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

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Abstract

A prototype of RF cavity for the KEK *B*-factory, KEKB, was designed by applying the idea of choke mode cavity originally proposed by Shintake as a damped accelerating structure for linear colliders. This prototype cavity has a HOM damping coaxial waveguide equipped with a notch filter to reflect and confine the electromagnetic wave of the accelerating frequency. The HOM properties were studied by using the electromagnetic field simulation code, MAFIA. Especially, external Q values were calculated by two different methods: one is a frequency-domain analysis using Slater's tuning curve method, and the other a straightforward time domain analysis.

1. INTRODUCTION

Coupled bunch instability is a serious problem when very high beam current is required such as in the case of proposed B-Factory. It is induced by the wake field of the bunches in the accelerator which deflects the orbit of the following bunches. One way to avoid this problem is to lower the Q value of the higher order modes (HOM's). Many cavities with damped structures have been proposed to achieve effective damping. Shintake first proposed the choke mode cavity as a damped cavity for linear colliders [1]. It has been modified for the use in KEKB [2] as shown in Fig. 1. The coaxial line connected at the outer radius of the main pillbox cavity extracts the energy of HOM's out of the cavity to the absorber at the other end of the coaxial line. The choke located between the cavity and absorber prevent the energy of the accelerating mode from flowing out of the cavity. This keeps the shunt impedance of the accelerating mode from degrading. We decided to place the absorber in the coaxial line instead of radial line as opposed to Shintake's original idea, because the

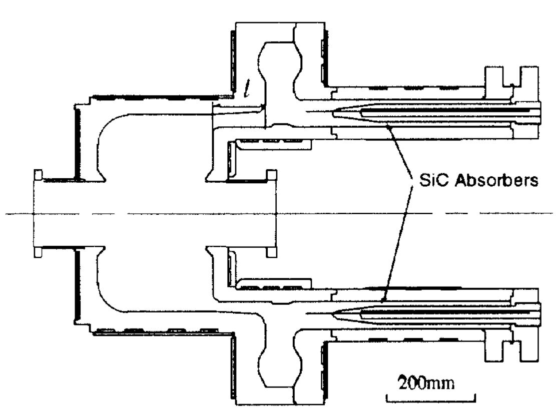

Figure 1. The choke mode cavity for KEKB.

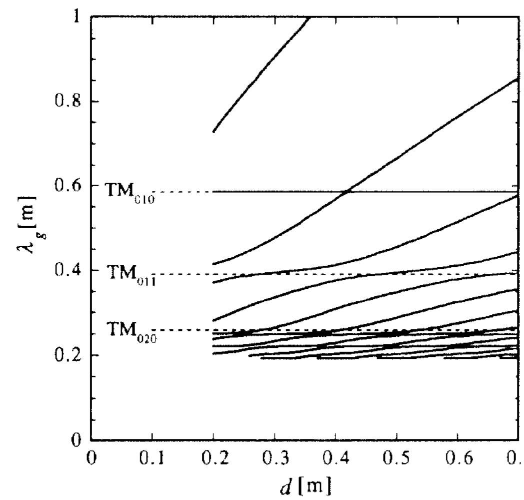

Figure 2. Slater plot for monopole modes of the choke mode cavity in Fig. 1.

RF frequency of 508MHz is fixed for KEKB and the radius of the whole structure would be otherwise extraordinarily large.

2. EXTERNAL Q OF HIGHER ORDER MODES

2.1. Slater's Tuning Curve Method

The resulting Q value of a HOM is determined by the external Q (Q_{ext}) of the cavity mode and the reflection coefficient of the absorbing structure. The external Q can be calculated using Slater's tuning curve method, which was independently proposed by Gluckstern *et al.* [3], Kageyama [4], and Kroll *et al.* [5], when the cavity is coupled to a waveguide. When the length d of the waveguide is changed with the other end of the waveguide electrically shorted, the resonant frequency ω of the system changes as [6]

