HOM Damping with Coaxial Dampers in the Storage Ring Cavities of the Advanced Photon Source *

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Abstract

Coaxial dampers with E-probe and H-loop couplers are used to damp higher-order modes (HOM) in a 352-MHz single cell cavity for the storage ring of the Advanced Photon Source (APS). Measurements have been made with three different types of dampers such as E-probe dampers, small H-loop dampers, and H-loop dampers with $\lambda/4$ short stub. Two dampers are used in each type. The dampers without fundamental frequency rejection filters are positioned to have a minimum deQing at the fundamental frequency: the E-probe dampers are used at the equatorial plane of the cavity, and the small H-loop dampers are used in the end wall of the cavity. The fundamental mode decoupling can be done by positioning the loop plane in the direction of the H-field of the mode.

1 INTRODUCTION

Coaxial dampers are used in both superconducting and normal conducting cavities for particle accelerators [1-5]. Aperture-coupled hollow waveguide type dampers have been investigated [6,7,8]. These hollow waveguide dampers are used in multiples (usually three to damp the degenerate modes). The fundamental frequency rejection is achieved by the cutoff characteristic of the waveguide. Multiple coaxial dampers have been used in a test pill box cavity [9].

The most important tasks in designing a HOM damping system are broadbanding and suppression of fundamental mode power couplings. E-probe dampers can be used in the cavity equatorial plane without any f_o rejection filter, since the radial component of the TM_{01}-like electric field is zero in the midplane. If H-loop dampers are used in the equatorial plane of the cavity, the loop plane must be positioned perpendicular to the fundamental mode H-field to couple to the higher-order TM modes. Then, a fundamental frequency rejection filter must be used. H-loop dampers use a half-wavelength short stub in parallel [1] or a quarter-wavelength short stub in series [2]. These short stub fundamental frequency rejection circuits also block the signal frequencies around the even and odd multiples of f_o, respectively, and increase the fundamental mode power loss due to the increased current path. Thus, the f_o decoupling is a difficult task.

The single cell cavity to be used in the APS storage ring is the optimized spherical type. The single-cell cavity has the fundamental frequency f_o=352 MHz. The general parameters of the storage ring of the Argonne APS are listed in Table 1. The instability growth rates and the deQing requirement on higher-order modes of the APS ring were reported [10].

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Table 1: APS Storage Ring Parameters

Beam energy	7 GeV
Beam current	300 mA
Number of bunches	54
Current per bunch	5.6 mA
Revolution frequency	271.55 kHz
Synchrotron frequency	1.5 kHz
Number of cavities	16

2 RF ABSORBER

For coaxial dampers, a matched load termination has been designed. The load must be able to dissipate a certain amount of power with good vacuum properties. Water cooling is provided through the center conductor of the coaxial structures. The load is made of AlN ceramic material with 40% SiC and shaped as a cylindrical cone as shown in Figures 3 and 5. This material has excellent vacuum properties. The extra ceramic window as a vacuum barrier is not needed with this load. The mechanical and electrical properties of this material are listed in Table 2. The frequency characteristic of the coaxial termination is shown in Figure 1.

3 COAXIAL DAMPERS

Figure 1 shows the coaxial dampers used in an APS single-cell cavity. The E-probes are used in the cavity equatorial plane. The H-loops are used in the cavity side-wall. The

Table 2: Properties of AlN with 40% SiC

Density	$3.19 g/cc$
Thermal Expansion (25° − 1200°)	$5.1 \times 10^{-6}/°C$
Thermal Conductivity	$43 W/m°K$
Modulus of Rupture	42,000 psi
Sustains Vacuum Levels	$< 10^{-10}$ torr
Dielectric Constant	
500 MHz	47 - j4
1 GHz	44 - j6
2 GHz	40 - j9

