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Characteristics of a Damped Structure

Tsutomu Taniuchi, Masashi Yamamoto*, Toshiyasu Higo and Koji Takata
National Laboratory for High Energy Physics (KEK)
* The Graduate University for Advanced Studies
1-1 Oho, Tsukuba, 305 Japan

Abstract

A damped structure with circumferential slots for the higher order mode damping has been investigated aiming at a multi-cell accelerating structure of the JLC X-band linac. The damping characteristics of this periodic structure were studied in this paper. In order to evaluate the wakefield in the periodic structure, the dispersion relations of the higher order modes were calculated by using a computer code, MAFIA. The external Q values of the resonant mode with the same phase velocity as the beam were obtained by a simulation based on Slater's tuning method. The external Q values of the longitudinal higher order modes were also evaluated. A time domain simulation was performed and found consistent with that by Slater's tuning method.

I. INTRODUCTION

To achieve a high luminosity in the Japan Linear Collider (JLC)[1], the multi-bunch operation is considered. In this operation, the long-range wakefield excited in the accelerating structure by the preceding bunches acts on the following bunches and causes the energy spread and the deflection of bunches. These effects become unacceptable in the X-band (11.424GHz) linac if a normal disk-loaded structure is adopted. In order to reduce the wakefield effect, two types of the accelerating structures were proposed. They are categorized in 'damped structure' and 'detuned structure'. In the damped structure, the wakefield is extracted into the waveguide attached to the accelerating cell so that the field in the cell is damped before the arrival of the next bunch. In the detuned structure, the frequency of the higher order mode in a cell is distributed to form a truncated Gaussian along the structure and the effect of the wakefield is canceled out within the whole structure.

We have investigated the fundamental properties of a damped structure with circumferential slots and a possibility to apply to the accelerating structure for JLC X-band linac. In the preceding papers[2, 3], the dependence of the external Q values (Q_{ext}'s) of the higher order modes and the accelerating performance such as the Q value and r/Q value on the geometry of the damping port were precisely investigated. The analyzing method of the Q_{ext} was also described in those papers. Furthermore, it was found that the Q_{ext} of the most dangerous TM_{110}-π mode could be lowered below the required value for the JLC X-band linac though the accelerating performance being degraded.

A schematic view of this structure is shown in Figure 1. The geometrical parameters and the accelerating performance of the normal disk-loaded structure and the damped structure are listed in Table 1 where the parameters concerning to the damping port are determined so that the Q_{ext} of TM_{110}-π mode becomes 15.

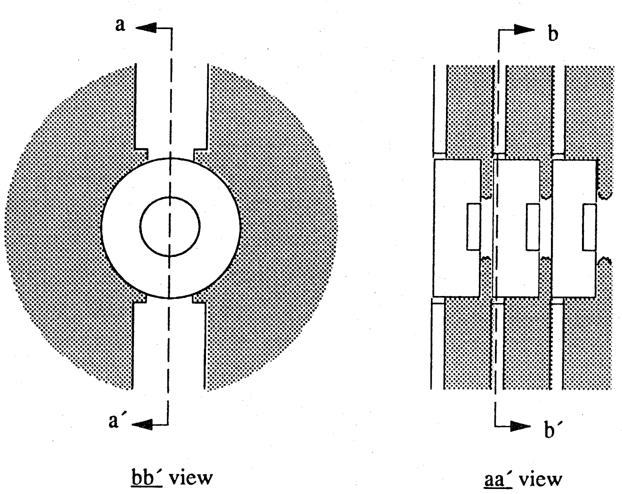

Figure 1. Schematic view of a damped structure.

Table 1. Geometrical parameters and the accelerating performance of the normal and damped structure.

Structure type		Normal	Damped
Accelerating frequency	[GHz]	11.424	11.424
Beam hole radius	[mm]	4.5	4.5
Iris width of slot	[mm]	–	9.0
Width of waveguide	[mm]	–	11.0
Height of waveguide	[mm]	–	2.0
Quality factor Q		6875	5755
Shunt impedance r	[MΩ/m]	79.7	63.3
r/Q	[kΩ/m]	11.6	11.0

In the analysis of the Q_{ext}, the phase advance per cell of the higher order modes was chosen to be 0 and π because the field pattern is close to that of the resonant mode in the pillbox cavity, so that the fundamental characteristics of each mode could be purely investigated. However, the bunch traversing the periodic structure most strongly feels the field of the mode whose phase velocity equals to the beam velocity, which is usually different from 0 or π mode. In this paper, therefore, the Q_{ext}'s of the synchronous mode were evaluated. Furthermore, the Q_{ext}'s of the longitudinal higher order mode were also evaluated. Additionally, a time domain simulation was performed and the result was compared with those by Slater's tuning method[4].

II. TRANSVERSE MODE

In order to find the phase advance per cell of the mode whose phase velocity equals to the beam velocity, the dispersion relation was calculated by using MAFIA[5]. Figure 2 shows the dispersion curves of the dipole modes below 40GHz in a normal disk-loaded structure with a/λ=0.17. The synchronous phases were determined from these curves. All the modes calculated are mixed with other mode at this a/λ, therefore, the Q_{ext} will change largely along the passband.