$$\tan\frac{2\pi d}{\lambda_g} = \sum_a \frac{1/Q_{ext,a}}{\dfrac{\omega}{\omega_a} - \dfrac{\omega_a}{\omega}} \tag{1}$$

where λ_g is the wave length in the waveguide and ω_a is the ath resonant angular frequency of the cavity without the waveguide. If the resonant frequencies are known as functions of d from either experiment or calculation, $Q_{ext\,a}$ can be obtained by least square fitting the results to Eq. (1). In Fig. 2, resonant frequencies of the choke mode cavity calculated using MAFIA are plotted as functions of d, the distance from the electrically shorted end to the pillbox cavity. Only monopole modes are plotted in Fig. 2. Unperturbed resonant frequencies of the pillbox cavity are also plotted as horizontal lines. It can be seen from Fig. 2 that the Slater method is difficult to apply. Similar plot for dipole modes shows that Slater's method is also difficult to apply to TM_{110} and TM_{111} modes. This is because (a) the coupling is very strong for these modes and (b) the choke, acting as a resonant structure, increases the number of resonant modes.

2.2 Time Domain Method with MAFIA

As an alternative, the 2D time domain solver (T2) of MAFIA was used to calculate Q_{ext}. The T2 module calculates electromagnetic field as a function of time for an axially symmetric structure. It can set a boundary condition of "open", which lets the incident wave on the boundary escape freely from inside, simulating ideal absorber. The value of Q_{ext} can be obtained by monitoring the decay of the field in the cavity as follows. First, the initial condition is calculated using the eigen mode solver (E) of MAFIA. The boundary condition of the absorber end of the coaxial line is set to electric short. The length of the coaxial line is adjusted so that the frequency of a mode coincide with that of the cavity without the coaxial line. This corresponds to the condition that the coaxial line is detuned from the cavity mode. Next, T2 module is invoked. The boundary condition at the absorber end of the coaxial line is set to "open" as stated above. The decay of the electric field is monitored at a point inside the cavity. Its location and the component of the monitored field was chosen so that the strength of the field is the strongest in the cavity. This procedure was applied to TM_{011}, TM_{020}, TM_{110} and TM_{111} modes. The results are shown in Fig. 3.

A comment is necessary for the analysis of TM_{111} mode.

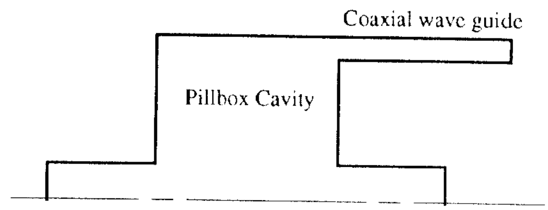

Figure 4. A cavity simplified in order to confirm the consistency between the time domain method with MAFIA and Slater's tuning curve method.

The envelope of TM_{111} mode did not show exponential decay. The Fourier Transformation of the decaying field of TM_{111} mode showed that TE_{111} mode, which had a much higher Q_{ext}, was excited at the initial condition. The excitation could not be suppressed by adjusting d. This problem was solved by monitoring two points where relative phase of the two modes differ by π. The plot of TM_{111} in Fig. 3 is the sum of the two monitored value with a proper scale factor. The other three modes show exponential decay without such correction.

In order to confirm the validity of this method, we compared the calculated Q values between Slater's tuning curve method and the present one for a simple system without the choke structure shown in Fig. 4. Slater's method is applicable in this case since the mode separation is wider because of the absence of the choke. In Fig. 5 the decay curves are shown together with the straight lines which is based on the Q value calculated using Slater's method. It can be seen that the results of the two methods are in good agreement.