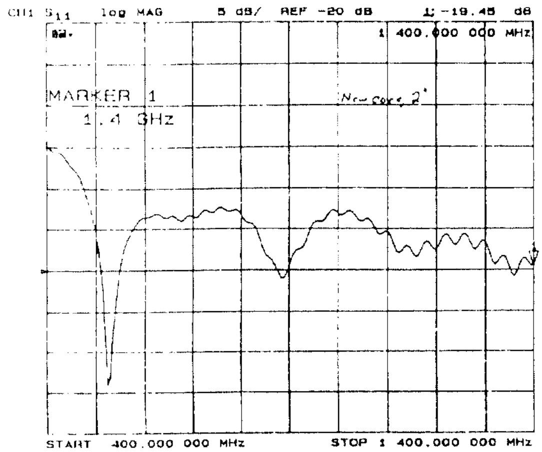

Figure 1: Frequency response of the coaxial termination made of AlN with $40\%SiC$.

loop plane is parallel to the TM_{01} mode H-field. Two dampers are used to increase the coupling to the degenerate modes. Both the size of the loop or the probe as well as the location in the cavity determine the coupling to specific HOM fields and thus the damping ratio. The fundamental mode coupling to the dampers is also dependent on the position and size. The deQing due to the dampers at f_o was measured and made to be minimal as shown in the following sections. Figure 2 shows the storage ring single cell cavity and the installed dampers.

3.1 E-Probe Damper

Two E-probe dampers are used in the cavity equatorial plane with an angular separation of 90°. The probe in this position should not couple with the fundamental TM_{01} mode field. But, due to imperfect probe alignment and mutual coupling between the two coupling devices, a small amount of coupling exists. The probe is made of 0.5 "copper tube. The fundamental mode deQing with this type of damper is measured negligible. Figure 3 shows the E-

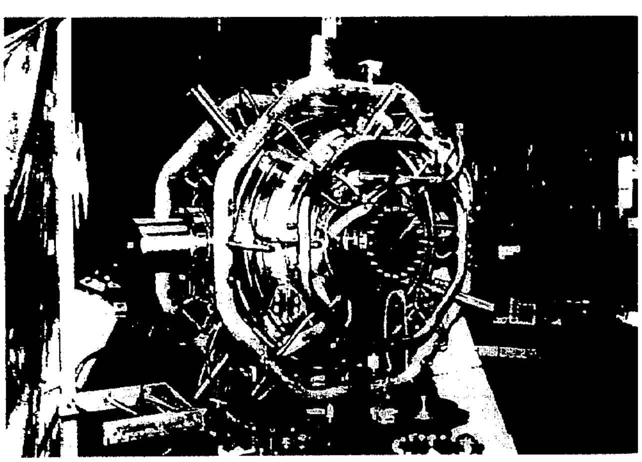

Figure 2: Storage ring single cell cavity with prototype dampers

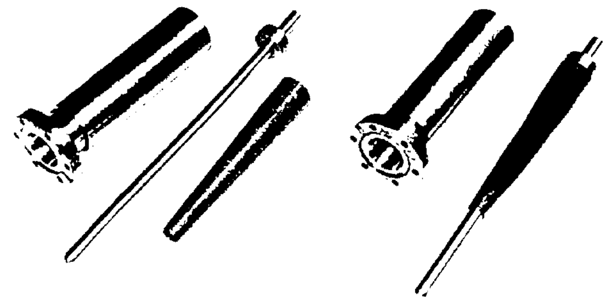

Figure 3: E-probe prototype dampers

probe dampers.

3.2 Small H-loop Damper

Two H-loop coaxial dampers are used in a cavity side wall uniformly spaced at $\theta = 60°$ as shown in Figure 2. This type of damper has a loop radius of 0.375 ". The loop is made of 3/16 "diameter copper tube. The plane of the loop area is turned carefully to have the minimum deQing at f_o. The fundamental mode deQing with this type of damper was measured negligible. This damper is shown in Figure 4.

