Damped Cavity for Linear Collider

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Abstract

In order to increase the luminosity of a linear collider, we adopt multi-bunch operation. In this case, higher order modes excited in an accelerating structure by the preceding bunches in a bunch train are likely to cause beam breakup in the following bunches. As a method to suppress this effect, we studied a cavity whose Q values are damped enough for the higher order modes. In this paper, we first explain the damping method and then we show the field calculations using a 3D code MAFIA to try to make the Q values less than 20 without decreasing the Q value of the fundamental mode. Finally, we describe results of low power measurements for a test cavity. The Q value of the TM110 π-mode was found to be decreased to 10.

Introduction

In an electron positron linear collider, luminosity L is given by

$$L = (Ne^+ \cdot Ne^-) \cdot N_b \cdot F_{rep} \;/\; A,$$

where Ne^+ and Ne^- are the number of particles in a bunch, A the cross section of the beam at the colliding point, N_b the number of bunches in a pulse and F_{rep} the repetition rate of the linac. As the wall plug power is limited, a multi-bunch operation will be necessary for obtaining a higher luminosity. In the multi-bunch operation, the wake field of unwanted higher order modes excited by the preceding bunches are likely to cause unacceptable momentum spread and deflection of the following bunches (beam breakup) because the Q values of the higher order modes are usually very high for conventional disk-loaded structures. One of the ways to supress this effect is to damp the excited higher order mode field before the following bunch comes by reducing the Q value of the higher order modes. The Q value less than 20 is desirable for the proposed parameters of Japan Linear Collider (JLC)[1,2,3]. A damped cavity was proposed by R. B. Palmer[4] to reduce the Q value, but he could not confirm the Q value of less than 20. Therefore, we examined in more detail his damping method for a cavity loaded with rectangular waveguides at its side wall and tried to realize the Q value less than 20 using the code MAFIA[5]. The calculations are confirmed also experimentally.

Method of damping

Dispersion curves of the longitudinal and transverse modes for a typical disk loaded structure fot the JLC main linac are shown in Fig.1. The structure is designed to operate at the $2\pi/3$ mode with the ratio of the beam aperture radius to the wavelength $a/\lambda = 0.15$. As shown in the figure, two dipole (TM110-like and TE11-like) mode passbands lie at about 1.5fa, where fa is the fundamental accelerating mode frequency, while all other higher modes lie above 2fa.

Because the fundamental mode should not be affected at all by this waveguide damping, the cutoff frequency of the waveguides must be higher enough than fa, and in our case it was set at about 1.5fa by choosing appropriate dimensions for the waveguide width WG2 shown in Fig.2. Then the damping of the higher order modes higher than 2fa would be sufficient.

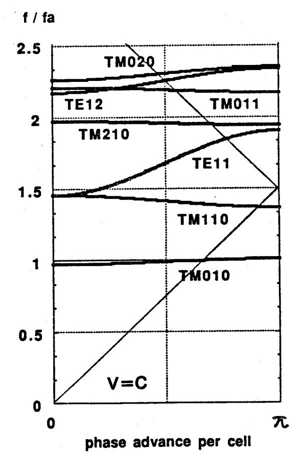

Fig. 1. Dispersion curves of longitudinal, transverse and quadrupole modes in a disk-loaded structure operated at the $2\pi/3$ mode. Frequency is normarized by the accelerating mode frequency fa.

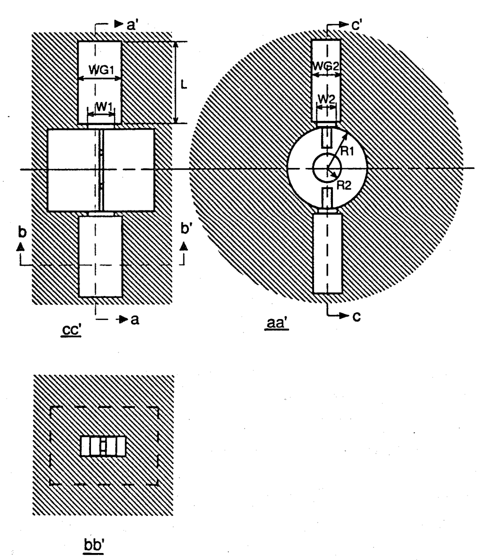

Fig. 2. Schematic drawing of the two-cell damped cavity. In the actual structure the waveguide is terminated with a matched load.

