MODE DAMPING MEASUREMENT FOR THE APS DEFLECTING CAVITY *

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Abstract

The Advanced Photon Source has considered using a deflecting-cavity-based scheme to produce short pulse x-rays. A deflecting cavity design has been completed. To verify the simulation result on this cavity, a copper prototype of the design has been fabricated for bench measurement. In this paper, we report our measurement results on this cavity. All the cavity modes below 5 GHz were identified by comparing the field distributions with calculations along different beam paths. After adding the damper, the measured Q_{ext}s of those modes were consistent with calculated values, which demonstrated that the cavity damping scheme was sufficient to reduce the wake impedances well below the safety thresholds.

INTRODUCTION

The Advanced Photon Source (APS) at Argonne National Lab (ANL) has considered using a superconducting deflecting-cavity-based scheme to generate x-rays on the order of 2 ps or less [1]. The unwanted cavity modes in cavities can drive coupled-bunch instabilities in high-current storage rings. Thus sufficient damping of those modes was very important. It is equally important to maximize the operating mode parameters and provide sufficient transverse kick to the beam. A cavity design has been proposed, as shown in Fig. 1. This cavity design is a single squashed-cell cavity with an on-cell waveguide damper and a Y-end group on the beam pipe [2]. The on-cell waveguide serves as lower-order mode (LOM) damper. One of the Y-end group waveguide damper works as a fundamental power coupler (FPC) and the other two dampers as higher-order mode (HOM) dampers. The cavity operates at 2815 MHz.

Extensive simulations have been performed, and we have demonstrated that the wake impedances are well below the stability thresholds [3]. In this paper, bench measurements were performed to verify numerical calculations. There were mainly two steps in the bench measurement. The first step was to identify the modes by measuring the field distributions using on-axis and off-axis bead-pulls. The second step was to characterize the damping performance by using actual high-power waveguide damper prototypes [4].
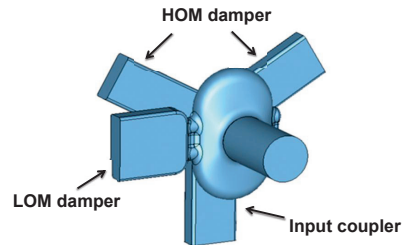
Figure 1: The APS deflecting cavity design.

COPPER PROTOTYPE CAVITY MEASUREMENT

Measurement Technique

The cavity modes were characterized by the Slater perturbation technique. With a small perturbing object, usually a dielectric bead or metal needle, passing through the cavity beam pipe, the longitudinal electrical field $E_z(r,\theta)$ along the beam path can be measured in terms of the frequency shift due to the perturbation. For a dielectric bead, the frequency perturbation can be related to the electric field strength as follows:

$$-\frac{\Delta\omega}{\omega} = g_1 e_\parallel^2 + g_2 e_\perp^2, \qquad (1)$$

where the coefficients g_1 and g_2 are geometric factors. They depend upon the bead size, material, and geometry. Eq. 1 shows that the electrical field in both longitudinal and transverse directions will contribute to the frequency change when the bead passes through the cavity. But for the R/Q measurement, only the longitudinal electrical field is of interest. In the APS deflecting cavity, there are many modes that have strong transverse electrical field compared to the longitudinal electrical field along the beam path. To get an accurate measurement of the R/Q, a slender bead with a length at least ten times larger than the diameter is required due to its insensitivity to the transverse electrical field with $g_1 \gg g_2$ [5]. However, our bead length needs to be relatively small to have adequate longitudinal resolution due to the compactness of the cavity. Given that, it is very difficult to have such a bead that can separate the transverse and longitudinal electrical fields. After exploring different beads and techniques, we selected a uniform dielectric bead with $g_1 \approx g_2$ to measure the electric field amplitude $E_{abs}(r,\theta)$ along different paths. Before the bead-pull mea-
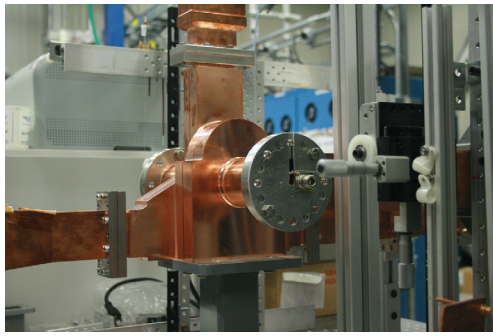
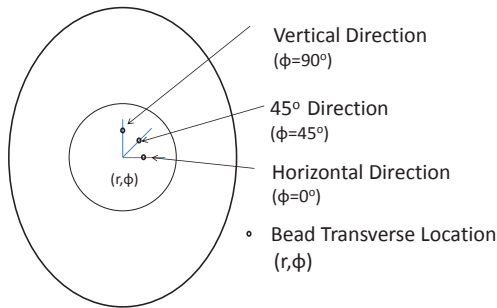Figure 2: Copper prototype cavity in bead-pull measurement. The bead transverse location can be changed.

