HOM (Higher-Order Mode) Test of the Storage Ring Single-Cell Cavity with a 20-MeV e⁻ Beam for the Advanced Photon Source (APS)*

J. SONG, Y. W. KANG, and R. KUSTOM
Argonne National Laboratory, Advanced Photon Source
9700 S. Cass Ave. Argonne, IL 60439, USA

ABSTRACT

To test the effectiveness of damping techniques of the APS storage ring single-cell cavity, a beamline has been designed and assembled to use the ANL Chemistry Division linac beam (20-MeV, FWHM of 20 ps). A single-cell cavity will be excited by the electron beam to investigate the effect on higher-order modes (HOMs) with and without coaxial dampers (H-loop damper, E-probe damper), and wideband aperture dampers. In order for the beam to propagate on- and off-center of the cavity, the beamline consists of two sections-- a beam collimating section and a cavity measurement section-- separated by two double *Aluminum* foil windows. RF cavity measurements were made with coupling loops and E-probes. The results are compared with both the TBCI calculations and 'cold' measurements with the bead-perturbation method. The data acquisition system and beam diagnostics will be described in a separate paper [1].

I. INTRODUCTION

HOMs of the prototype APS-SR 1-cell cavity were already analyzed as shown in Table 1. The left column is a summary of the URMEL calculations [2], showing the mode type, frequency, and R/Q. Ten modes were calculated to have impedance that will cause coupled-bunch instabilities near the 300 mA of positron beam current that is the design goal of the APS. These modes were also measured with the standard bead-perturbation method [3]. All the frequencies of the modes are very close to those predicted by URMEL simulation, though they are not exactly the same, since one cannot simulate a real structure with a 2-D computer code such as URMEL.

Table 1 Mode Comparison

URMEL Calculation			Measurements	Measurements
			perturbation	(20 MeV Beam)
# mode	f	R/Q	All 4 tuners in flush	No tuners/input coupler
	(MHz)		f	f
0 E-1	353.6	114.3	352.6	351.3
0 M-1	536.7	40.7	536.4	537.3
1 E-1	588.7	200	588.3	587
1 M-2	761.1	483	758.6	759
0 E-3	922.5	5.8	920.1	919
0 M-2	939	5.5	936.4	940
1 E-3	962	113	958	950.5
1 M-4	1017.4	63.4	1015	1018
1 E-5	1145.1	29.3	1141	1146
0 M-3	1210.8	5.2	1208	1205
0 E-6	1509.1	4.1	1507	1509

HOMs can be observed and identified with field probes by sending a beam on-axis and off-axis of the cavity. Various types of HOM dampers are also tested with this measurement. The primary reason for building this test facility is to measure those HOMs near and above the cutoff frequency of the beampipe. These modes cannot be easily calculated well because of strong geometric effects. Bench measurements cannot be easily related to beam-induced effects. With the beam-cavity measurement, one can evaluate impedance measurement techniques such as the bead-perturbation method and the wire method with the synthetic pulse [4].

The 20-MeV electron beam will be good for testing because of the similarities of its pulse shape and charge to those of the APS storage ring bunch. Comparisons of the linac beam and the APS storage ring bunch parameters are given in Table 2.

Table 2 Main Beam Parameters for the APS-SR System and the Chemistry Linac.

	7-GeV APS Storage Ring			20-MeV Linac
Mode	single	Nominal	Maximum	1 - 60 Hz
# of bunch	1	20	60	
average current	5 mA	100	300	>1.5 μA
peak current	700 A			> 625 A
bunch length (FWHM)	27.5 ps	50	72.5	25 - 40 ps
Total # of particle	1.2×10^{11}	2.3×10^{12}	6.9×10^{12}	$>1.5\times10^{11}$
total charge	18.5 nC			1 - 20 nC
natural emittance	8.2 x 10-3 mm-mrad			10 mm-mrad

II. BEAMLINE SYSTEM

The Argonne Chemistry linac is an 'L' band (1.3 GHz) traveling wave accelerating structure. An electron beam (1-60 Hz repetition rate, 1 - 20 nC total charge, and 25 - 40 ps bunch length) can be obtained.

A beam position monitor or beam stripline (BPM) and an integrating current transformer used in the first section

*Work supported by U.S.Department of Energy, Office of Basic Sciences, under Contract W-31-109-ENG-38.

are used in the first section for beam diagnostics. The BPM serves as a triggering signal for the rest of the beam diagnostic system. The second section of the beamline includes the RF cavity, two fluorescent screens (FS), an integrating current transformer, and a beam dump. One FS is located upstream of the cavity and the other downstream of the cavity. A detailed description of the beam parameter measurement can be found in reference [1].

The second section is movable with respect to the first section by ± 2 cm in the X and Y directions and 10 cm along the beamline to have a beam off-center of the cavity. The beamline pressure is about 1 x 10 $^{-4}$ Torr.

