Some modes' field patterns have complicated structure; for example, the mode at 13.4 GHz marked by "???" in Figure 4. This is because the large beam pipe has a profound effect on the shape of the mode fields. The large beam pipe aperture is constrained due to the injection acceptance requirement.

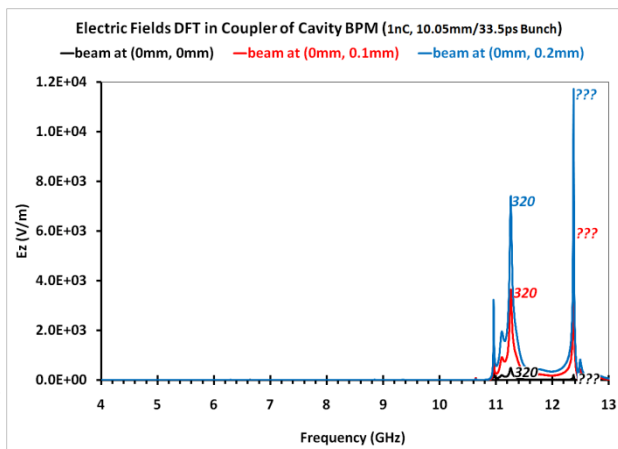


Figure 4: Spectrum of the modes in the output coupler.

SUPPRESSING THE DAMAGING MODES

From Figures 3 and 4, the unwanted modes such as TM_{110} , TM_{310} , and TM_{130} are very strong in the cavity, and steps must be taken to suppress these modes.

Three possible damping methods have been tested in simulation: resistive E-probes in the cavity, slots with ceramics on the top/bottom of the cavity, and an external waveguide network.

Four E-probes in the Cavity

Four resistive E-probes were located at the weakest electric field spots of the working mode TM_{320} , shown in Figure 5. The resistance of E-probes was optimized to damp unwanted modes efficiently without additional losses of TM_{320} . In practice these probes would use coaxial feedthroughs with variable external impedance, but here their conductivity was simply varied.

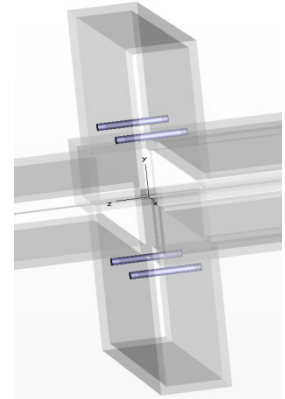


Figure 5: Four E-probes in the cavity

The simulation results are shown in Figure 6 where the electrical conductivity was set to be a factor of 128 below that of copper. The unwanted mode TM_{110} is suppressed by a factor of 20 while TM_{320} retains its pattern and magnitude (not shown).

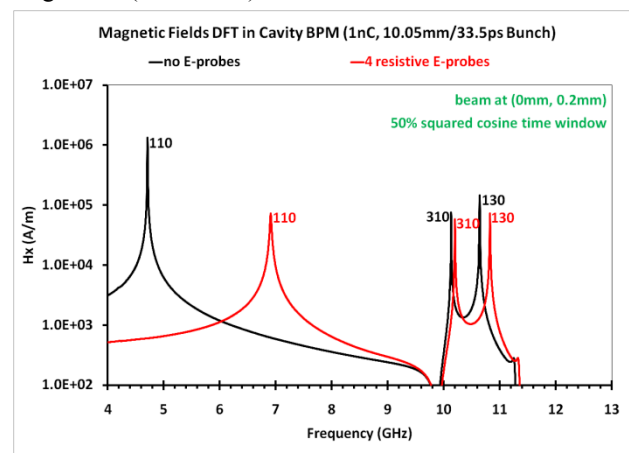


Figure 6: Comparing the E-probes' effects on damaging modes. The electric conductivity is a factor of 128 less than that of copper. Beam vertical offset is 0.2 mm.

External Network Attached to the Cavity

The resistive E-probes damp the lowest mode TM_{110} effectively but do not efficiently damp TM_{310} and TM_{130} due to their similarity with the TM_{320} mode of interest.

One idea was to use an external waveguide network (Figure 7) to combine and preferentially damp the strongly beam-driven modes while simply reflecting

energy from the desirable mode back into the cavity. The TM_{130} and TM_{310} were damped by a factor of 10; however, the TM_{320} mode of interest had low Q because of excessive wall losses.