Figure 3: Bead pull measurement along different paths in horizontal, vertical, and 45° directions.

surement on the copper prototype, we calibrated the beads with a pillbox cavity, in which the field distributions of different modes had been well understood. The geometric factors $g1$ and $g2$ were obtained by the monopole mode and dipole mode measurements.

Even though the azimuthal symmetry is broken in the APS deflecting cavity, the cavity modes can still be approximately classified as monopole mode, dipole mode, and quadrupole mode. It is hard to get the mode identity based on the field distribution E_{abs} on a single path. To fully characterize the mode azimuthal property (monopole, dipole, or higher) and identify the mode, bead-pull measurements were performed with different transverse offsets in different directions, as shown in Fig. 2 and Fig. 3. We focused on the horizontal , vertical, and 45° angle displacement. The bead-pull measurements were performed using an Agilent E6362B network analyzer with a Labview program. With all waveguide ports and beam pipe ports shorted and sealed, the cavity mode was excited by a probe inserted through the beam pipe, and the signal was picked up through a probe on the waveguide damper or a probe inserted into the other side of the beam pipe. The frequency shift due to the bead perturbation was measured in terms of the phase shift, which was more sensitive than direct measurement. Different probes were developed for mode excitation. By changing the probes and varying the probe orientation, it was possible to enhance the profile of the mode we were measuring and reject the interfering mode.
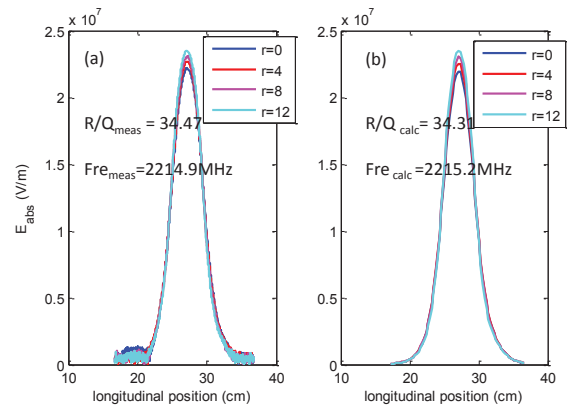
Figure 4: Measured (a) and calculated (b) field distribution of the TM010$_{like}$ mode along different paths with an increasing horizontal offset r. The measured R/Q value is very consistent with simulation.
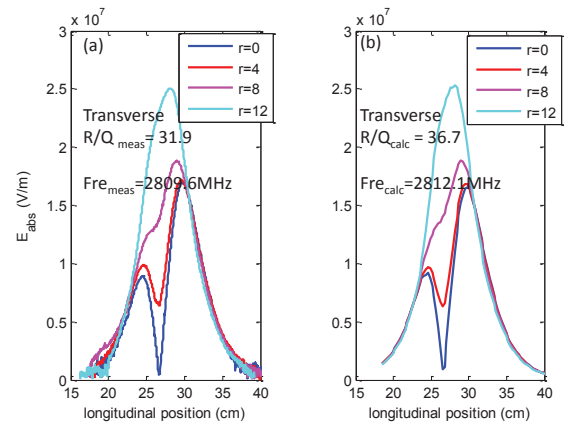

Figure 5: Measured (a) and calculated (b) field distribution of the TM110y$_{like}$ mode along different beam paths with an increasing vertical offset r.

