© 1993 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

Design of a HOM Damped Cavity for the ATF Damping Ring

S. Sakanaka, K. Kubo and T. Higo
National Laboratory for High Energy Physics (KEK)
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan

Abstract

A HOM (Higher-Order-Mode) damped cavity for the ATF Damping Ring was designed at KEK. Damping both by waveguides and by big beam holes was adopted. Numerical calculations on external-Q's of low-frequency HOMs showed good damping characteristics. Low-power measurements are under way with a cold-model cavity.

I. INTRODUCTION

A 1.54 GeV Damping Ring (DR) [1] is being constructed at KEK as an accelerator subsystem of ATF (Accelerator Test Facility). This facility is purposed to investigate the feasibility of providing highly-brilliant electron beams of multi-bunches which is required for future linear collider project. The ATF DR will be operated with beam currents up to 600 mA with multibunches.

A frequency of 714 MHz, a subharmonic of the injector linac frequency, was chosen for rf acceleration, considering beam dynamic issues related to wake fields of the fundamental mode [2]. The need for short bunches (σ_z<5 mm) requires a gap voltage of 1 MV, which will be provided by four single-cell copper cavities. Because the ATF DR adopts very narrow beam pipes (ϕ26 mm in arc sections), there exist many HOMs in the rf cavities up to the cutoff frequencies (8.83 and 6.76 GHz for TM01- and TE11- modes, respectively). Therefore, the requirement to store a large beam current free from coupled-bunch instabilities forces one to design the cavities whose longitudinal and transverse coupling impedances arising from HOMs are sufficiently reduced.

The requirements for the HOMs are derived from tracking simulations [2], and are summarized below:

$(R_{sh}/Q)\cdot Q\cdot f$ < *10-30 [kΩ·GHz/ring]* for monopole modes,
$(R_T/Q)\cdot Q$ < *2-3 [MΩ/m/ring]* for dipole modes*,

* assumed that a bunch-to-bunch tune spread of 10^{-3} (peak-to-peak) will be introduced in each bunch-train.

where R_{sh} is the shunt impedance ($=V^2/P$), f the resonant frequency and R_T the transverse impedance. For TM011-like mode, which has particularly large R_{sh}/Q, a severer condition of Q<*(15-20)* may be required.

II. CAVITY DESIGN

Among several schemes for HOM damping , we adopted a waveguide damping scheme similar to that proposed for PEP-II [3]. A cylindrical cavity, with round corners (R=30 mm) and nose cones, was chosen for the basic shape (see Figs. 1 and 2). For damping HOMs, four waveguides (170mm×20mm, R=5 mm at corners; cutoff freq. is 885 MHz) are attached at the corners, where magnetic fields of most HOMs are large. Two of the waveguides are attached to one (z>*0*) side of the cavity, parallel to horizontal (x) axis, while the other two to the other (z<*0*) side, parallel to vertical (y) axis. In this configuration, each of degenerated dipole modes, together with monopole modes, will be damped, while holding 180° rotational symmetry of the shape. The cooling for this shape may be easier than that for PEP-II because of more spaces between the waveguide-slots, though the rotational symmetry is lower.

Even with the damping by waveguides, it is difficult to damp all HOMs up to the beam-pipe cutoff because too many modes exist. Thus, an additional beam-hole damping scheme [4,5] was introduced, in which the power from high-frequency HOMs propagates out of the cavity via big beam-holes (ϕ100 mm) and is dissipated in microwave absorbers attached on big beam-pipes beside the cavity. The beam-hole radius was chosen so that several HOMs which do not couple to the waveguides well are extracted, while holding the fundamental

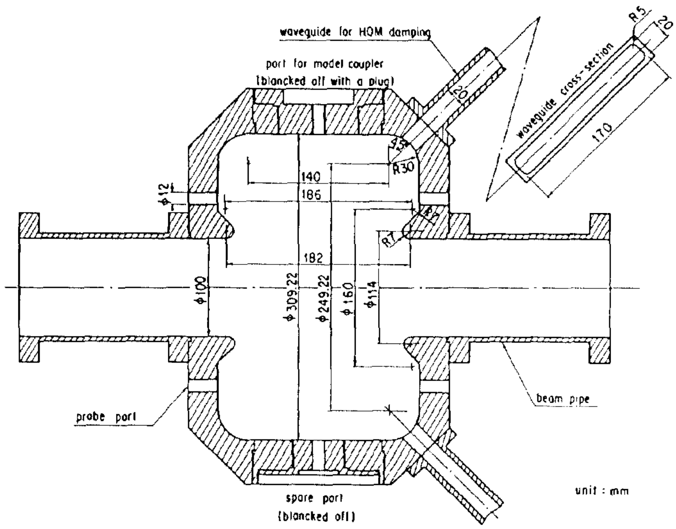


Fig. 1. Cross-section of a low-power test cavity.