Next we must consider damping of the two dipole modes. First we need little concern about the TE11-like mode because its impedance is negligibly small as computer calculations show. On the other hand, the TM110-like mode is the most dangerous one. As the phase shift which coincides with the beam velocity is quite near π, we must damp the Q value of the TM110-like π-mode enough. As the cutoff frequency determined from WG2 is almost the same as the mode, the damping method for the modes above 2fa is not effective. In order to damp the mode to the waveguide, radial slots are cut on the disk through to the waveguide as first R. B. Palmer proposed[4]. Then the slot intercepts the wall current of the TM11-like mode and plays as an antenna for the waveguide. As this waveguide mode has a polarization perpendicular to that of the mode excited by the leakage field of the fundamental accelerating mode, the cutoff frequency, determined in this case by the width WG1 can be set rather low without worrying about the fundamental mode.

In addition to the dependence of the damping on the waveguide sizes WG1 and WG2, we studied that on the sizes of the rectangular coupling iris W1 and W2, and also that on the slot length and width. We, however, assumed the depth of the iris to be negligibly small.

Calculation

The calculation of an external Q value Q_{ext} is based on the tuning curve characteristics described in the text of J. C. Slater[6,7]. For a cavity coupled with a waveguide which is shorted at the distance L from the coupling iris, the resonant frequency was calculated by the code MAFIA. The Q_{ext} is determined from the following relation

$$\frac{dL}{d\lambda_g} = \frac{2n+1}{4} + \frac{Q_{ext}\, v_g}{\pi\, v_p}$$

where λ_g, v_g and v_p are the wave length, group velocity and phase velocity in the waveguide, respectively, and n is an integer.

Fig. 2 shows the schematic drawing of a C-band (fa=5.5GHz) two-cell damped cavity. The optimization was carried out by varying the slot width, slot length and window size shown in the figure. The results of the window size dependence are summarized below and in Fig. 3.

Mode	Q_{ext}	W1	W2	WG1	WG2	(mm)
TM011,TM210	<30	22	22	22	22	
TM110	10	18	10	22	10	

As shown in the list, it was found that the Q_{ext} of less than 30 can be easily obtained for all the higher order modes by this damping method. The Q_{ext} for the TM110-like mode is affected largely by the structure of the slot in the disk. As seen in the dependence on the slot width shown in Fig. 4, there is an optimum slot width, half the window height for the case of W1=W2=10mm. The dependence on the slot length shown in Fig. 5 should also be stressed. Three cases of the slot length are shown in Fig. 6. Case (a) is full the slot case, while cases (b) and (c) are for the slot which does not reach the beam hole. If we chose the proper length of the slot such as the case (c), the Q_{ext} can be decreased near to that of the full slot case (a). The merits of the case (c) are as follows; 1) no sharp edge on the beam aperture of the disk where strong accelerating field exists, 2) no slot modes near or below the accelerating mode and 3) large mechanical strength.

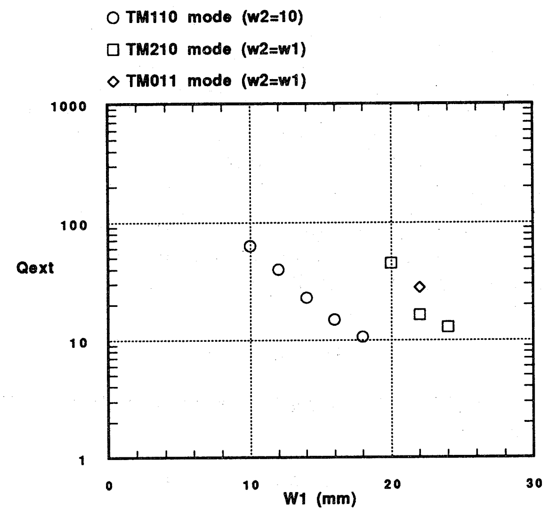

Fig. 3. The dependence of the Q_{ext} on the window size for TM110 mode, where WG1=22mm and WG2=W2=10mm and for TM011 and TM210 modes, where WG1=WG2=w2=W1.

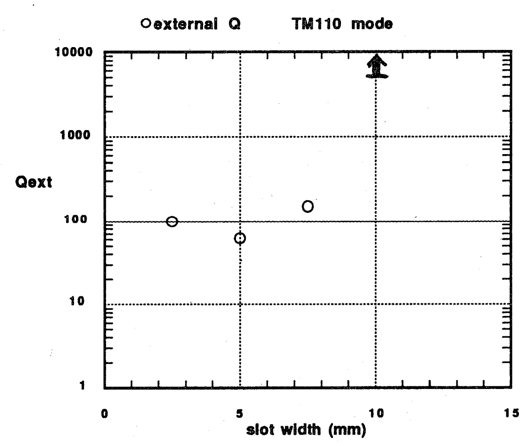

Fig. 4. The dependence of the Q_{ext} on the slot width for TM110 mode. Here, W1= W2= WG2=10mm and WG1= 22mm.

Measurement for a test damped cavity

To confirm the reduction of the Q value, a two-cell C-band cavity shown in Fig. 2 was examined by varying the size of the slots and the windows leading into the waveguides terminated with broadband loads for the measurement.

