

Measurements on Prototype Cavities (352 MHz) for the Advanced Photon Source (APS) *

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Abstract

Measurement of the higher order modes of a prototype single-cell 352-MHz cavity for the APS 7-GeV Storage Ring will be presented and discussed. A 352-MHz cylindrical pill-box cavity made of aluminum has been built to test and verify the measurement instruments using the analytically-derived resonant frequencies of both the fundamental and higher-order modes. A cavity made from solid copper was built according to dimensions derived from URMEL program runs. The longitudinal and transverse impedances of the first several higher-order modes have been measured using various shaped metal beads.

I. INTRODUCTION

The prototype all-copper cavity for the APS storage ring has been measured for higher-order modes (HOMs) and the data has been categorized by bead-pulling techniques. Those modes which may interfere with beam stability [1] have been damped with low-power devices.

HOM measurements have been previously made on a cylindrical cavity with the E_{010} mode at 351.9 MHz, the accelerating mode for the APS 7-GeV storage ring [4, 5]. This was done to check the instrumentation and to familiarize ourselves with the technique by using a cavity shape that can be analytically solved for higher modes. The accelerating cavity shape is basically spherical with a rounded, slightly reentrant beam pipe (see Figure 1). However the aspect ratio and volume are about the same as in the previously studied cylindrical cavity, therefore the frequency and Q of the modes are also about the same.

II. METHOD

We used standard bead perturbation techniques [2, 3, 4], primarily with metallic cylinders 25.4mm long by .8mm diameter, to measure the longitudinal E-field for monopole and dipole modes. Such needle-like objects do not significantly perturb the magnetic field or the transverse component of the electric field.

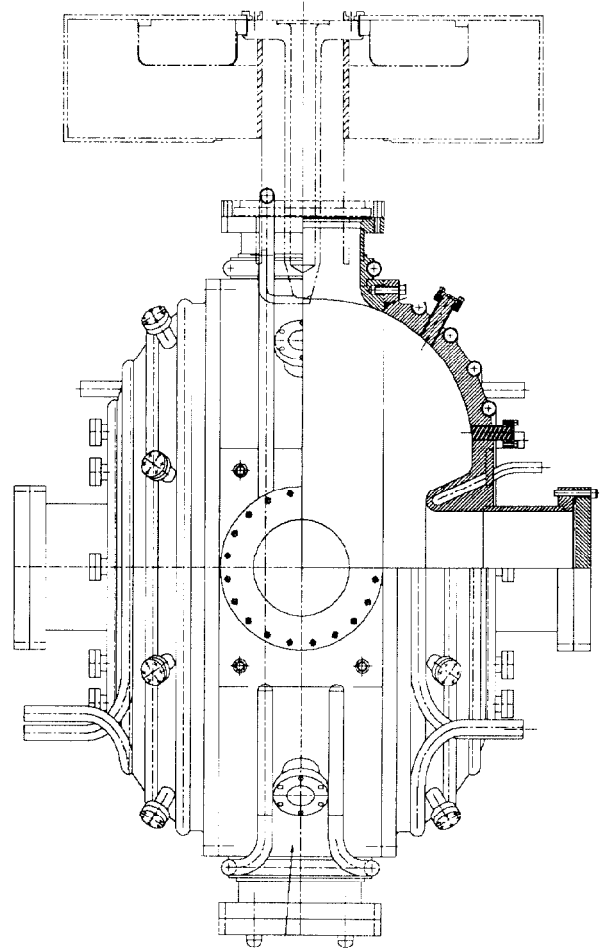


Figure 1

The perturbation of the longitudinal component \vec{E}_{\parallel} of the electric field is related to the phase shift ϕ of the resonance by

$$-\tan \phi = \frac{Q}{W} 3\Delta V \epsilon_0 F_1 |\vec{E}_{\parallel}|^2 / 2 \quad (1)$$

(equation (18) on page 8 of [3]) where Q and W are the quality factor of and energy stored in the mode, and ΔV is the volume occupied by a prolate spheroidal perturber of high aspect ratio oriented parallel to \vec{E}_{\parallel} . Then

$$R_{shunt} = \frac{2 \left| \int_0^L (-\tan \phi)^{\frac{1}{2}} e^{i\omega_0 z/c} dz \right|^2}{3\omega_0 \epsilon_0 F_1 \Delta V}, \quad (2)$$

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is obtained by solving (1) for \vec{E}_{\parallel} and substituting it into the general equation $R_{shunt} = |V|^2/P$ where $P = \omega_0 W/Q$ is the mean power dissipated and $V = \int_0^L \vec{E}_{\parallel} e^{i\omega_0 z/c} dz$ is the accumulated voltage difference experienced by a positron during its passage from $z = 0$ to $z = L$.

