© 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.

Suppression of Higher-Order Modes in an RF Cavity by Resistive Material

Tadashi Koseki, Masaaki Izawa* and Yukihide Kamiya
The Institute for Solid State Physics, The University of Tokyo, Tanashi, Tokyo 188 Japan
*Photon Factory, National Laboratory for High Energy Physics, Tsukuba, Ibaraki 305 Japan

Abstract

A new 500-MHz cavity which has a simple damped structure for the 1.5-GeV VUV ring will be presented in this paper. The feature of the cavity design is that higher-order modes(HOMs) propagate out from the cavity through the beam-duct with a large diameter and are absorbed in resistive parts in the duct. A low power measurement on a prototype model of the cavity has been carried out and the Q-values of HOMs are confirmed to drastically reduce. Thus the coupled-bunch instabilities due to HOMs are expected to be sufficiently suppressed.

Introduction

A high-brilliant synchrotron radiation source for soft x-ray and VUV experiments is being designed at ISSP of the University of Tokyo in collaboration with the Photon Factory at KEK. The storage ring with an energy of 1.5 GeV has a circumference of 240 m and twelve long straight sections for extensive use of insertion devices. It is aimed at obtaining a low emittance of several nm·rad and a maximum beam current of 400 mA. The main parameters of the storage ring are summarized in Table 1.

Table 1: Main parameters of the ring.

Energy [GeV]	1.5
Circumference [m]	236.4
Superperiod	12
Length of straight section [m]	7.0
Maximum beam current [mA]	400
Natural emittance [m·rad]	6.4×10^{-9}
Energy spread	5.8×10^{-4}
Momentum compaction	1.5×10^{-3}
Energy loss/turn [keV]	90.2
RF frequency [GHz]	497.12
Harmonic number	392
Number of RF cavities	4
Momentum acceptance($\triangle p/p$) [%]	± 3.0
RF voltage [MV]	1.4
Bunch length [mm]	3.5

Because of its relatively low beam energy and proposed high beam current, very low impedances of higher-order modes are required for the accelerating cavity to suppress the coupled-bunch instabilities. Furthermore, a simple cavity structure is preferable for reliable operation. We have designed an RF cavity and carried out its low-power test with the prototype model. The specific features of the present cavity are that a beam-duct with large diameter is attached to the cavity and that a part of the beam-duct is made of the resistive material. Since the frequency of accelerating mode is sufficiently below the cutoff frequency of the beam-duct, the accelerating field is fully trapped in the cavity. On the other hand, the HOMs, which can propagate out of the cavity through the beam-duct, are damped by the resistive part.

Design Consideration

Four cavities made of copper will be installed in a long straight section of the VUV ring. They are required to generate an RF voltage of 1.4 MV in total. To maintain the dissipation power for each cavity below 40kW, it is desirable that the cavity should have the shunt impedance of more than 6 MΩ. The cavity shape was optimized using the computer codes of SUPERFISH and URMEL. In this calculation, the power loss of HOMs on the wall was estimated by taking into account the conductivity of resistive material.

The schematic of a quadrant of the designed cavity is shown in Fig. 1. In this design, the conductivity of the

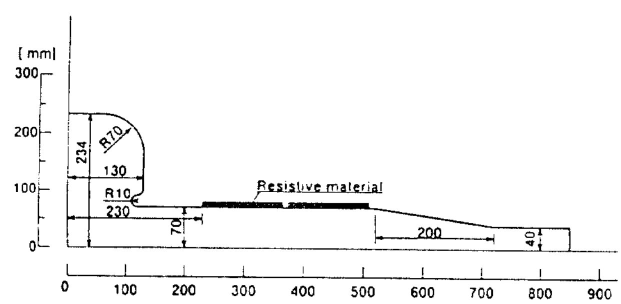

Figure 1: Schematic view of the cavity.

resistive material was assumed to be 100 $(\Omega m)^{-1}$. The small nose cones are introduced to the cavity not only to increase shunt impedance of accelerating mode but also to prevent the accelerating power from being absorbed in the region of resistive material. We obtained the shunt impedance R_s of 7.75 MΩ and Q-value of 44000 for the accelerating mode.

0-7803-1203-1/93$03.00 © 1993 IEEE

Figures 2 and 3 show the longitudinal and transverse coupling impedances of the HOMs in this cavity, respectively. The critical impedances in these figures denote the impedances, above which a coupled-bunch instability may occur at the beam current of 400 mA. Most of HOMs, whose frequencies are higher than the cutoff frequency of the large beam-duct, are absorbed by the resistive material and their impedances become smaller than the critical impedance. For some survived HOMs, having high Q-values, the coupled-bunch instabilities will be suppressed by a detuning of resonance frequencies of the cavity[1].

