HOM (HIGHER-ORDER MODE) DAMPER TESTS
OF
ADVANCED PHOTON SOURCE STORAGE RING CAVITY
WITH a 20-MeV e^- BEAM*

J. J. Song, S. O. Brauer, Y. W. Kang, R. L. Kustom, and A. Nassiri
Argonne National Laboratory, Advanced Photon Source,
Accelerator Systems Division, Argonne IL 60439

ABSTRACT

A beamline has been assembled with the ANL Chemistry Division linac (20-MeV e^- beam with FWHM of 30 ps) to test the effectiveness of damping techniques of the APS storage ring single-cell cavity. The beamline consists of two sections--the beam collimating section and the cavity measurement section--separated by two single *Al* foil windows. The beam diagnostics include a beam position monitor, integrating current transformers, fluorescent screens, and a Faraday cup. The EPICS (Experimental Physics and Industrial Control System) is used for beamline control, monitoring, and data acquisition. The cavity was excited by the electron beam to investigate the HOMs. The HOMs were measured with various conditions such as unloaded, critically-coupled, and overcoupled cavity to the waveguide. An rf cavity was also tested with and without various types of dampers. The HOM measurements were made with H-loops and E-probes. The spectral analysis of the HOMs is discussed and compared with both the bead-perturbation method and the computer calculation.

1. INTRODUCTION

The 20-MeV linac beam at the Argonne Chemistry Division was used to measure the rf properties of the single-cell cavity and waveguide system. The primary reason for building this test facility was to measure those HOMs near and above the cutoff frequency of the beam pipe. These modes cannot be easily calculated because of the complicated geometry. For example, the HOMs near the cut-off frequency cannot be accurately computed with a 3-D rf code, such as MAFIA 3.0, when the cavity is connected to the waveguide through the input coupler and/or the beam port is opened. Another reason to take HOM measurements with the beam is to test the various types of dampers such as H-loop type, E-probe type, and wideband aperture dampers.

Bench measurements cannot be easily related to beam-induced effects. Some of the HOMs generated by the rf source from the network analyzer do not exist with the beam. Higher-order modes (HOMs) of the storage ring (SR) single-cell cavity are studied by sending the beam on-axis and off-axis of the cavities. One can even calculate the longitudinal and transverse impedance from the data. The 20-MeV chemistry electron beam is good for testing because its pulse shape and charge are similar to those of the APS SR bunch. Comparisons of the linac beam and the APS storage ring bunch parameters are given in Table 1.

Table 1 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	~30 ps
Total # of particle	$1.2X10^{11}$	$2.3x10^{12}$	$6.9X10^{12}$	$<1X10^{11}$
total charge	18.5 nC			1 - 10 nC
natural emittance	8.2 x 10-3 mm-mrad			10 mm-mrad

2. BEAMLINE SYSTEM

The Argonne Chemistry linac is an L-band (1.3-GHz) traveling wave accelerating structure. The linac beamline exits through an *Al* foil window and then through a beam collimator. After tuning the linac for an optimized beam condition, the collimator is removed to provide a maximum beam current through the cavity section. Our beamline consists of two sections (a beam collimating section with a 1.5"-OD vacuum line and a cavity test section with a 3"-OD vacuum line), separated by two double *Al* foil windows, as shown in Fig. 1.

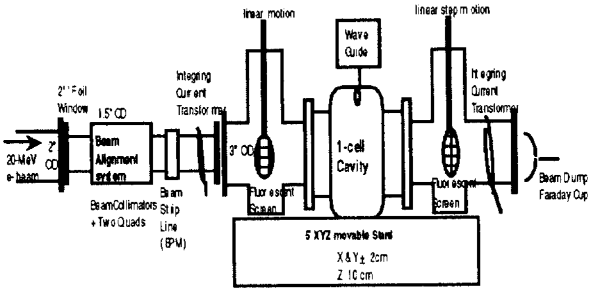

Fig. 1 Schematic of the Beamline to Test HOMs of the APS/SR RF Cavity.

The collimating section consists of a water-cooled collimator and an *Al* foil window in order to get a small-sized beam. The second section of the beamline includes the rf cavity, two fluorescent screens, an integrating current transformer, and the beam dump. The second section is movable

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by ± 2 cm in the X and Y directions with respect to the first section. It can be moved by 10 cm along the beamline to create a beam off-center of the cavity. To align the beamline, many three-point adjustment mounts were used and a He-Ne laser beam was used to check the alignment. The vacuum pressure is about 1 x 10^{-4} Torr. A detailed beamline design can be found in Ref. [1].