The form factor F_1 was adjusted by calibration against the analytically known fields and impedances in the right-circular cylindrical cavity, dimensioned so that its resonant frequencies corresponded to those of the prototype cavity.

The analytic value for the R/Q of the fundamental mode in our cylindrical cavity is 209Ω , with no transit time factor. Our measured value was, instead, 319Ω . In agreement with Jacob [3] we attribute the difference to the greater amount of metal contained in a cylindrical needle than in an ellipsoidal one of the same length and width. In the "crudest approximation" (see page 319 of [2]) the frequency shift depends only on the volume of the perturber. The volume ratio between cylinders and spheroids of the same dimensions is $3/2$, so we have used that ratio as our calibrating correction factor throughout. The resulting calculations of longitudinal and transverse shunt resistances from measured data agreed closely with the same values calculated by URMEL (see Tables 2 and 3 in [1]).

For dipole modes the longitudinal shunt resistance is zero along the axis of the cavity. By measuring two more longitudinal shunt resistances, off axis but close to and parallel to it, and noncollinear with it, we can get an approximation to the transverse gradient of the longitudinal shunt resistance at the axis. From this, by the Panofsky-Wenzel Theorem, we determine the transverse mode impedance as on page 6 of [3].

III. DATA

Data was recorded using an 8510 network analyzer and an HP Vectra computer with our own software. Measurements of the phase deviation of S21 were recorded as the bead was shifted along parallel to the axis of the cavity. Two small loops on the perimeter of the cavity were used as the input and output ports for both the Q and the perturbation measurements. Some data was obtained by driving the cavity through the full-size, high-power loop which was rotated so as to have 50Ω input impedance at the fundamental frequency, 351.9 MHz.

Ten modes were calculated to have impedances that will cause coupled-bunch instabilities near or below the 300 mA positron current which is the design goal of the APS [1]. These modes were measured and are listed in Table 1 along with the impedances calculated using URMEL [1].

Table 1.

Frequency (MHz)	R (Normal M Ω)	Threshold Current (mA)	Damping Ratio (dB)
536.7	1.67	80	23.
588.7	13.6	81	9.
761.1	25.6	43	30.
922.5	0.62	130	-
939.	0.23	340	40.
962.	6.1	180	-
1017.4	2.6	320	13.
1145.1	2.7	80	5.
1210.8	.49	80	-
1509.1	0.36	80	20.

Figure 2 shows the phase shift data for the fundamental mode 351.9 MHz and Figure 3 shows the E_{013} mode at 1210 MHz. These two graphs are typical of all the data, although some modes were noisy and had to be averaged to increase the signal-to-noise ratio.

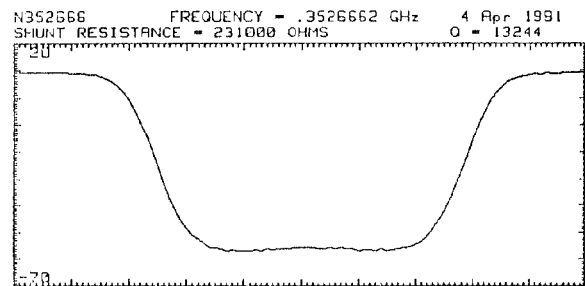


Figure 2

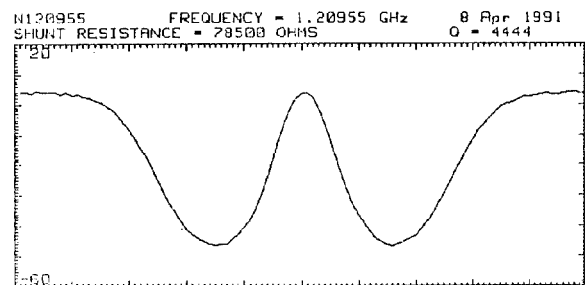


Figure 3

IV. RESULTS

We have measured the modes in Table 1, and significantly damped most of them whose instability thresholds were below 300mA. There are two sets of such modes: those which the magnetic field on the mid-plane coupled to the fundamental drive loop, and those with an E-field perpendicular to the beam at the circumference at the mid plane.