Mode Characterization

Comparison of E_{abs} along different paths turned out to be a very effective way to identify all the cavity modes. Figure 4 compares calculated and measured field distributions of the monopole TM010$_{like}$ mode along different horizontal paths. This mode was the lowest mode of the cavity and it had very strong beam coupling. Due to the strong coupling with on-cell waveguide damper, the field amplitude had a gradient along the horizontal direction, which was confirmed by both calculation and bead-pull measurement. There was negligible transverse electrical field effect, and the R/Q measurement gave a very consistent result with the simulation. Figure 5 shows the field distributions of the operating dipole mode along different vertical paths. The measured field amplitude was the superposition of the longitudinal electrical field and the transverse electrical field; it was very hard to separate the longitudinal

Table 1: Comparison of Mode Frequencies and Q_{ext}s with Prototype Dampers

| Mode identity	Frequency calc. (MHz)	Q_{ext} calc.	Frequency meas. (MHz)	Q_{ext} meas.
TM010$_{like}$	2295.82	67.96	2294.2	76.4
TM110y_{like}	2812.12	1×10^6	2809.8	1.03×10^6
TE111x_{like}	2987.12	273	2985.23	256
TE111y_{like}	3027.2	515	3026.74	512
TM110x_{like}	3347.4	10.2	3326.74	24
TM020$_{like}$	3937.3	200.3	3935.4	152
TM210$_{like}$	4269.7	4270	4267.7	3890
TE211a_{like}	4505.7	1340	4520.4	1130
TE211b_{like}	4599.7	1376	4610.4	1425
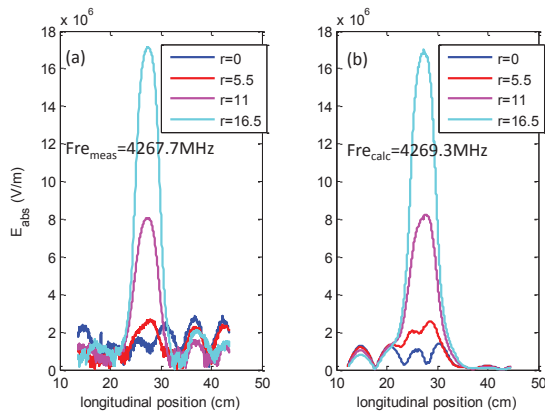
Figure 6: Measured (a) and calculated (b) field distribution of the TM210$_{like}$ mode along different beam paths with an increasing 45° offset.

effect. Thus the measured transverse R/Q was less consistent with the simulation. Figure 6 shows the field distributions of the quadrupole TM210$_{like}$ mode along different 45° paths. Around the cavity center, the field strength was very low but the field strength inside cavity increased significantly with a growing offset r in 45° direction, as demonstrated in simulation and bead-pull measurement.

Mode Damping

After the cavity modes were identified by the bead-pull, all the waveguide couplers were connected with the proper loads. Q was measured by S_{21} transmission between the probes either inserted into the beam pipe or on the waveguide damper. After adding the damper, the loaded Qs of the cavity modes (except the operating mode) were much lower. Normally, we started the measurement with the same probes mounted in the same positions around the cavity as we did in the previous measurement when all the waveguides were shorted. The Q_{ext}s could be derived by the difference of the inverses of the measured Q_{load}s. If the mode Q_{ext} was very low, the probe location was adjusted to have stronger coupling. Table 1 compares the measured Qs with the calculation by ACE3P. It could be shown that the measured Q_{ext}s of the cavity mode were quite consistent

with the simulation results.

One thing to note is that the measurement of the operation mode TM110$_y$ was different. The mode had a weak coupling with all the waveguides. To measure the coupling, a matched tophat was used on the waveguide coupler. The transmission S_{21} between the matched tophat and the tuned beam pipe probe was used to calculate the coupling through the waveguide.

SUMMARY

A copper prototype cavity has been fabricated and extensive measurements have been performed on the cavity. The bead-pull measurements were performed for all the modes below 5 GHz. The cavity modes were identified by comparing the measured field distributions with calculations along different paths. The field distribution of different modes were consistent with the calculated results. After adding the prototype damper, the measured Q_{ext}s were in agreement with the simulation results, which indicates that the fabricated cavity could meet the design criteria and the wake impedances were well below the stability thresholds for operating in the APS storage ring with 150-mA current.

ACKNOWLEDGMENT

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