3. CAVITY MEASUREMENT SYSTEM

3.1 COMPUTER SIMULATION AND PERTURBATION MEASUREMENTS

HOMs of the 1-cell cavity were already analyzed as shown in Table 2. The left column is a summary of the URMEL calculations [2], showing the mode type, frequency, and R/Q. Only ten modes are shown, which would cause coupled-bunch instabilities when the positron beam current reaches a maximum of 300 mA. 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 the URMEL simulation, but they are not exactly the same since one cannot simulate a real structure with a 2-D computer code such as URMEL.

Table 2 Mode Comparison between URMEL and Perturbation Measurements

URMEL Calculation				Perturbation Measurements
mode	f	R/Q	Current	All 4 tuners in flush
	(MHz)		mA	f
0 E-1	353.6	114.3		352.6
0 M-1	536.7	40.7	80	536.4
1 E-1	588.7	200	81	588.3
1 M-2	761.1	483	43	758.6
0 E-3	922.5	5.8	130	920.1
0 M-2	939	5.5	340	936.4
1 E-3	962	113	180	958
1 M-4	1017.4	63.4	320	1015
1 E-5	1145.1	29.3	80	1141
0 M-3	1210.8	5.2	80	1208
0 E-6	1509.1	4.1	80	1507

3.2 CAVITY MEASUREMENT SYSTEM WITH BEAM

H-Loop and E-Field Probe

HOMs were measured with up to three H-loops and four E-field probes that were connected to the cavity. Two H-loops are oriented to couple to the TM-like modes and the other H-loop (H_2) is oriented to couple to the TE-like modes. The coupling to 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.

HOM Dampers

Coaxial dampers with E-probe and H-loop couplers, and a broadband waveguide damper have been tested with the beam. These (up to three E-probe type and one H-loop type HOM dampers) are connected onto the ports of the equatorial plane after the HOMs were identified with three H-loop probes. For the coaxial type of HOM damper, 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 H-loop damper also has a $\lambda/2$ notch filter to avoid coupling to the fundamental mode of the cavity. A broadband waveguide damper is a matched load terminated waveguide (TE_{11} cutoff frequency is ~ 1.2 GHz), which has a resistive microwave absorber at the end. A more detailed design and field measurements with those HOM dampers can be found in Ref. 4.

3.3 MEASUREMENT MODE

Spectrum Analysis

Data were collected with an HP spectrum analyzer (SA) up to 2.9 GHz and saved onto a RAM card for future analysis. The analyzer does a Fourier analysis via convolution of the spectrum with a narrow (impulse-like) filter after it detects the signal. Depending on the kind of signal to be measured, the measurement parameters, such as input bandwidth, the IF or resolution bandwidth (RBW), the post detection or video bandwidth (VBW), sweeping time (ST), attenuation, etc., must be determined.

With Pulsed Signal

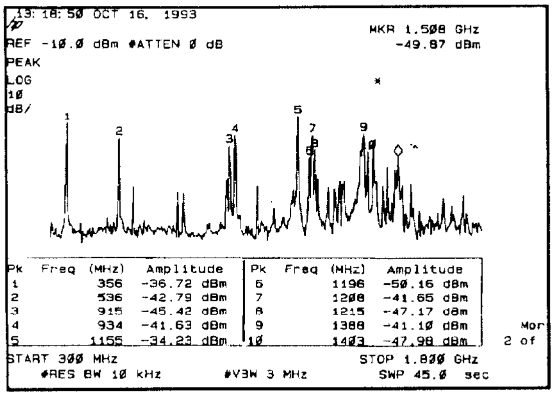
A pulsed signal with a low pulse repetition frequency (PRF) has a broadband spectral intensity distribution. The signal is composed of a group of impulses, and the spectrum is the composite spectral intensity of these impulses in units of V/Hz. With a low PRF such as the linac beam (up to 60 Hz), one needs to set the VBW wider, the ST longer, and the RBW higher than the PRF, but not too high.

There are two ways or modes to measure the HOMs with the modern SA: the time-gate mode [5] and the free-run mode. The time-gate mode allows one to measure the spectrum of a specific part of a signal. Time gating is achieved by selectively interrupting the path of the detected signal of the SA. This is very useful with the pulsed rf, the time-multiplexed signal, and the burst-modulated signal. Another powerful feature of the modern SA, when the free-run mode is selected, is MAX-HOLD. MAX-HOLD maintains the maximum level for each trace point of the signal, then it upgrades each trace point if a new maximum level is detected in successive sweeps.

