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Higher-Order Modes in the APS Storage Ring Waveguides

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Abstract

Twelve higher-order modes (HOMs) in the single-cell accelerating cavities for the Advanced Photon Source (APS) storage ring were calculated to have complex impedances that will cause coupled-bunched instabilities near or below the 300mA positron current which is the design goal. Some of these modes couple, through the coupling loop, from the storage ring cavity into the waveguide. This study investigates the transmission of these modes from the cavity into the waveguide. The standing wave ratio (VSWR) of a WR2300 hybrid waveguide component has been measured at each HOM frequency, and its effect on the transmitted modes in the waveguide is studied.

I. INTRODUCTION

When a particle bunch from a stored beam travels through an RF cavity, the electrical charge and current of the bunch produce electric and magnetic fields at the walls of the cavity [1]. Induced charges and currents are generated in the walls of the cavity by the fields and these charges and currents induce wakefields that can interfere with the bunch and can cause deflections or changes in energy of the particles in the bunch. After the passage of the beam bunch, electromagnetic energy is deposited in resonant HOMs which are determined by the geometry of the RF cavity. These HOMs of RF cavities are the largest contributors to coupled-bunch instabilities.

In the APS, the stored beam will have approximately 60 bunches, 5mA per bunch, for a total beam current of 300 mA. In a multibunch operation of a storage ring, the stability limit is reached at a threshold current value which is inversely proportional to the shunt impedance R_s of the driving HOM [2]. The threshold current value for instabilities is determined by the synchrotron radiation damping rate and the growth rate of the instabilities. During the synchrotron acceleration process the amplitude of small phase oscillations and radial oscillations of the bunch are reduced as energy increases; this is defined as synchrotron radiation damping [3]. The radiation damping rate is a constant while the instability growth is proportional to the stored current. The current at which the instability growth is equal to the damping rate is the stability threshold. Since the maximum beam current is 300mA, the threshold current for a HOM with a value less than 300mA may cause coupled-bunch instabilities. Twelve HOMs with current thresholds less than or close to 300mA are listed in Table 1 [4].

Table 1

Longitudinal Modes (Monopoles)		Transverse Modes (Dipoles)	
freq HOM (MHz)	Ithresh (mA)	freq HOM (MHz)	Ithresh (mA)
536.7	80	588.7	80
922.5	130	761.1	43
939.0	340	962.0	190
1173.2	340	1017.4	435
1210.8	130	1145.1	410
1509.1	130	1219.2	315

To avoid the development of beam instabilities due to the existence of these HOMs in the RF cavity, damping of the modes will be required. E-probe and H-loop dampers will be used for damping some HOMs in the cavity. The possibility of the HOMs present in the RF cavity coupling into the loop coupler and traveling through the coupler into the waveguide, may allow damping of some of the HOMs by the insertion of dampers into the waveguide adjacent to each cavity. In order to investigate the feasibility of using waveguide dampers, the HOMs which couple into the waveguide must be determined.

II. BEAD PULL MEASUREMENTS

Several of the HOMs listed in Table 1 were not considered because the I_{thresh} was substantially higher than the 300mA limit. Additionally, three of the modes were successfully damped in the 352-MHz cavity [5]. Table 2 lists the remaining HOMs to be studied, their corresponding frequencies and modes in an equivalent (348 MHz) pillbox cavity (radius = 0.33m, length = 0.375 m), and the per unit difference between the two. The difference is small enough that the pillbox can be used for a good model.

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Table 2

Mode	f pillbox	f cavity	fcav/fpillbox	Δ
TM110	554.0	588.7	1.0626	0.0626
TM012	872.0	922.5	1.0579	0.0579
TM112	973.0	962.0	0.9887	0.0113
TM120	1014.0	1145.0	1.1293	0.1293
TM013	1249.0	1210.8	0.9684	0.0305
TM122	1292.0	1219.2	0.9437	0.0563

Verification of the HOM field configuration in the pillbox for each one of the frequencies under consideration was done by performing a bead-pull measurement. According to perturbation theory, the resonant frequency of a mode in a cavity is shifted when an object is placed inside the cavity, by [6]:

$$\frac{\delta\omega}{\omega} = \frac{\iiint_{v_1} (E_1D_0 - E_0D_1) - (H_1B_0 - H_0B_1)\,dv}{\iiint_{v_0} (E_0D_0 - H_0B_0)\,dv} \qquad (1)$$