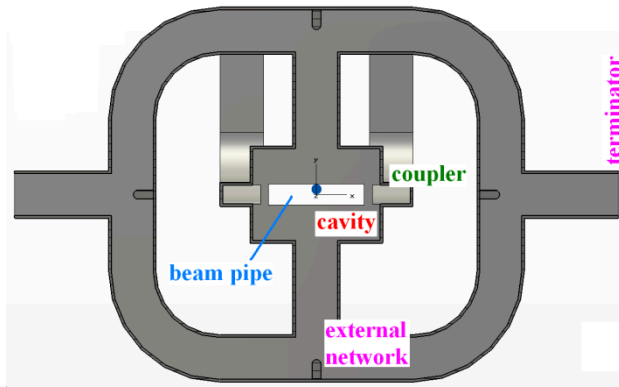


Figure 7: Front view of cavity, coupler, and external network waveguide.

Slots and Lossy Ceramics

Another idea was to use strategically placed lossy ceramics inside the cavity. Two slots are opened perpendicular to the wall current on the top/bottom of the cavity where the unwanted modes have higher magnetic fields. The ceramic (Ceralloy 13740Y, $\epsilon_r=20$, $\tan\delta=0.25$) [8] was filled in the slots. Another option was that block ceramics were mounted on the top/bottom walls. Both options are shown in Figure 8.

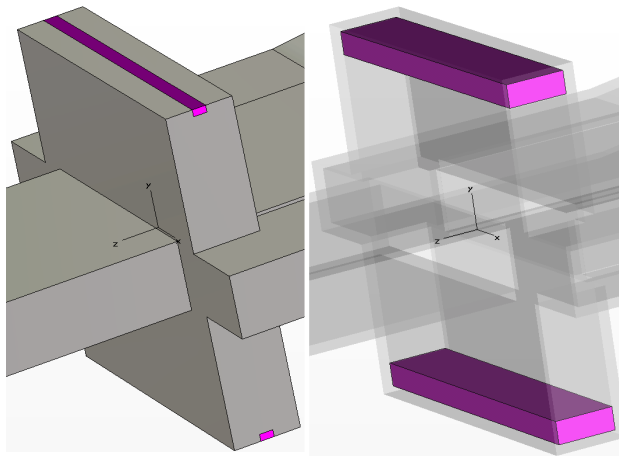


Figure 8: Slot with ceramics (left) or block ceramics (right) on the top/bottom of the cavity.

The simulation results for both options are shown in Figure 9. The suppression effects are best for the block ceramic geometry.

SUMMARY

Simulations of a rectangular cavity BPM/tilt monitor for use in a storage ring were performed. The output coupler waveguide prevents strongly driven modes from getting to the processing electronics due to the symmetry and choice of cut-off frequency. These modes must be

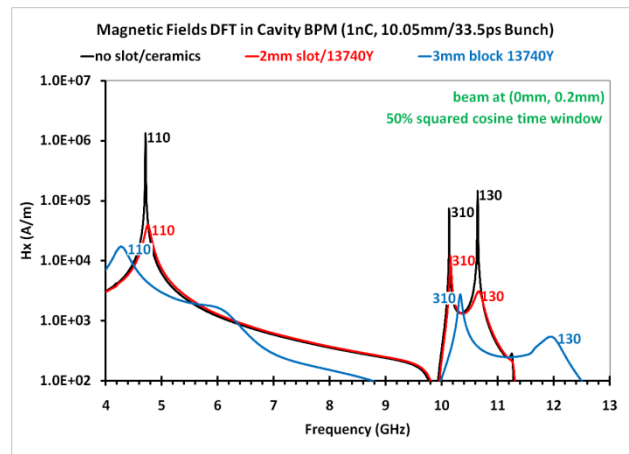


Figure 9: Comparing the slot and ceramics effects on damaging modes. Beam vertical offset is 0.2 mm.

damped in the cavity to be compatible with storage ring impedance requirements and to reduce unwanted heating.

The lowest order mode TM_{110} can be damped efficiently using four resistive E-probes in the cavity. Using slots and lossy ceramics on the top/bottom of the cavity appears to be a promising approach to damping unwanted modes. An external network was considered to damp the undesirable modes, but it negatively impacted the mode of interest. Once a strategy is finalized, a cold-test prototype will be constructed and tested.

ACKNOWLEDGMENTS

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