Higher-Order Mode (HOM) Characteristics of the Choke-Mode Cavity for the KEK B-Factory(KEKB)

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Abstract

The prototype of the choke-mode HOM-damped cavity, which is an accelerating cavity part of the ARES cavity for the KEK B-Factory, has been constructed, high-power tested, and beam-tested. In order to determine the coupling impedances of the HOM's, the electromagnetic fields were measured along the beam axis. Since almost all of HOM's are strongly damped as designed, those of only several modes could be measured. The HOM impedances were also calculated with both frequency-domain and time-domain methods by using the 'MAFIA'. These results were consistent with the frequency spectrum of the field excited by the beam. The performance of the cavity well meets the requirement regarding longitudinal beam instability.

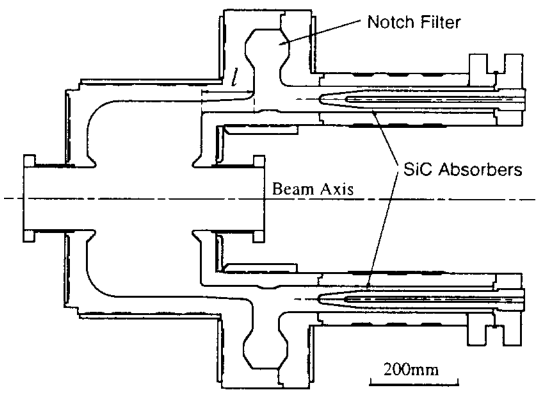

Fig.1 : A schematic drawing of the test cavity. Sixteen bullet-shaped absorbers are inserted from the coaxial waveguide end.

1. INTRODCTION

For the KEKB, a choke-mode HOM-damped cavity was designed[1], and its prototype has been constructed. This cavity will be an accelerating cavity part of the three-cavity system, ARES[2]. The schematic drawing of this cavity is shown in Fig. 1. The cavity is loaded with a coaxial waveguide equipped with a notch filter of a radial-waveguide type. The filter reflects back the TEM wave coupled with the accelerating mode, the frequency of which is located at the first stop frequency of the filter. The RF waves passing through the filter are absorbed by sixteen bullet-shape sintered SiC absorbers inserted from the waveguide end. For the detailed RF characteristics, refer to [1] and [3].

The notch filter has the second stop frequencies at 1.67GHz for the TEM waves and at 1.68GHz for the TE_{11} waves, respectively. In the vicinity of these frequencies, some HOM's may be trapped within the cavity. In order to make these modes propagate through the beam pipe, the beam bore diameter was enlarged to 150mm (The cut-off frequencies of the bore for TM_{01} and TE_{11} become 1.53GHz and 1.17GHz respectively.) and the HOM's, the frequencies of which are located near the stop band of the filter, are damped by the "beam-pipe damper." It is basically a radial-line waveguide (gap 20mm) connected with the beam pipe, or cylindrical absorber attached to the wall of the beam duct.

2. HOM CHARCTERISTICS

The HOM Characteristics obtained by the measurement and the 'MAFIA' calculation are summarized in Table 1, Fig.2 and Fig.3. The following remarks should be noted.

2-A Field Measurement

In order to obtain the longitudinal coupling impedances of HOM's, the field distributions were measured along the beam axis for the prototype of the cavity shown in Fig.1 by using the bead measurement method (The bead was a aluminum sphere, radius=1cm). The results are shown in the first column of the Table 1. The measurement and the definitions of the shunt impedance are the same as those of Ref. [4].The Q-values were obtained from peak width of transmission spectrum of the cavity. The mode assignment in Table 1 is determined by comparing with the results of the following calculation.

2-B Calculation

The HOM properties were calculated with the following two methods by using the electromagnetic field simulation code, MAFIA[5].

The first one is the frequency domain method. The MAFIA solved 2D eigen-mode problem of the cavity without loss in the SiC absorber, and then for these particular modes the shunt impedance and Q-value were calculated by assuming the perturbation loss arising from the solved fields in the absorber. Although the absorber is of the form of sixteen bullet-shape structure, we had to approximate the absorber by the axially symmetric one with the relative dielectric constant and $\tan\delta$ reduced by the volume ratio ($\varepsilon'/\varepsilon_0$=2.3 and $\tan\delta$ =0.1[6][7]). These results are shown in the second column of the Table 1.

The second one is the time domain method. By using the MAFIA 3D time domain solver (MAFIA-3T), the wake potential was calculated for the bunched beam passing through the cavity along the beam axis. This time we can use the more realistic bullet-shaped absorbers. The Fourier transformation of the wake potential then gives one the coupling impedance. This result is shown in Fig.2 together with the required impedance per cavity for comparison. If all the cavities in the KEKB LER (Low Energy Ring) are below the required impedance, the growth time of the longitudinal coupled-bunch instability for the designed beam current will be longer than radiation damping time of 23ms, that is, the threshold current is higher than the designed value. The calculation was performed on the following conditions. The beam pipe at both ends was matched (no reflection) for any propagation wave, that the bunch length was σ_z=10mm (Gaussian bunch), and that the relative dielectric constant $\varepsilon'/\varepsilon_0$=20, the conductivity σ=0.21Ω^{-1}m^{-1} for absorber.