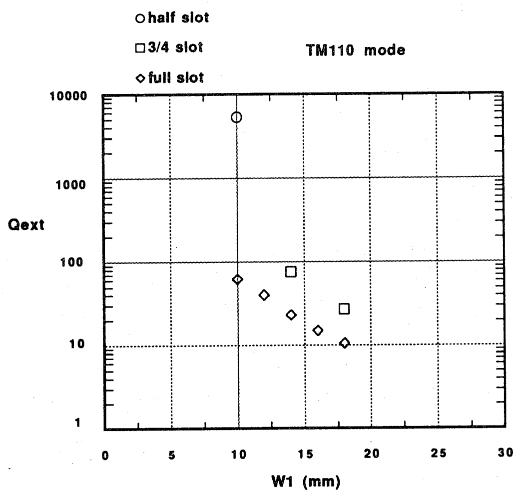

Fig. 5. The dependences of the Q_{ext} on the slot length for TM110 mode. Here, W2= WG2=10mm and WG1= 22mm.

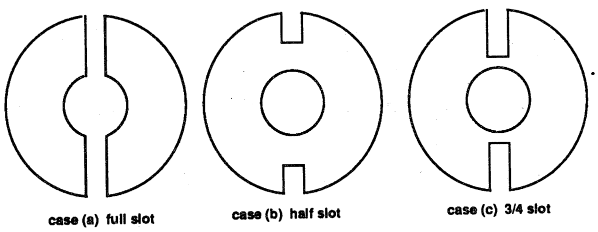

Fig. 6. Three types of the slot with different length; (a) full slot, (b) half slot and (c) 3/4 slot.

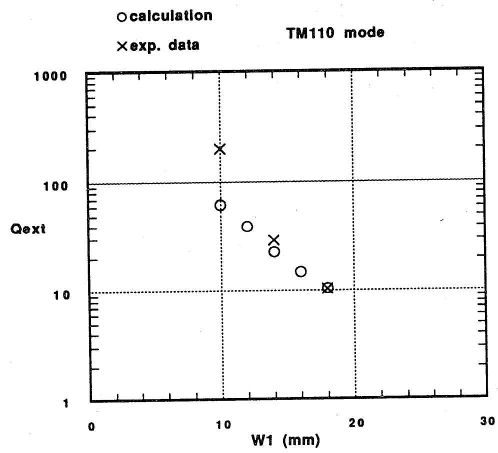

Fig. 7. Measured Q values for the TM110 π–mode. Here, W2= WG2=10mm and WG1= 22mm. The open circles show the calculated Q_{ext}. The crosses are Q_{ext} measured experimentally.

The overall frequency spectra were obtained from the transmission measurement between a pair of the antennas at both endplates. When the Q value was as low as 50, the evaluation of the Q value became difficult because of insufficient calibration of the measuring system (especially antennas) for a wide frequency range and also because of the overlapping of the other modes into the peak of the mode of interest. However, if we measure the transmission frequency spectrum between the facing waveguides, the calibration of the system becomes reliable and also the undamped modes which does not couple to the waveguides are eliminated from the spectrum. Therefore, we could obtaine the Q value even if it is very low.

The measured loaded Q values of the TM110-like π-mode are plotted in Fig. 7 together with those calculated. They are in good agreement with each other. The Q value of the accelerating mode in the damped cavity was found to be the same as that of the cavity without any damping structure within an accuracy of a few percent.

Discussions

The calculation of the Q_{ext} from the tuning curve characteristics using MAFIA was found very useful for the optimization of the damped cavity.

From this calculation, the Q value for the TM110-like π-mode was found to be decreased down to 10. This Q value was also confirmed experimentally. We could also obtain experimentally the Q value of the unwanted higher order modes less than 30 for the test cavity without degrading the Q value of the accelerating mode. Further optimization and experimental study are in progress.

We conclude that the damped cavity of this method could be a hopeful candidate for the accelerating structure of a linear collider in a multi-bunch operation. This kind of cavity can also be useful for the accelerating cavity in a circular machine.

Acknowledgement

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References

(1) S. Takeda et al., 14 Int. Conf. on High Energy Accelerators, August 22-26, 1989, Tsukuba, Japan.
(2) T. Higo et al., 14 Int. Conf. on High Energy Accelerators, August 22-26, 1989, Tsukuba, Japan, KEK-Preprint 89-93.
(3) K. Yokoya, private communication.
(4) R. B. Palmer, SLAC-PUB-4542 (1989).
(5) K. Klatt et al., Proc. of the 1986 Linear Accelerator Conf., SLAC, 1986, SLAC report-303
(6) J. C. Slater, Microwave Electronics, Van Nostrand, 1950, Chap. 5.
(7) T. Kageyama, KEK-report 89-4 (1989).