III. CAVITY MEASUREMENT SYSTEM WITH HOM DAMPERS

HOMs are measured with two H-loops and two E-probes that are connected to the cavity. One H-loop (H_1) is oriented to couple to the TM-like mode and the other H-loop (H_2) is oriented to couple to the TE-like mode. These are connected onto the ports of the equatorial plane which are 90 degrees apart (i.e., orthogonal to each other). The coupling with these H-loops is easily changed without breaking the vacuum.

The E-probes are made of 1/4" Cu coaxial transmission line and connected through SS Quick-Disconnects (or a Wilson Seal) to give the probe coupling flexibility. One E-probe (E1) is near the beam port, and the other (E_2) is near, but not on, the equatorial plane. The output of these H-loops and E-probes are connected to the HP microwave multi-throw switches and HP switch driver. These probes are well calibrated with the calibration cavity (f_0 = 1.6 GHz) and the HP 8510 network analyzer.

The EPICS (Experimental Physics and Industrial Control System) software is used for control and data collection (mainly beam parameter measurements). The operator interface (OPI) is a SUN workstation running the UNIX operating system. The SUN workstation communicates with a VME-based Input/Output Controller (IOC) through an Ethernet LAN. By controlling the HP switch driver, one can switch from one probe to another easily and quickly.

H-loop and E-probe dampers have been tested as shown in Fig. 1. An alumina ceramic disk window is used in the coaxial line near the vacuum flange to isolate the ferrite load from the cavity vacuum. The center conductor is water-cooled. The E-probe damper was tested successfully in the cavity up to 100 kW CW input power [5]. The H-loop damper also has a $\lambda/2$ notch filter to avoid coupling to the fundamental mode of the cavity. The dampers are connected to ports on the equatorial plane. Tests were made with only one E-probe damper with about 1 inch into the cavity, two E-probe dampers orthogonal to each other, and one H-loop damper alone.

IV. RESULTS AND DISCUSSION

Data was taken with an HP spectrum analyzer up to 2.9 GHz and saved onto a 128 K ram card for future analysis. Typical data taken from the E_1 probe without any HOM damper is shown in Fig. 2. Most HOMs are found, even though the resolution of the frequency response is not accurate in this broadband frequency span.

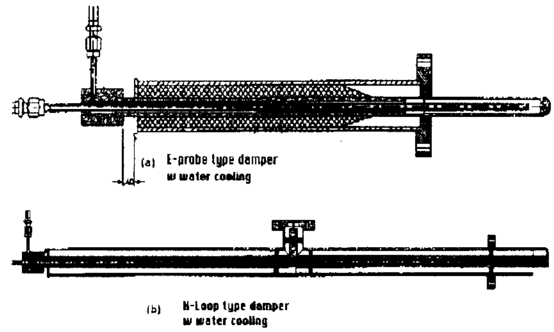
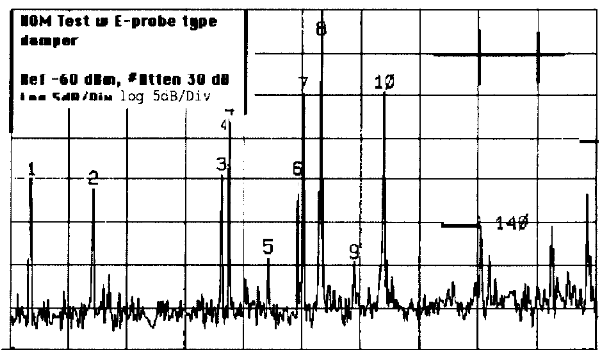


Fig. 1 HOM dampers:
(a) E-probe Damper, (b) H-loop Damper.

The results are summarized in the third column of Table 1. The amplitudes of most of the signals are large enough so that a 30-dB attenuation is regarded over the frequency span. Notice that there are more than eight HOMs above 1.3 GHz which is the cutoff frequency of the beampipe near the cavity. Their signal amplitudes are above - 50 dBm and their Q-values are comparable to those of the fundamental mode. These are the modes that will be most extensively studied.



Freq	(MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	355	-79.97 dBm	6	1133	-8Ø.Ø9 dBm
2	538	-81.14 dBm	7	115Ø	-69.9Ø dBm
3	912	-79.57 dBm	8	12Ø1	-6Ø.Ø7 dBm
4	933	-72.74 dBm	9	1299	-89.64 dBm
5	1Ø48	-89.17 dBm	1Ø	1384	-69.65 dBm

Fig. 2 HOMs in the Cavity w/o any Damper.

Signals from H-loops appeared to be very selective and sensitive to the couplings as expected. The H_1 probe picks up mainly TM0 modes, but H_2 couples only strongly at 1210 and 1386 MHz.