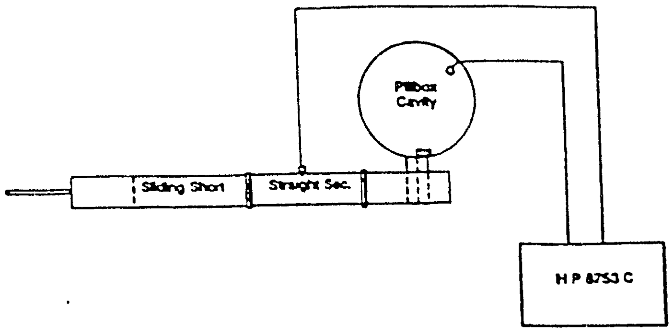
The bead-pull measurement setup consisted of the pillbox, a small conducting needle epoxied to a silk string, an apparatus to suspend the string through the beam axis of the conducting cavity, a stepper motor to step the needle through the cavity, a Hewlett Packard 8753 C Network Analyzer to take measurements of the phase shift of the resonant frequency due to the needle, and for automated control of the 8753 C, an IBM PC. From the results of the bead-pull measurements and their comparison to a previous bead-pull done on the prototype single-cell RF cavity [7], Table 2 was confirmed.

III. MEASUREMENTS IN WAVEGUIDE

To obtain the measurements needed for the determination of the mode configuration of the HOMs at the frequencies of interest, the pillbox, analyzer, and waveguide components were arranged as shown in Figure 1. The loop coupler used to couple the RF power from the waveguide into the cavity was inserted into the pillbox and the transition between the coaxial loop coupler and the waveguide was attached to the coaxial end of the coupler. A straight section of half-height WR2300 waveguide, 1.2 meter (λ_g), was added to the transition and it was terminated with a sliding waveguide short. In the center of the straight section, perpendicular to the flanges, small E-probe antennas were inserted. They were evenly spaced along one broad-wall and one side-wall for measurement of any E-field that would be perpendicular to the wall of the guide.

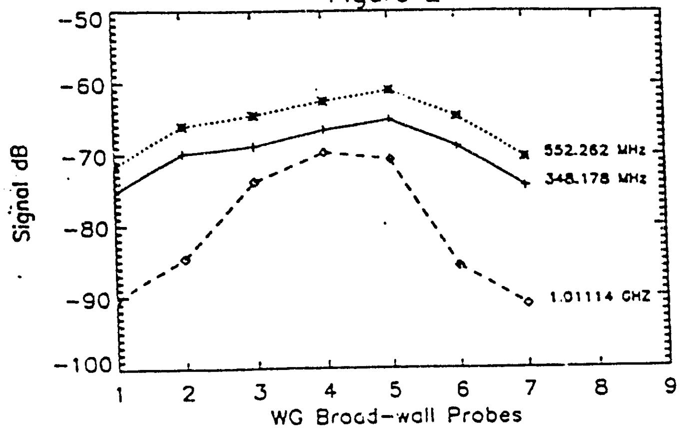
Because some shift in frequency was expected due to the insertion of the coupling loop into the cavity, bead-pull measurements were taken at each frequency to verify that the correct mode was being excited in the cavity. Measurements were taken from the E-probe antennas at each corresponding frequency. The sliding short was used to optimize each resonant frequency in the guide which provided the best possible signal from the probes.

Figure 1



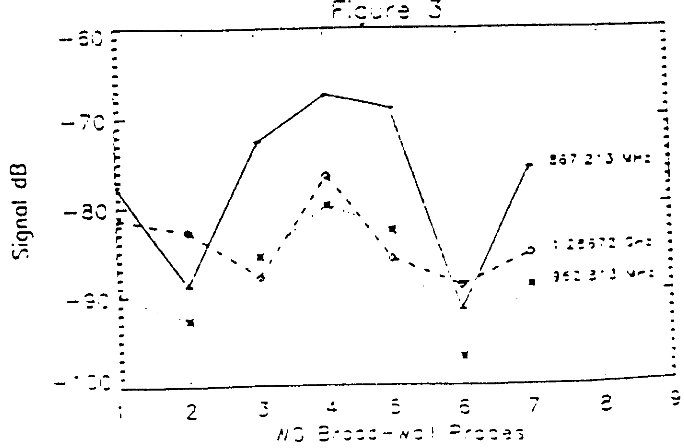
All of the modes listed in Table 2 were found in the waveguide. Figures 2, 3, 4, and 5 show graphs of the signal versus position of the seven probes that were placed in the broad-wall of the waveguide. As shown in Figures 4 and 5, only one of the modes found in the waveguide had E-field components perpendicular to the broad-wall and side-wall. The loop coupler was located on the radial wall of the pillbox. As a result, the variation of the E and H fields along the length of the cavity with respect to the loop was the main contribution to the determination of the configuration of the mode in the waveguide.