3.3 H-loop Damper with a $\lambda/4$ Short Stub

The H-loop damper with a $\lambda/4$ short stub is shown in Figure 5. The outside diameter of the coaxial short stub is 5.6 ". This short stub is connected to the resistive load in series. Two H-loop dampers of this type were used in the big 6 "ports separated by 90° as shown in Figure 2. Each damper has a loop radius of 0.375 ". The coaxial stub was designed to have the characteristic impedance $Z_o \simeq 75\Omega$ for higher Q. Figure 5 shows the H-loop dampers

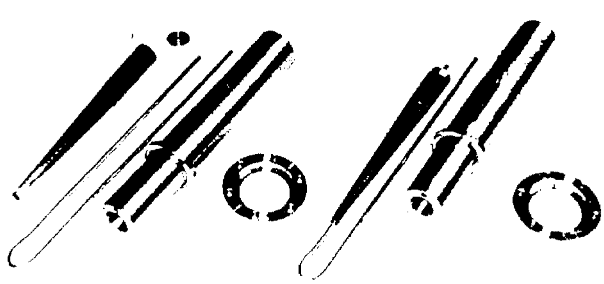

Figure 4: Small H-loop dampers

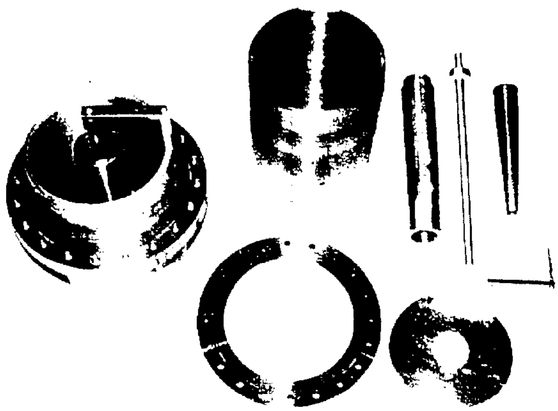

Figure 5: H-loop dampers with a $\lambda/4$ short stub in series

with a $\lambda/4$ short stub. The effective electrical length of the short stub is slighty greater than the length found with free space wavelengths. The disadvantage of this design is that the short stub has a narrow bandwidth; the length of the short stub must be precisely adjusted for the accelerating frequency.

4 MEASUREMENT

Two E-probe dampers, two small H-loop dampers, and two H-loop dampers with $\lambda/4$ were used together in the measurement. The measured deQing ratios are shown in Table 3. These modes are the higher-order TM modes of the storage ring single cell cavity to be used in the APS and can cause beam instability [10]. Q-factors are measured using a vector network analyzer and compared with the computed results. TM0 denotes the monopole modes and TM1 denotes the dipole modes. ME and EE denote the boundary conditions with magnetic and electric conductors in the cavity equatorial plane, respectively. The result shows that most modes (both ME and EE boundary) are damped effectively. The first monopole mode and the first dipole mode are most difficult to damp.

Table 3: HOM damping with E- and H-dampers.

Mode type	Computed		Measured	
	$f(MHz)$	Q_o	Q	$\frac{Q_o}{Q}$
TM0-ME-1	534.65	41000	4400	9.3
TM1-EE-1	582.73	68000	6430	10.5
TM1-ME-2	758.19	53000	$\ll$100	>530
TM0-EE-3	914.83	107000	340	315
TM0-ME-2	929.30	42000	$\ll$100	>420
TM1-EE-3	953.50	54000	$\ll$100	>540
TM1-ME-4	1014.00	41000	620	66
TM1-EE-5	1147.40	92000	470	196
TM0-EE-4	1164.41	44000	10800	4
TM0-ME-3	1206.73	94000	9900	9.5
TM1-EE-6	1222.64	41000	790	52
TM0-EE-6	1502.41	88000	1800	49

5 CONCLUSION

The results of HOM damping measurements show that many HOMs can be damped with coaxial dampers successfully. Compared with the deQing requirement of the HOMs in the APS storage ring, measured deQing was satisfactory for most modes except the modes at 534MHz and 582MHz. The E-dampers in the equatorial plane and the H-dampers in the endwall have negligible deQing at the fundamental frequency without using decoupling circuits.

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