3. Distance between the Cavity and Choke

The choke mode cavity has many structural parameters to decide, reflecting its complicated structure. The distance l

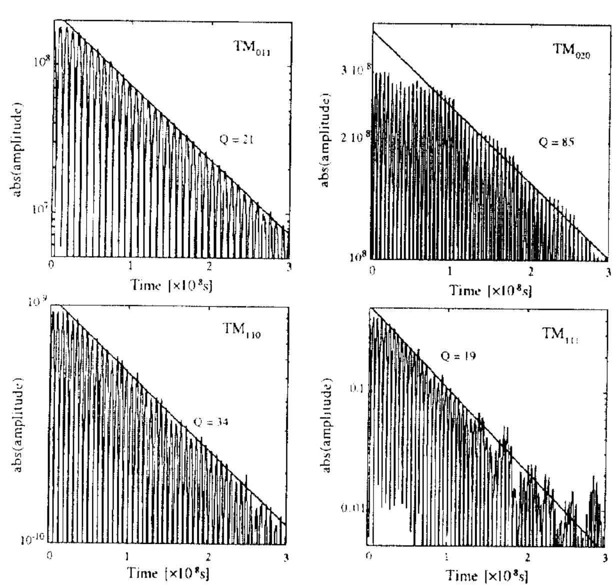

Figure 3. Calculated decay of the field in the choke mode cavity for TM_{011}, TM_{020}, TM_{110}, TM_{111} modes.

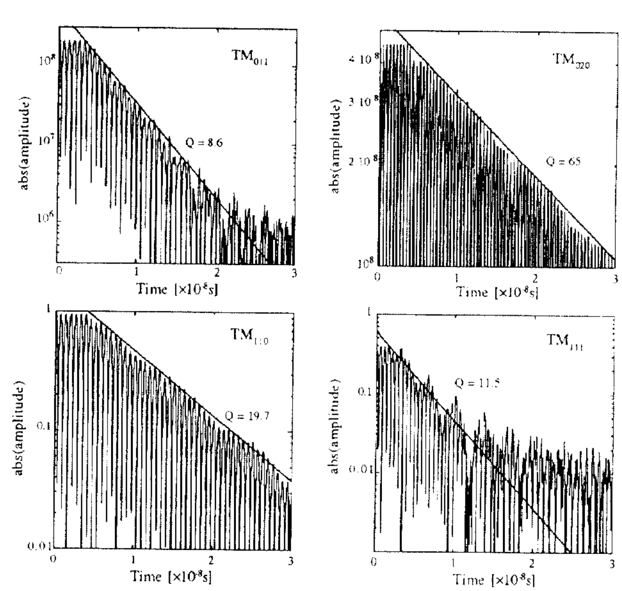

Figure 5. Calculated decay of the field in the cavity without the choke for TM_{011}, TM_{020}, TM_{110}, TM_{111} modes.

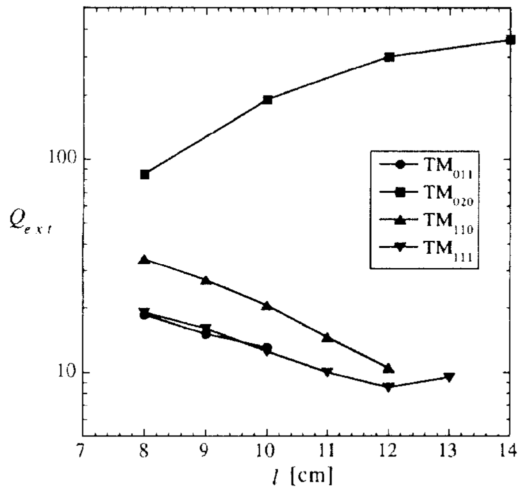

Figure 6. Q_{ext} as a function of the distance between the cavity and choke.

