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Storage Ring Cavity Higher-Order Mode Dampers for the Advanced Photon Source*

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Abstract

Coaxial, mode selective higher-order mode (HOM) dampers for the Advanced Photon Source (APS) storage ring cavities have been fabricated and tested. Two types of dampers will be employed. Electric field probe dampers are positioned in the equatorial plane of the cavity so as to not couple to the fundamental TM_{01} accelerating mode. Additionally, two magnetic field probe dampers with quarter-wavelength stub rejection filters are positioned in the cavity equatorial plane 90 degrees apart to facilitate dipole mode damping. Both damper types use a vacuum compatible, aluminum nitride (AlN) ceramic rf absorber as the matched load. Measurements were made to optimize the frequency response of the tapered absorber. The design eliminates the need for a ceramic vacuum window.

I. INTRODUCTION

Higher-order mode (HOM) dampers are routinely used in particle accelerators to maintain beam stability at high currents. The two most important features of any HOM damping approach are the ability to damp higher-order modes over a broad frequency range and the suppression of coupling to the fundamental accelerating mode. Typically, either coaxial electric and magnetic field probe dampers [1, 2, 3, 4] or aperture-coupled, hollow waveguide dampers [5, 6] are used.

Both approaches involve trade-offs in performance. Coaxial probe dampers are broadband in nature which can make fundamental mode rejection difficult. Usually the probe position and orientation is used to minimize fundamental mode coupling. Aperture-coupled, hollow waveguide dampers are also inherently broadband. Rejection of the fundamental mode is achieved by using the cutoff frequency of the waveguide. This can be effective but typically involves a degradation of the Q-factor at the fundamental frequency, f_0.

Coaxial HOM dampers have been extensively investigated for use on the storage ring cavities of the Advanced Photon Source (APS) [7, 8]. The coaxial probe type dampers were chosen in order to make the dampers compact, lightweight, and inexpensive. Also, A coaxial design allows for convenient cooling and does not disturb the cavity heat distribution. Additionally, fundamental mode power loss may be minimized through the use of a proper rejection scheme. The APS storage ring cavity fundamental frequency is 351.93 MHz. The storage ring parameters are listed in Table 1. The instability growth rates and the Q requirements for the higher-order modes are given in [9].

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

Two types of dampers will be employed. Two electric field probe dampers will be positioned in the equatorial plane. Since the radial component of the electric field of the fundamental TM_{01} mode is zero in the midplane, the electric field probes may be used without coupling to the fundamental mode. In the APS storage ring cavities, the TM_{01} mode cutoff frequency for the 5.5-inch beam pipe is approximately 1.6 GHz. The dampers have been designed to damp the higher-order modes below cutoff. Additionally, to facilitate higher-order TM mode damping, two magnetic field probe dampers are situated 90 degrees apart in the equatorial plane with the loop planes perpendicular to the magnetic fields of the TM_{01} mode. In order to reject the fundamental frequency, the dampers were designed with quarter-wavelength stub rejection filters in series. Both damper types will use a tapered, vacuum compatible, AlN ceramic rf absorber as the matched load. The dampers were designed with this absorber in such a way as to allow water cooling of the center conductor and to eliminate the need for a ceramic vacuum window.

II. ABSORBER DESIGN AND MEASUREMENTS

For efficient HOM damping, a broadband matched load termination must be designed. The load must have good thermal properties to dissipate the power in the damped modes and must also possess good vacuum properties to avoid the use of a ceramic vacuum window. The first two designs tried used an AlN ceramic with 7% glassy carbon content as the absorber. It was decided later to use an AlN ceramic with a 40% SiC content due to its superior properties. The properties of both absorbers are shown in

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Table 2: Ceramic properties.

	AlN (7% C)	AlN (40% SiC)
Density (g/cm^3)	2.95	3.19
Thermal exp. (1/^{0}C)	4.7	5.1 $\times 10^{-6}$
Thermal cond. (W/cm-K)	0.55	0.43
Vacuum levels (torr)	< 10−10	< 10−10
ϵ_R @ 500 MHz	29-j4	47-j4
ϵ_R @ 1 GHz	23-j5	44-j6
ϵ_R @ 2 GHz	22-j5	40-j9

Table 2.

Investigations on the absorber shape were carried out to optimize the broadband matching properties of the taper. Numerical simulations of the reflection coefficient can be used for this purpose but were unavailable at the time of this study. In lieu of this approach, a rough taper was designed by making the length of the taper equal to approximately one-quarter of the effective wavelength of the fundamental mode in the ceramic (AlN with 7% C). This gives a taper length of 1.5 inches. The coaxial structure was designed to present a 50-Ω characteristic impedance to the cavity with a 0.5-inch inner conductor diameter. The total absorber length was 4.5 inches.