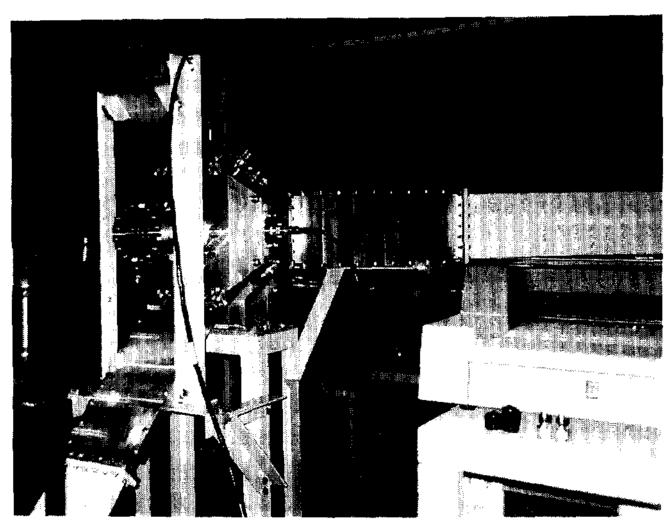


Fig. 2. Low-power test cavity under measurement.

Table 1. RF related parameters of the ATF DR.

rf frequency	f_{rf}	714 MHz
Shunt impedance per cavity	R_{sh}	3.6 MΩ
Unloaded-Q	Q_0	22,100
Dissipated power per cavity	P_c	17.4 kW
Total gap voltage per ring	V_c	1 MV
Radiation loss per turn	U_0	0.190 MeV
Maximum beam current	$(I_0)_{max}$	600 mA
Transmission power per coupler	P_{gl}	45.9 kW
Coupling coefficient of coupler	β	2.6

shunt impedance acceptable. Principal parameters of the cavity were calculated with such codes as SUPERFISH and MAFIA, and are shown in Table 1. The Q_0-value in the table includes the degradation of ~23% (calculated) arising from attaching the waveguides and further of ~20% (assumed) from other causes.

III. CALCULATIONS OF HOM DAMPING

External-Q's of low-frequency HOMs were calculated with the method developed by Slater, Gluckstern , Kageyama, Kroll, Yu et al. [6-10]. The resonant frequencies of the lossless cavity-waveguide coupled structure were calculated with MAFIA 3D code, with waveguides shorted at different lengths. Figure 3 shows the cavity shape used for the calculations. Only 1/8 of the cavity was modeled to save the number of mesh-points, though the actual cavity is not symmetrical at $z=0$ plane. Then, the phase ϕ ($=2\pi L/\lambda_g - n\pi$) were plotted against the frequencies, where L is the distance of a short from the cavity center, λ_g the guide wavelength and n the branch number. Near resonances, ϕ can be represented by the following relations [10]:

$$\phi(\omega) = \sum_i \arctan\left(\frac{v_i}{\omega - u_i}\right) - \chi(\omega)\ ,$$

$$\chi(\omega) \approx \chi_0 + \omega \cdot \chi'\ ,$$

where $u_i + jv_i$ represents the complex resonant frequency of i-th mode and $u_i/2v_i$ gives the external-Q (Q_{ex}).

Figure 4 shows an example of the phase-frequency plot obtained from six MAFIA runs for a MME-boundary condition (i.e. Magnetic-, Magnetic- and Electric- short conditions on $x=0$, $y=0$ and $z=0$ planes, resp.). As the range 1.45-2.05 GHz contains four overlapped-resonances, the data in this range were fit with ten parameters (u_i, v_i, $i=1$-4, and χ_0, χ'). The resonant frequencies and Q_{ex}'s obtained are summarized in Table 2. By inspecting field plots of the above resonances, it was found that these could be the mixed modes of the original (no waveguides) modes. It is worth noticing that this "mode mixing" phenomenon sometimes limits the performance of the waveguide damping. Let us show an example in our early design of the cavity. The frequency separation between TM012- and TM210- like modes was only 13 MHz without waveguides. When the waveguides were attached, these modes mixed and split into two modes, one has a very large Q_{ex} (=1600) while the other a small (Q_{ex}=17), both having an R_{sh}/Q of a few ohms. This was caused by a large perturbation introduced by the waveguides. In our present design, this problem has been removed by making the frequency separation large via modifying the cavity shape.