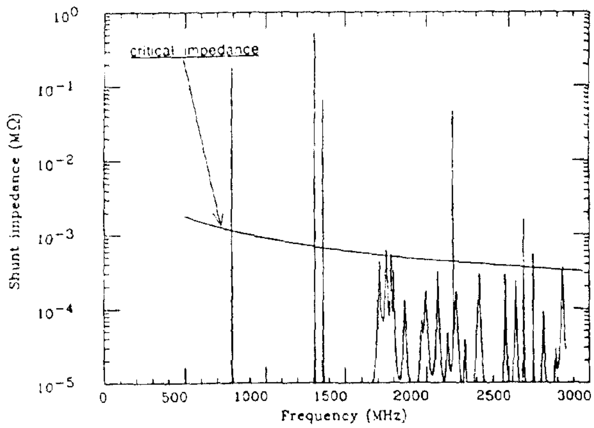

Figure 2: Longitudinal HOMs in the cavity.

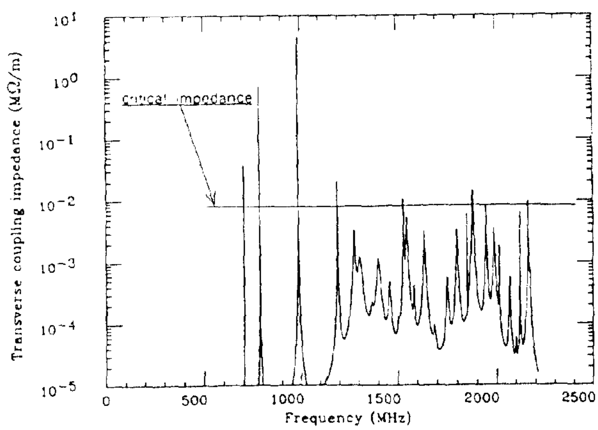

Figure 3: Transverse HOMs in the cavity.

Low power measurements

A prototype cavity of the same size as in Fig. 1 was made and its low power test was carried out. The prototype was made of aluminum and two types of beam-duct were prepared for the test. One is made of aluminum and the other of sintered SiC. The RF characteristics of both fundamental and HOMs were measured using a network analyzer (HP8510C).

Figure 4 shows the field distribution of the fundamental mode in the case of Al-duct. It was measured with the method of the perturbation technique[2],[3] using metallic sphere of 10 mm diameter. R_s/Q, calculated from the field distribution, was 168 Ω and the calculated value by SUPERFISH was 177 Ω. We measured the field distributions of all longitudinal HOMs, whose frequencies are below the cutoff of the ϕ80 mm duct, and some of transverse HOMs. The measured field distributions well agree with those calculated by URMEL.

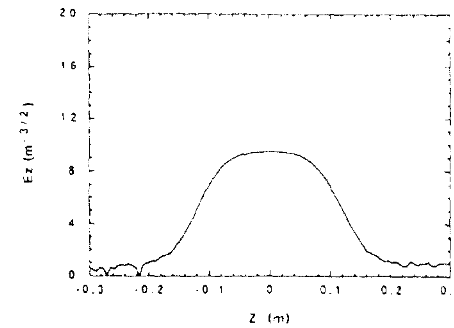

Figure 4: Field distribution of the fundamental mode.

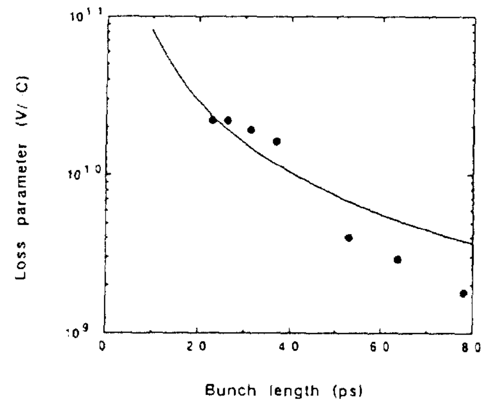

Figure 5: Loss parameter of the SiC-duct.

The resistive duct is 135 mm long and is made of sintered SiC (TPSS, TOSHIBA CERAMICS). From Q-measurement of the SiC-duct, the conductivity of the SiC was estimated to be 250~500 $(\Omega\text{m})^{-1}$ in the frequency region of 1.5 GHz to 4.5 GHz. As shown in Fig. 1, two SiC-ducts were installed each side of the cavity. The Q-values for Al- and SiC-duct are summarized in Table 2, where the measured and calculated Q-values are denoted as Q_m and Q_c, respectively. Assuming the conductivity of Al alloy as 2.0×10^7 $(\Omega\text{m})^{-1}$ and that of SiC as 333 $(\Omega\text{m})^{-1}$, most of measured Q-values are consistent with calculated ones in both cases of the Al-duct and the SiC-duct. As seen in this table, strong reduction of Q-values were observed for the SiC-duct. The conductivity of the sintered SiC is slightly larger than the required value in the design stage described in the previous section. Therefore some of the HOMs are not damped sufficiently. However if we use a little high-resistive SiC, we will be able to damp these HOMs enough to suppress the coupled-bunch instabilities in the VUV ring.

We measured the loss parameters of the SiC-duct by using the network analyzer in a similar method described in ref[4]. The results are shown in Fig. 5. The solid curve is the loss parameter k_r calculated by[5] ;

$$k_r(\sigma) = \frac{1}{\pi}\int_0^\infty Re\{Z(\omega)\}e^{-\omega^2\sigma_b^2}d\omega, \qquad (1)$$

where σ_b is the bunch length. $Z(w)$ is the impedance of

Table 2: Summary of Q-values for Al- and SiC-duct.