4. RESULTS AND DISCUSSION

The beam measurement results can be found in detail in Ref. [6]. Typical data taken from the E_2 probe without any HOM damper are shown in Fig. 2. In this case, a short piece of the waveguide was critically coupled to the cavity through the input coupler and it was terminated with a broadband 50-Ω load. Most HOMs are found, even though the resolution of the frequency response is not accurate in this wide frequency span. At the fundamental mode f_0 = 351.9 MHz, the loaded Q is 19800, compared to unloaded Q of about 40000. These are a little smaller than the URMEL calculations, but very close to the bead pulling measurements. The frequency of HOMs is changed mainly due to the vacuum.

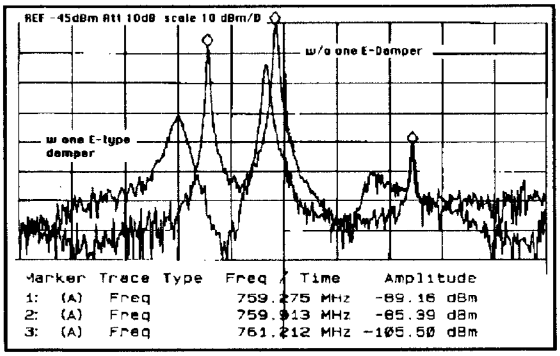
Notice that there are more than five HOMs near 1.6 GHz which is the cutoff frequency of the beampipe near the cavity. Their signal amplitudes are above - 50 dBm and their Q-values are comparable to those of the fundamental mode. These HOMs were identified with the three H-loop probes, combined with the 3-dB power splitter.



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	356	-36.72 dBm	6	1196	-50.16 dBm
2	536	-42.79 dBm	7	1208	-41.65 dBm
3	915	-45.42 dBm	8	1215	-47.17 dBm
4	934	-41.63 dBm	9	1388	-41.10 dBm
5	1155	-34.23 dBm	10	1403	-47.98 dBm

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

To measure the damping ratio, a frequency response from E probes is obtained for each HOM. Typical data are measured around 759 MHz and are shown in Fig. 3. One is without damper and the other is with only one E-probe damper. The effect of the E-probe damper can be easily seen in this figure. This is an TM_{111}-like mode. This dipole mode is damped out by 12.4 and 9.8 dB at 759.28 and 759.91 MHz, respectively. One HOM at 761.21 MHz is not affected by one E-probe damper.



Marker	Trace	Type	Freq / Time	Amplitude
1:	(A)	Freq	759.275 MHz	-89.16 dBm
2:	(A)	Freq	759.913 MHz	-85.39 dBm
3:	(A)	Freq	761.212 MHz	-105.50 dBm

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

The damping ratios of all the HOMs measured with the beam are similar to those by the bead-perturbation method, except for some dipole modes. It appears that the dipole mode is split in two with the HOM dampers and the damping is usually effective to one orientation. Based on the beam measurements, the maximum growth rates are calculated and plotted in Fig. 4. The dotted line is for the over coupled case and the continuing line is for the critically coupled case. As one can see, the maximum growth rates for the longitudinal instability are smaller than the synchrotron damping rate (213 sec^{-1}). The transverse growth rate is somewhat larger than the synchrotron damping rate (106 sec^{-1}) which is not shown here. An active feedback system for the transverse case is needed to make the beam stable.

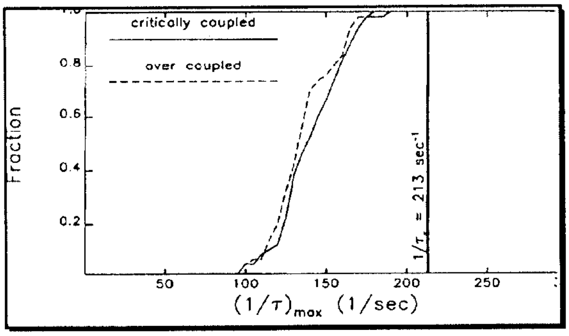


Fig. 4 Cumulative Distribution of Maximum Growth Rates for Longitudinal Instability, using two sets of measured Q's of HOMs below cut-off.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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