The design was tested by measuring the reflection coefficient on a network analyzer. Time domain gating techniques were used to eliminate unwanted reflections due to the connecting hardware. These measurements showed that this first design was not very desirable below frequencies of about 1.1 GHz. Increasing the overall absorber length did not significantly improve the performance.

Analysis of the network analyzer data showed that the reflection coefficient was high due to the rather abrupt taper. The taper was then lengthened to 3.143 inches, keeping an overall length of 4.5 inches. This design exhibited acceptable behavior above 800 MHz. By increasing the total length to 9 inches, the absorber showed well-matched performance over all frequencies of interest (above 500 MHz). A typical measurement with this design is shown in Figure 1. The associated time domain measurements showed that the dips in $S_{11}(\omega)$ were due to resonances within the ceramic test structure resulting from a two-piece ceramic absorber. These resonances are not expected to be present in the final one-piece damper structure.

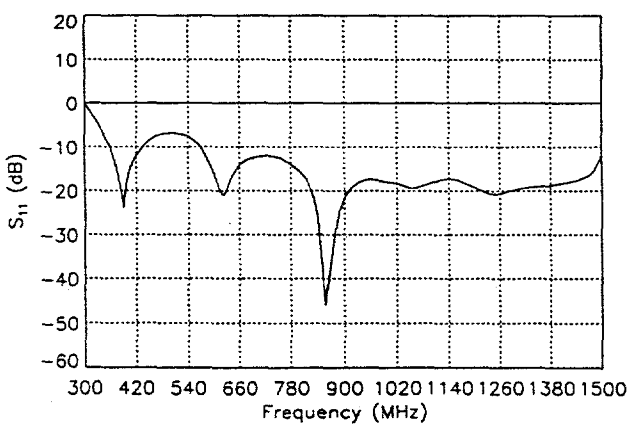

Figure 1: Absorber (AlN with 7% C) reflection with a 3.143" taper and a 9" overall length.

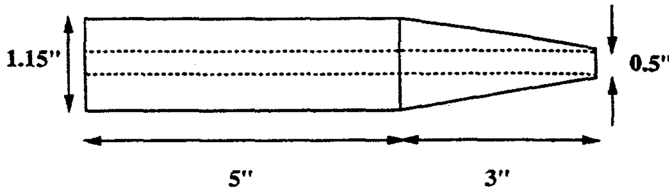

Figure 2: The final absorber design.

A final design was tried using the AlN with 40% SiC. The taper was 5.5 inches long with an overall length of 7 inches. Additionally, the outer radius of the coaxial line was slightly increased to give a 55-Ω characteristic impedance. Although the taper is much more gradual, performance was only slightly better than the previous design. Performance was improved by increasing the overall length to 11 inches which results in a rather long structure. However, financial as well as spatial constraints led us to decide on the absorber shape shown in Figure 2 using AlN with 40% SiC. This design is similar to the second design described above. This absorber design will be used in both the electric field probes and the magnetic field probes with the quarter-wavelength rejection stub.

III. QUARTER-WAVELENGTH STUB DESIGN

The design of the quarter-wavelength stub magnetic field damper has been previously described [8]. The length of the stub was calculated from the free space wavelength of the fundamental mode, giving a value of 21.31 cm. Measurements showed that the damper still coupled to the fundamental mode and significantly decreased the Q. This was attributed to an effective increase of the stub length from the presence of the loop which acts as a parallel wire waveguide. In order to find the proper length for the stub, the ratio of Q_L/Q_0 was plotted as a function of frequency. A plunger tuner was used to change the cavity fundamental frequency. Results are shown in Figure 3 for a 1-inch coupling loop. An extrapolation from a linear least-squares fit to the data showed that the stub length was optimized for a frequency of 336 MHz. Taking the ratio of the fundamental frequency to this frequency gives the adjustment factor for the stub length. The stub was shortened to 20.96 cm and re-measured. Again the results are shown in Figure 3. Coupling to the fundamental mode was significantly reduced and the damper-loaded Q was approximately 85% of the unloaded Q.