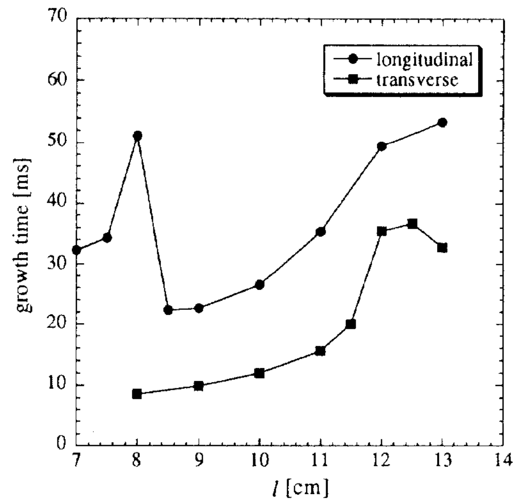

Figure 7. Growth time of coupled bunch instability as a function of the length between the cavity and choke.

between the pillbox and choke particularly changes Q_{ext}. Figure 6 shows the values of Q_{ext} as a function of the distance l between the pillbox and the choke. For TM_{011} and TM_{110} modes, the time domain method was not applicable for larger l because exponential decay curves were not obtained even with the subtraction between different points.

We also calculated the growth time of coupled bunch instability as a function of l. The formulae of Sacherer [7] were used. We did not use the time domain method because the modes which are trapped in the choke or coaxial line have to be taken into account. The modes were calculated with the MAFIA 2D eigen mode solver. The absorber was approximated to be axially symmetric. The permittivity was assumed to be 7, which is about half the measured value of some sample blocks of SiC [2] to compensate the packing factor of bullet-shaped SiC used in Fig. 1. The Q value and shunt impedance were calculated in the MAFIA postprocessor (P) assuming that $\tan\delta$ of the absorber was 0.3. Then the calculated frequencies, impedances and Q values are substituted in the formulae of Sacherer with the ring parameters in Table 1. Although the ring parameters in Table 1 are intended to be those of the low energy ring of the projected KEK *B*-Factory, some of them are not firmly fixed yet. The results are plotted in Fig. 7. From Fig. 7, l = 12~13cm seems to be a good choice for l. Then the growth time is larger than 30ms. However, we must be careful about this value because the Q calculation in the MAFIA postprocessor is based on the eigenmode obtained with no loss in the absorber.

Table 1. Ring parameters used in the calculation of the growth time of the coupled bunch instability

Parameters		
Beam Energy	3.5	GeV
Beam Current	2.6	A
RF Frequency	508.6	MHz
Number of Bunches	5120	
Momentum Compaction	2.5×10^{-4}	
Synchrotron Frequency	1.7	kHz
Number of Cavities	8	

4. SUMMARY

The time domain method to obtain Q_{ext} presented in this paper is easier to apply than Slater's tuning curve method when the separation of the modes is small. Calculated values of Q_{ext} are consistent between the two methods. Through this method, the choke mode cavity in Fig. 1 has shown a sufficient performance for use as an accelerating cavity of ARES [8], which suppresses the coupled bunch instability from the accelerating mode in addition to the HOM's.

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5. REFERENCES

[1] T. Shintake, "The Choke Mode Cavity", Jpn. J. Appl. Phys., vol. 31, pp. L1567-L1570 November, 1992.

[2] T. Kageyama, N. Akasaka, Y. Takeuchi and Y. Yamazaki, "Design of a Prototype of RF Cavity for the KEK B-Factory (KEKB)", this conference.

[3] R. L. Gluckstern and R. Li, "Calculation of Cavity/Wave Guide Coupling", in Proc. 1988 Linac Conf., pp. 356-358.

[4] T. Kageyama, "A Simple Method using MAFIA to Calculate External Q Values of Waveguide-Loaded Cavities", KEK Report 89-4, 1989.

[5] N. M. Kroll and D. U. L. Yu, "Computer Determination of the External Q and Resonant Frequency of Waveguide Loaded Cavities", SLAC-PUB-5171, Jan. 1990.

[6] J. C. Slater, Microwave Electronics, Van Nostrand, 1950.

[7] F. J. Sacherer, IEEE Trans. Nucl. Sci., NS-20, p. 825, 1973.

[8] K. Akai and Y. Yamazaki, "Computer-Aided Studies of the Three-Cavity System for Heavily Beam-Loaded Accelerators", this conference.