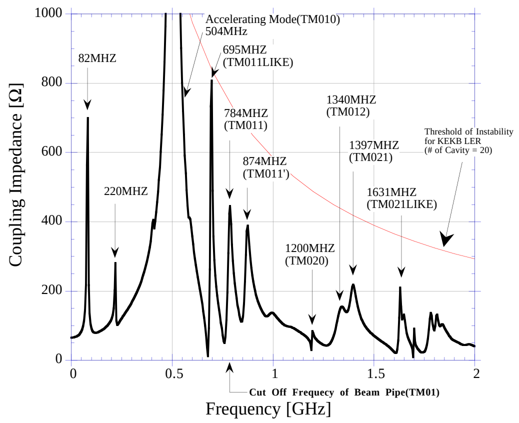

Fig.2 : The longitudinal coupling impedance for the choke mode cavity calculated by MAFIA 3D time domain. (Bunch length σ_z=10mm, $0<s<66$m) The height of the peak corresponds to $R_{sh}/2$ of Table 1.

2-C AR Beam Test and Shunt Impedance Measurement by using the Beam.

In March '96, the beam test was carried out for the cavity installed in the TRISTAN Accumulation Ring(AR). (See Fig.3.) This system is equipped with the above-mentioned beam pipe dampers, witch were located[8] near the standing-wave maxima of most dangerous HOM's propagating in the beam pipe. So the HOM's that couple with the propagation modes of beam pipe, are to be absorbed with the beam pipe damper.

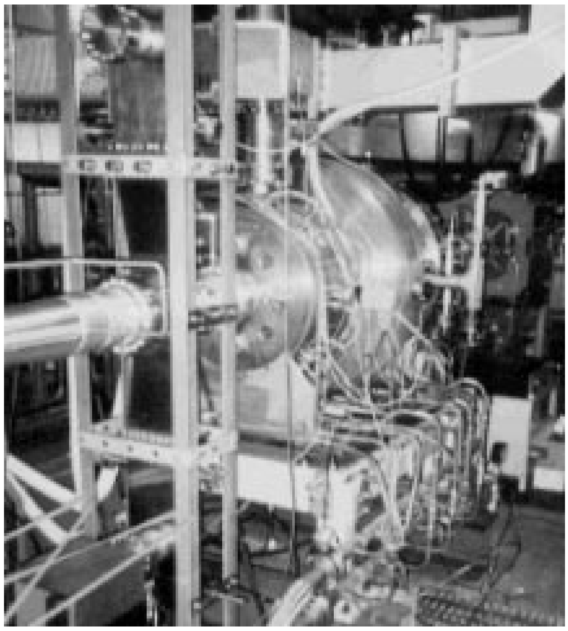

Fig.3 : The picture of the HOM-damped cavity installed in the AR beam line with the beam pipe damper.

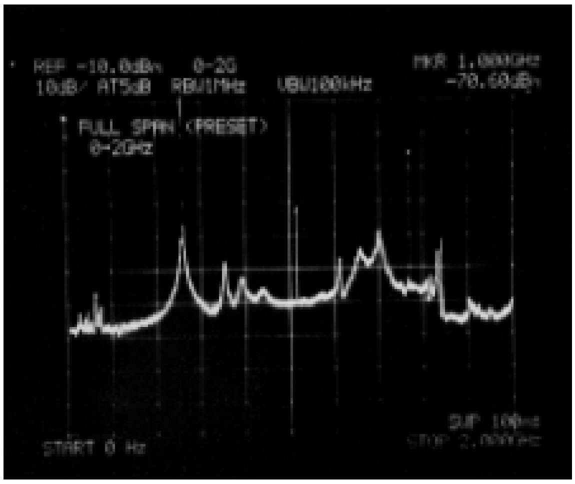

Fig.4 : The frequency spectrumi (0 to 2GHz) of field excited by the beam in the cavity. (single bunch , 65mA)

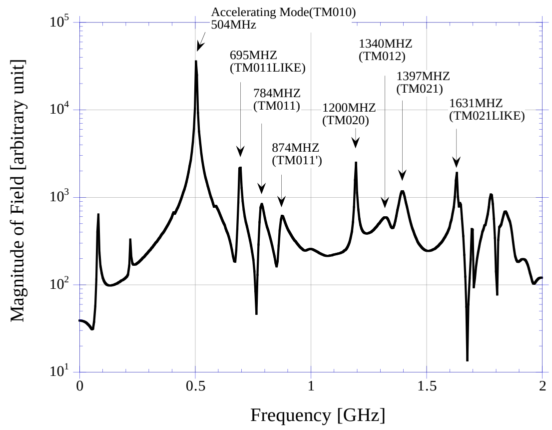

Fig.5 : The spectrum of field calculated by MAFIA 3D time domain.