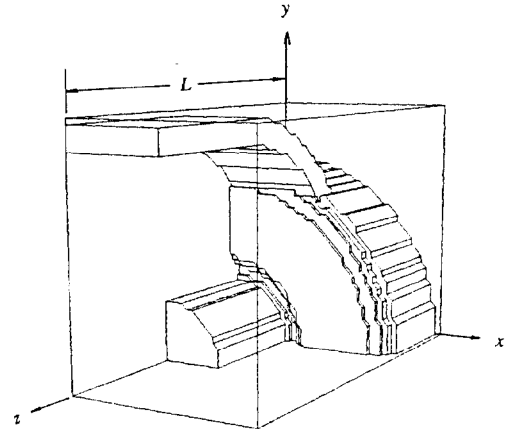


Fig. 3. Cavity shape used for the MAFIA calculations.

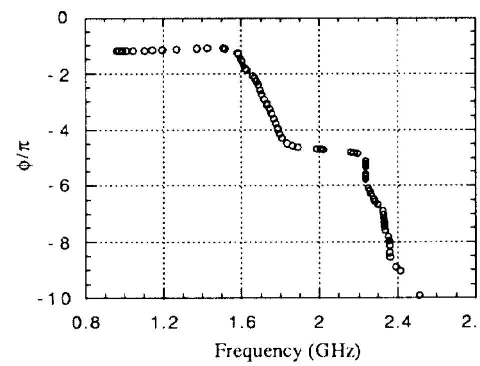


Fig. 4. Phase-frequency plot for MME-boundary condition.

Table 2 also shows the results for other boundary conditions. For harmful HOMs below the beam-hole cutoff, the calculated Q_{ex}'s seem to be acceptable for the requirement. These results are to be checked by calculations with a 1/4 model, correctly taking the cavity symmetry into account.

IV. MEASUREMENT WITH A TEST CAVITY

A low-power test cavity (Figs. 1 and 2) was made by assembling three pieces machined from aluminum alloy (A5052) blocks. The cavity has four ports for test- couplers and tuners (blancked-off with plugs at present) and seventeen probe ports, together with damping waveguides and beam pipes.

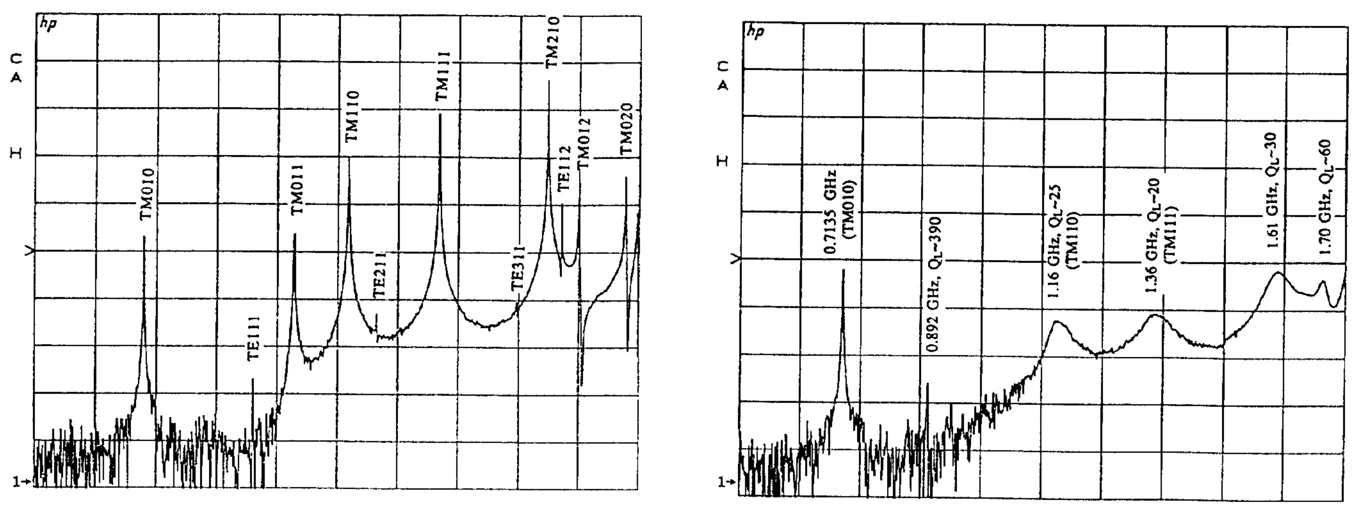
Firstly, we observed undamped resonance-spectrum by shorting waveguide-slots. Figure 5(a) shows the transmission parameter S_{21} between two antennas put at both end-plates, measured with an HP8510B Network Analyzer. Then, the damping waveguides with 80-cm-long terminating loads were attached to the cavity. As shown in Fig. 5(b), most resonances in the measured range were heavily damped to $Q_L<100$, except for the fundamental (TM010) mode and for the mode appeared at 0.89 GHz. TM011-like mode is not discernible, and the loaded-Q's (Q_L) for TM110- and TM111- like modes are ~25 and ~20, respectively. The peak at 0.89 GHz (Q_L ~390) is, possibly, a damped TE101-like resonance in the waveguide coupled to some cavity modes (TE111 or TM011), which arises from the poor termination of the loads slightly

Table 2. Result of the calculations on HOM damping by 164mm×20mm rectangular waveguides (f_c=914 MHz). A 1/8 part of the cavity was modeled. Note that the waveguide dimensions are slightly different from those of the final design.