Figure 2



freq	cavity mode		wg mode
348.178 (MHz)	TM010	⇒	TE10
522.626 (MHz)	TM110	⇒	TE10
1011.14 (MHz)	TM120	⇒	TE10

Figure 3



freq	cavity mode		wgmode
867.213 (MHz)	TM012	⇒	TE30
962.813 (MHz)	TM112	⇒	TE30
1.28677 (GHz)	TM122	⇒	TE30

Figure 4

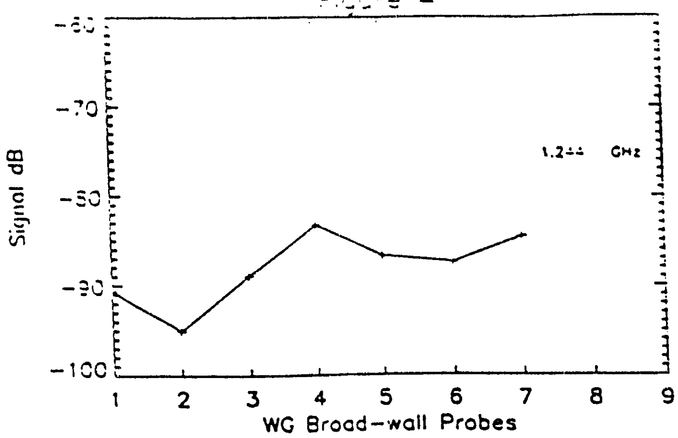
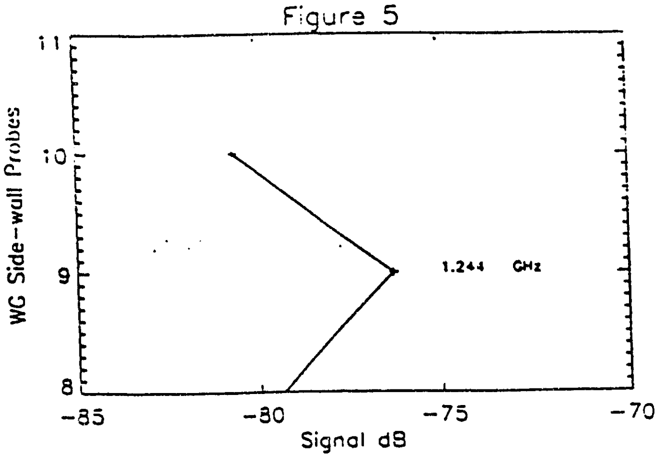


Figure 5



freq	cavity mode		wgmode
1.24424 (GHz)	TM013	⇒	TE31 or TM31

IV. HYBRID MEASUREMENTS AND EFFECTS

Those modes which couple into the waveguide and are not damped by loads on the hybribs become resonant and will require waveguide dampers. The previous measurements were taken with the waveguide terminated in a short resulting in total reflection. This will not be the case in the storage ring RF system. Rectangular waveguide components generally are not broadband devices and the impedance of the component varies substantially at frequencies other than the designed fundamental frequency. In order to determine which HOM frequency will couple to loads and be damped and which will become resonant in the waveguide, a measurement of the VSWR of the component at each HOM frequency was made. The first component that was measured was the WR2300 3dB Hybrid. Results are listed in Table 3.

Table 3

freq HOM (MHz)	VSWR	freq HOM (GHz)	VSWR
552.24	17.228:1	1.0143	3.970:1
867.11	57.367:1	1.2442	30.004:1
961.5	1.322:1	1.2867	4.850:1

V. CONCLUSION

The above measurements show that the HOMs listed in Table 2 are coupled into the waveguide. The measurements of the standing wave ratio (VSWR) of the WR2300 hybrid indicate that three of the six modes under consideration will not be damped by the coaxial loads in the hybrids and will require additional waveguide dampers.

VI. REFERENCES

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