Figure 4 shows the frequency spectrum of field excited by the beam (single bunch, 65mA) in the cavity. The spectrum shown in Fig.5 is the Fourier transformation of the calculated time-dependent field at the position of the antenna used in the above measurement. The calculation is the same MAFIA 3D time domain one as section 2-B.

3. RESULT AND DISCUSSION

It is seen from the comparison between Fig.4 and Fig.5 (Fig.2) that the observed spectrum is in good agreement with the calculation by MAFIA. The detailed comparison is possible by inspecting Table 1. The overall agreement is pretty good among the frequency-domain calculation, time-domain calculation, and beam test result, except for the 1.65GHz mode. (This mode is located near the stop band of the choke filter, propagating through the beam pipe. The beam pipe is equipped with no absorber in the frequency-domain calculation, with the matched load in the time-domain calculation, and with the absorber in the actual beam test. The Q-values are consistent with these conditions.)

As expected the field measurement by the bead-perturbation method was very difficult for the low-Q modes, in particular for the modes with the Q-values lower than 50. This fact should be taken into account, when comparing the R_{sh}/Q of the first column in the Table 1 with those of the other columns.

All the three modes below 1GHz have the TM_{011}-like field pattern. The TM_{011} mode splits into these three modes through the coupling of the accelerating cavity TM_{011} mode with the cavity-like notch filter and the coaxial waveguide line as a cavity.

4. SUMMARY

The longitudinal coupling impedances were carefully calculated and measured by several methods. The impedances of the modes below 2GHz are sufficiently reduced for storing the designed beam current, including the 1.65GHz stop-band mode damped well by the beam pipe damper. It is noted that the time-domain calculation of the wake potential with MAFIA is simpler and more convenient method for evaluating coupling impedances than the frequency-domain method.

The frequency-domain calculations for the dipole modes were also performed. The results are shown in Table 1. All the dipole modes below 2GHz are well damped for storing the designed beam current.

5. REFERENCE

[1] T.Kageyama et al., "Design of a Prototype of RF cavity for the KEK B-Factory(KEKB)", EPAC94, 1994.

[2] Y.Yamazaki and T.Kageyama, "A Three-Cavity System Which Suppresses the Coupled-Bunch Instability Associated with the Accelerating Mode", Part. Accel., Vol.44, 1994, pp.107-127.

[3] N.Akasaka et al., "High Order Mode Characteristics of the Choke Mode Cavity for the KEK B-Factory", EPAC94, 1994.

[4] Y.Yamazaki et al., "Measurement of The Longitudinal and Transverse Coupling Impedances of The Higher-Order Modes of The Re-Entrant Accelerating Cavity", KEK80-8,1980.

[5] The MAFIA Collaboration: "Users Guide Ver. 3.20", CST, 1994.

[6] Y.Takeuchi et al., "HOM Absorber for the KEKB Normal Conducting Cavity", PAC95, 1995.

[7] Y.Takeuchi, "RF Characteristics of the Bullet-shape SiC Absorber for KEKB", KEK Preprint 95-116, 1995.

[8] T.Kobayashi, "Study of a Beam Pipe Damper for HOM Damped Cavity for the KEKB Accelerator", Master's Thesis, Institute of Applied Physics, Tsukuba Univ., 1996.

	Measured (Bead Measurement)			**Calculated (MAFIA) (2D Frequency Domain)**				**Calclated(MAFIA) (3D Time Domain)**			**Beam Test Spectrum**	
Pilbox MODE	**Freq. [MHz]**	Q_L	R_{sh}/Q [Ω]	**Freq. [MHz]**	Q_0	R_{sh}/Q [Ω]	R_T/Q [Ω/m]	**Freq. [MHz]**	**Q**	R_{sh}/Q [Ω]	**Freq. [MHz]**	Q_L
TM010	508	13000	158	509	33000*1	157		504			508	
TM011-like	697	90	12	696	90	15		695	80	20	694	80
TM011	784	40	3	791	50	24		784	40	22	774	34
TM011'	866	35		880	45	16		874	30	26	866	20
TM020	1203	300	1.4	1203	225	1		1200	200	1	1213	250
TM021-like	1652	600	1.1	1652	1800*2	2		1631	200	2	1656	470
TM110				809	82		82					
TM111-like				877	51		40					
TM111				989	78		128					
TM111'				1071	48		29					
TE111				686	210							
TE111-like				743	116							

Table 1 : The summary of the HOM characteristics. For definition of the shunt impedance, see Ref. [3].
*1 : This value is unloaded Q-value (excluding the external Q-value for the power input coupler).

*2 : The reason of high Q-value is that the boundary at the beam pipe end is 'electric short' for this calculation.