The loop size was then increased to 2" to try to more effectively damp the higher-order modes. Since this changes the geometry of the loop, the effective length of the stub

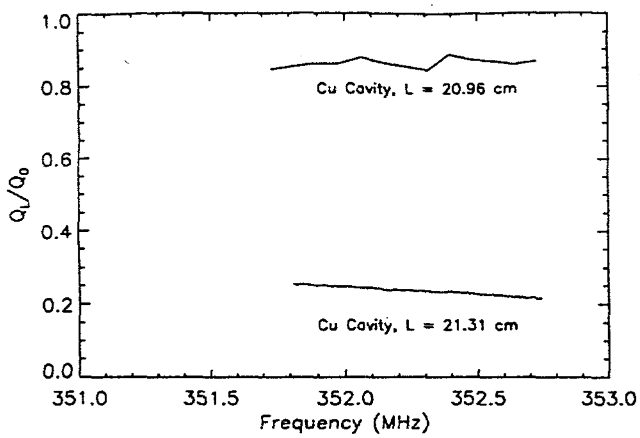

Figure 3: Q_L/Q_0 as a function of frequency for the magnetic field damper.

filter will also change. Because of this effect, the design length for any given loop size or geometry should be experimentally determined before manufacturing. Using the modified stub length of 20.96 cm with the 2" loop, the fundamental mode Q factor was decreased to approximately 45% of the unloaded Q factor. By again decreasing the stub length to 20.65 cm, the Q factor could be increased to approximately 73% of the unloaded Q factor. This can be further improved by slightly decreasing the stub length.

IV. DISCUSSION

Measurements have been made on the HOM damping with the prototype dampers in a storage ring cavity. Using the two types of dampers, two of each design, most higher-order modes were sufficiently damped according to the requirements in [9]. The monopole mode at 536 MHz and the dipole mode at 588 MHz were both damped by a factor of approximately 10 [8]. In order to reduce the required damping factor, the storage ring cavity HOM frequencies were staggered by increasing the cavity lengths by 0.3 mm. Assuming that the frequency staggering is not effective for the lowest frequency higher-order modes, the level of damping for the above two modes may not be sufficient [9].

Simulations indicate that the APS multi-bunch beam can be stable for beam currents up to approximately 100 mA without dampers [10]. Further studies of the physics of the machine are needed to determine whether the present level of damping is adequate for a 300 mA beam with cavity frequency staggering.

V. CONCLUSIONS

The use of coaxial HOM dampers for the APS storage ring cavities was discussed. Two damper types have been proposed and studied. The coaxial designs for these dampers result in a compact, simple, inexpensive, and effective damping scheme.

The tapered absorber reflection characteristics were measured to ascertain the broadband matching characteristics. Time domain gating techniques on a vector network analyzer were used for these measurements. The results were used to arrive at an optimized absorber design.

The effect of the magnetic field dampers with the quarter-wavelength stub rejection filter on the fundamental accelerating mode was investigated. Measurements showed a significant lowering of the Q factor. Changing the stub length to tune the rejection filter to the proper frequency resulted in improved performance. The length must be experimentally determined for each given loop geometry.

VI. REFERENCES

[1] Y. Yamazaki, K. Takata and S. Tokumoto, "Damping Test of the Higher-Order Modes of the Re-entrant Accelerating Cavity," *IEEE Trans. on Nuclear Science*, NS-28, pp. 2915–2917, June, 1981.

[2] B. Dwersteg, E. Seesselberg and A. Zolfaghari, "Higher Order Mode Couplers for Normal Conducting DORIS 5-cell Cavities," *IEEE Trans. on Nuclear Science*, NS-32, pp. 2797–2799, Oct., 1985.

[3] E. Haebel and J. Sekutowicz, "Higher Order Mode Coupler Studies at DESY," DESY M-86-06.

[4] A. Mosnier, "Developments of HOM Couplers for Superconducting Cavities," *Proc. 4th Workshop on RF Superconductivity*, August 1989.

[5] G. Conciauro and P. Arcioni, "A New HOM-free Accelerating Resonator," *Proc. 2nd Euro. Particle Accel. Conf.*, Nice, France, June 12-16, 1990, pp. 149–151.

[6] R. Rimmer, D. Goldberg, G. Lambertson, F. Voelker, K. Ko, N. Knoll, R. Pendleton, H. Schwarz, F. Adams and M. DeJong, "Higher-order Mode Damping Studies on the PEP-II B-Factory rf Cavity," *Proc. 3rd Euro. Particle Accel. Conf.*, Berlin, Germany, March 24-28, 1992.

[7] Y.W. Kang, R.L. Kustom and J.F. Bridges, "HOM Damping with Coaxial Dampers in a Pillbox Cavity without Fundamental Mode Frequency Rejection Filter," *Proc. 1993 Int. Particle Accel. Conf.*, Washington, D.C., May 17-20, 1993.

[8] Y.W. Kang and R.L. Kustom, "HOM Damping with Coaxial Dampers in the Storage Ring Cavities of the Advanced Photon Source," *Proc. 4th Euro. Particle Accel. Conf.*, London, U.K., June 27 - July 1, 1994.

[9] L. Emery, "Required Cavity HOM deQing Calculated from Probability Estimates of Coupled-bunch Instabilities in the APS Ring," *Proc. 1993 Int. Particle Accel. Conf.*, Washington, D.C., May 17-20, 1993.

[10] L. Emery, private communication.