Boundary condition	No waveguides (MAFIA) Mode	f(MHz)	Qo	Rsh/Q or R_T/Q	With four waveguides (MAFIA/Kroll-Yu) (Mode)	f(MHz)	Qex*	Rsh/Q or R_T/Q**
MME	MME-1 (TM010)	724.7	34,500	168.6 Ω	(TM010)	709.3	below cutoff	168.0 Ω
	MME-2 (TM210)	1591	59,400		(mixed mode)	1605	40	~ 0.2
	MME-3 (TM012)	1682	35,700	10.7	(mixed mode)	1693	48	~ 8.3
	MME-4 (TM020)	1747	63,000	0.21	(mixed mode)	1754	29	~ 0.5
	MME-5 (TE2xx)	1803	44,100		(mixed mode)	1791	37	~ 0.5
MMM	MMM-1 (TM011)	1044	28,000	62.5	(~TM011)	1075	7.1	~ 37
	MMM-2 (TE211)	1217	39,400		(~TE211)	1215	21	~ 0.1
	MMM-3 (TM211)	1787	43,700		(TE411+TM211)	1800	~870	~ 0.02
	MMM-4 (TE411)	1804	39,800		(TM211+TE411)	1808	18	~ 0.7
	MMM-5 (TM021)	1959	38,500	6.6	(~TM021)	1952	27	~ 5
MEE	MEE-1 (TM110)	1152	45,400	263 Ω/m	(~TM110)	1160	24	~ 190 Ω/m
	MEE-2 (TE112)	1600	45,900	17	(~TE112)	1605	100	~ 20
MEM	MEM-1 (TE111)	953.6	38,700	2.0	(TE111)	896.6	below cutoff	9.6
	MEM-2 (TM111)	1349	33,900	726	(~TM111)	1363	24	~ 490
	MEM-3 (TE311)	1502	40,300		(TE311+TM111)	1500	115	~ 50

* For dipole modes, two times the calculated results are shown by taking the proper symmetry of the cavity into account.

** Note that non-zero R_{sh}/Q or R_T/Q can be introduced to (originally) higher-multipole (m>1) modes due to the mode mixing. R_{sh}/Q or R_T/Q, which are evaluated at the detuned waveguide length for each resonance, are shown in this column as a measure of the mode mixing. But in some cases, they may be different from those of individual resonances due to mode-overlapping.



(a) Without waveguides. (b) With waveguides and terminating-loads.

Fig. 5. Resonance spectrum of the test cavity. Abscissa: frequency, 0.5-1.75 GHz. Ordinate: transmission parameter S_{21}, 10 dB/division, reference value (center line) -60 dB.

above the guide cutoff. As this mode may be contaminated by TM011-like mode, further efforts are needed to measure its R_{sh}/Q.

Work is continuing to check the performance of the designed cavity both experimentally and computationally. Especially, study on the beam-hole damping of high-frequency modes should be performed. As the next step, cooling design has to be made towards the high-power test cavity. Developments on input couplers, tuners and in-vacuum waveguide loads are also needed.

Acknowledgments

The authors wish to thank Y. Yamazaki for valuable advices, M. Izawa, S. Tokumoto and members of ATF group for useful discussions.

V. REFERENCES

[1] J. Urakawa et al., *Proc. of XVth International Conference on High Energy Accelerators*, Hamburg, 1992, Vol. I, p. 124.
[2] K. Kubo, KEK Proceedings 92-6, pp. 155-165 (edited by J. Urakawa and M. Yoshioka).
[3] R. Rimmer et al., *Conference record of the 1991 IEEE Particle Accelerator Conference*, Vol. 2, pp. 819-821.
[4] T. Weiland, DESY 83-073.
[5] H. Padamsee et al., *Conference record of the 1991 IEEE Particle Accelerator Conference*, Vol. 2, pp. 786-788.
[6] J.C. Slater, Microwave Electronics, D.Van Nostrand, 1950.
[7] R.L. Gluckstern and R. Li, *1988 Linear Accelerator Conference Proceedings*, 1988, pp. 356-358.
[8] T. Kageyama, KEK Report 89-4 (1989).
[9] N.M. Kroll and D.U.L. Yu, Part. Accel. 34 (1990) p. 231.
[10] N.M. Kroll and R. Rimmer, *Conference record of the 1991 IEEE Particle Accelerator Conference*, Vol. 2, pp. 801-803.