	Al-duct		SiC-duct	
Freq.(MHz)	Q_m	Q_c	Q_m	Q_c
Longitudinal mode				
496.466	24000	25000	24000	25000
790.908	22000	22000	21000	22000
1153.14	32000	35000	31000	34000
1308.64	32000	33000	33000	33000
1362.33	24000	27000	23000	25000
1660.16	17000	24000	100	110
1662.73	18000	23000	-	120
1710.64	24000	27000	290	300
1729.52	22000	24000	200	200
1754.68	23000	25000	350	310
1786.33	29000	31000	690	570
1801.78	40000	42000	690	590
1852.60	24000	27000	290	270
1869.72	24000	28000	320	280
1968.67	-	30000	320	270
1995.71	24000	26000	300	240
2067.31	33000	33000	350	390
2127.39	28000	28000	320	290
2160.14	23000	28000	350	360
2177.43	-	26000	-	1100
2232.61	29000	29000	510	450
2292.61	-	27000	340	310
2320.40	26000	29000	510	460
2402.41	-	33000	460	540
2449.07	-	28000	420	340
2478.96	38000	43000	630	710
2541.39	28000	34000	770	370
2581.88	-	30000	450	400
2590.37	35000	35000	4500	3900
Transverse mode				
702.931	24000	30000	22000	27000
786.049	26000	33000	24000	28000
985.814	18000	25000	12000	14000
1189.47	-	31000	-	1500
1216.21	39000	49000	-	2900
1276.75	19000	21000	200	210
1287.27	15000	18000	-	90
1305.93	16000	20000	130	120
1363.72	18000	20000	210	170
1399.48	17000	21000	180	150
1456.52	-	23000	270	220
1502.09	30000	38000	510	490
1529.57	30000	33000	1300	690
1547.88	-	24000	480	370
1581.14	31000	35000	640	470
1635.88	-	28000	410	340
1685.28	23000	27000	290	320
1749.80	-	29000	390	340
1798.85	-	27000	540	410
1850.12	-	75000	33000	25000
1869.33	-	33000	550	450
1880.97	21000	27000	560	580
1945.87	-	35000	960	760
1986.94	-	30000	600	470

the duct written as[6] ;

$$Z(\omega) = (1+i)\frac{L}{2\pi b\delta\sigma}. \tag{2}$$

Here δ is the skin depth, σ the conductivity of the duct. L and b are radius of the duct and its length. The constant conductivity of 333 $(\Omega\mathrm{m})^{-1}$ was used in this calculation. The measured loss parameters well agree with this simple calculation.

The wall heating due to ohmic loss in the SiC-duct become serious for a short bunch such as in the VUV ring. At the bunch length of 11.7 ps (3.5 mm), which is the design value of the VUV ring, the loss parameter calculated by Eq.(1) is 0.12 V/pC per one SiC-duct. Here, the conductivity of the SiC-duct is assumed to be 100 $(\Omega\mathrm{m})^{-1}$. In addition, since there are HOM losses due to cavity shape, the problem of the wall heating become more serious. In our rough estimation of the HOM losses, cooling system for the SiC-duct is necessary.

Near-future plan

Another type of SiC-duct with the conductivity of about 5 $(\Omega\mathrm{m})^{-1}$ will be tested and a comparison between these two type of SiC will be made in detail. Then the shape of the cavity, especially the position and length of the SiC section will be optimized furthermore. We also intend to investigate the effects of tuner and coupler on the RF characteristics by using the prototype cavity. The vacuum test of the SiC-duct is also now in progress.

Acknowledgements

We would like to thank Prof. T. Ishii, director of the Synchrotron radiation laboratory of ISSP, and Prof. H. Kobayakawa, director of the light-source division of the Photon Factory, for their continuous support. We also thank Dr. T. Toyomasu for useful discussions.

References

[1] H.Kobayakawa, *et al.*, *"Suppression of beam instabilities induced by accelerating cavity"*, Rev. Sci. Instrum., Vol.60, No.7, pp. 1732-1735, July 1989

[2] J.Jacob, *"Measurement of the higher order mode impedances of the LEP cavity "*, ESRF-RF/88-02, January 1988.

[3] Y.Yamazaki *et al.*, *"Measurement of the longitudinal and transverse coupling impedances of the higher-order modes of the re-entrant accelerating cavity"*, KEK 80-8, August 1980.

[4] M.Izawa *et al.*, *"Impedance measurements at the Photon Factory storage ring"*, Rev. Sci. Instrum., Vol.63, No.1, pp. 363-366, January 1992.

[5] P.B.Wilson, *"Fitting the SPEAR II impedance function using measured energy loss data"*, PEP-233, February 1977.

[6] For example, see F.Sacherer, *"Transverse instabilities of relativistic particle beams in accelerators and storage ring, Part II- Bunched beams"*, CERN 77-13, pp. 198-218, 1977.