To measure the damping ratio, a frequency response from the E_2 probe is obtained for each HOM. One is without damper and the other is with only one E-probe damper. Typical data are measured around 759 MHz and are plotted in Fig. 3. The effect of the E-probe damper can be easily seen in this figure. As one can see, there are two peaks adjacent to each other. This is due to the nature of the dipole mode. This is an E111-like mode. They are damped out by 12.4 and 9.8 dBm at 759.275 and 759.913 MHz, respectively. One HOM at 761.212 MHz is not affected by the E-probe damper.

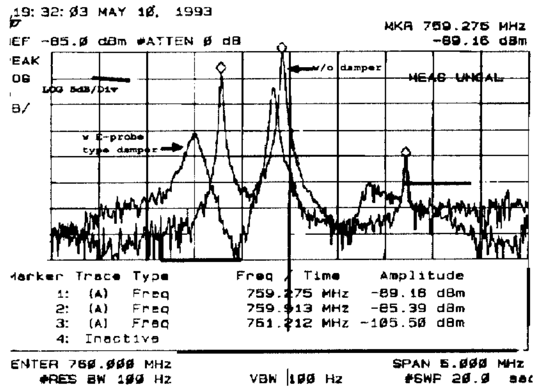


Fig. 3 HOM at 759 MHz (Dipole), with & without one E-probe Damper.

Figure 4 shows the HOMs for the Monopole mode at 940 MHz. The damping ratio is more than 20 dBm.

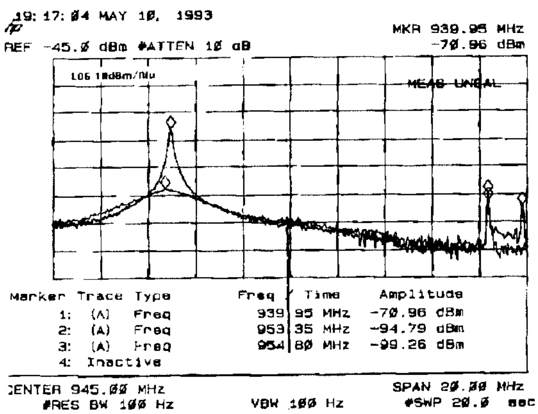


Fig. 4 HOM at 940 MHz (Monopole), with & without one E-probe Damper.

Table 3. HOM Damping Ratio.

		Measurements perturbation		Measurements (20 MeV Beam)	
	Thres-hold	2 E-probe dampers	H-Loop damper	Vacuum 1x10-4	E-probe damper
# mode	Current	damping ratio	damping ratio	No tuners No input coupler	damping ratio
	mA	dB	dB	f	dB
0 E-1		No effects		351.3	1
0 M-1	80	23		537.3	7.4
1 E-1	81	9		587	?
1 M-2	43	30	30	759	12.4
0 E-3	130			919	no
0 M-2	340	27		940	22.6
1 E-3	180			950.5	N/A
1 M-4	320	13		1018	10
1 E-5	80		5?	1146	no
0 M-3	80			1205	no
0 E-6	80		20	1509	not found

The damping ratios for most of the HOMs are summarized in Table 3. For comparison, the results from the perturbation measurement are also tabulated in columns 3 and 4 for two E-probe and one H-loop dampers, respectively. Also shown are the calculated threshold currents for coupled bunch instabilities in the second column. There is no effect on the fundamental mode to within 30 Hz resolution of BW measurements of the HP spectrum analyzer. In most cases, the damping ratio measured with the beam is followed by the bead-perturbation method. To accurately test the dipole mode, at least two identical dampers are needed.

V. CONCLUSION AND FURTHER WORK

The results of the HOM test with the beam-cavity measurements agree very well overall with the previous measurements, especially for the monopole modes, but more study on the dipole mode is needed.

HOMs near and above the cutoff frequency will be investigated and tested with various HOM dampers, including a broadband aperture-coupling damper. Figure 5 shows HOMs between 2.5 and 2.7 GHz.

The transverse impedance due to the HOMs will be measured, having the beam off-center of the cavity.

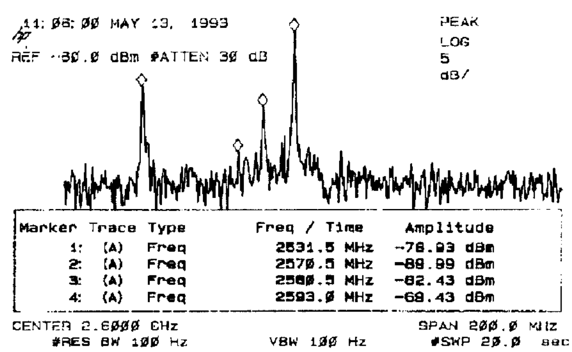


Fig. 5 HOMs above Cutoff Frequency

VI. ACKNOWLEDGMENTS

The authors would like to thank Don Ficht, Eric Landahl, Ed Wallace, and Portia Young for their technical support.

VIII. REFERENCES

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