The loop-coupled modes were damped by using a 50Ω resistor on the input port to the loop (see Figure 4) .

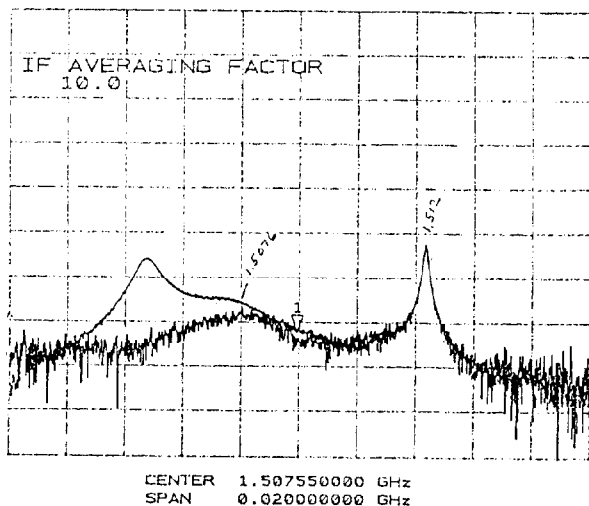


Figure 4

In the final design these modes will be damped by lossy material inserted in the input waveguide near the drive loop. This arrangement will also prevent these frequencies from returning to the splitters, circulator, and eventually the klystron, which are not meant to handle them. Those three modes not damped by the driving loop will be further investigated.

The E-field modes were damped between a factor of 13 and 34 dB using a resistance which was optimized for maximum damping at 940 MHz (see Figure 5).

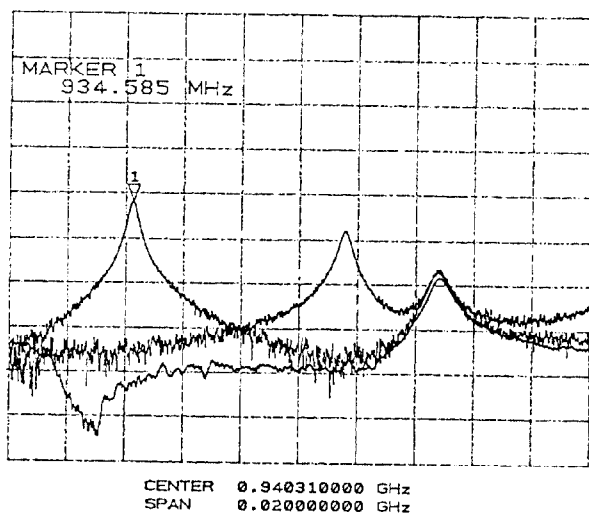


Figure 5

The marker is on the undamped resonance peak. The E-field probes shift the peak about 7MHz higher when inserted into the cavity. Resistively loading the probes damps the resonance about 40dB. (The peak at about 956 MHz is essentially unchanged.)

V. FUTURE WORK

We will design and test a magnetically coupled damper for those modes not damped by the drive loop (i.e., 923, 962, and 1211 MHz).

We intend to measure two more sets of HOMs: monopole and dipole modes with instability thresholds between 300 and 600 mA, and a few of the lower quadrupole modes.

We also intend to investigate damper design in more detail, in particular to try to design a damper that will be conjugately matched to the bothersome modes and that will be optimized using the criteria that the damping ratio of each of the modes will raise the instability threshold currents to the same value for all modes. This value might be arbitrary, say 1A, or it might be set at the average of those thresholds between 300 and 600 mA depending on the number in that interval and the ease of damping.

We intend to lengthen the cavity by using shims of copper to learn how the HOMs shift in frequency. Based on this information we may design the cavities to have different shapes in order to spread the HOMs and thereby reduce cavity-bunch instabilities [1].

VI. ACKNOWLEDGEMENTS

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