In the simulation using MAFIA, the TE_{30} mode of the waveguide appears above 41GHz. Therefore, the resonant mode higher than 41GHz cannot be analyzed. However, such modes will not be so serious because the cutoff frequency of the TE_{11} mode corresponding to the beam hole is sufficiently lower than 41GHz and the wake potentials of the modes higher than the cutoff frequency of the beam hole are small.[6]

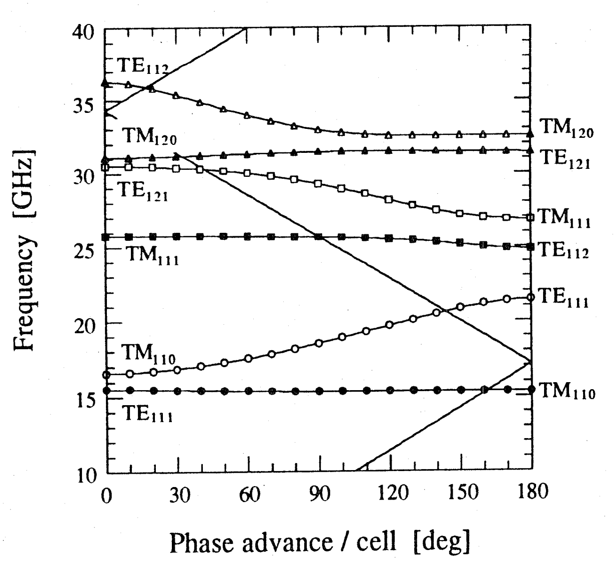

Figure 2. Dispersion relation of dipole modes. (a/λ=0.17) Straight line represents v_p=c.

In order to evaluate the Q_{ext} in the periodic structure, one cell geometry and the periodic boundary condition were used in MAFIA to simulate Slater's tuning method. This configuration is equivalent to that where an infinite number of the shorting planes of the damping waveguide were moved at the same time. The phase advance per cell was set to the value obtained from the dispersion curve. The calculated Q_{ext}'s are given in Table 2 together with the resonant frequency, phase advance per cell, wake potential and target Q value. Wake potentials in the table were calculated for a normal disk-loaded structure with a/λ=0.17 and target Q values were determined so that the emittance growth originated from the injection error was suppressed within 10% and the misalignment tolerance of the structure was increased up to 10μm. All the listed modes almost satisfy the target values though the Q_{ext} of TE_{111} mode seems a little high.

Table 2. Q_{ext} of the synchronous dipole modes.

Mode	Freq. [GHz]	Phase /cell	Wake [$\times10^{17}$V/C/m^2]	Q_{target}	Q_{ext} (cal.)
TM_{110}	14.8	160°	0.918	19.3	13
TE_{111}	20.3	145°	0.075	54.6	60
TM_{111}	25.3	90°	0.112	42.1	< 10
TE_{121}	31	45°	0.022	504	< 100
TM_{120}	33	30°	0.034	127	< 10

III. LONGITUDINAL MODE

This type of the damped structure is also effective for the longitudinal higher order mode whose resonant frequency is higher than the cutoff frequency of the damping waveguide if there is the circumferential magnetic field near the damping slot. Figure 3 shows the dispersion curves of the longitudinal modes below 30GHz. The TM_{011} and TM_{020} mode are mixed with each other at a/λ=0.17. Using the phase advance obtained from the dispersion curve, the Q_{ext}'s of two monopole modes were evaluated by the simulation of Slater's tuning method. In the simulation of Slater's tuning method using MAFIA, the shorting plane of the damping waveguide in only one direction was moved in the case of the transverse mode because the transverse mode did not couple to the TE_{10} mode of the other waveguide simultaneously. On the other hand, the longitudinal mode couples to the TE_{10} mode of both damping waveguides perpendicular to each other. Therefore, both shorting planes must be moved at the same time.

The result is given in Table 3. Both modes were found heavily damped. The effect of the longitudinal wakefield will be cured by some kind of the energy compensation, however, the damping of the higher order mode makes the problem easier.

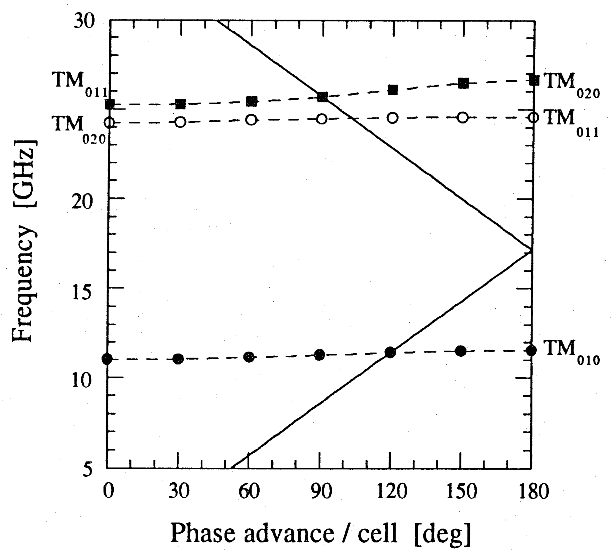

Figure 3. Dispersion relation of monopole modes. (a/λ=0.17)
Straight line represents v_p=c.

Table 3. Q_{ext} of the synchronous monopole modes.

Mode	Frequency [GHz]	Phase / cell	Q_{ext} (cal.)
TM_{011}	24.3	100°	20
TM_{020}	26.3	90°	25

IV. TIME DOMAIN ANALYSIS

In order to confirm the Q_{ext} obtained by the simulation of Slater's tuning method, the time domain analysis was performed by using MAFIA. As a mesh geometry, one cell structure with two waveguides was adopted. The length of the waveguide was set so that the traveling wave which was reflected by the shorting plane of the waveguide did not reach the cell within 1.5nsec. Because of the limitation in MAFIA, the boundary condition in the beam direction was set to the electric short. Therefore, the TM_{110}-0 mode and other modes which satisfied the same boundary condition were excited. The structure was excited by a Gaussian bunch with σ_z=5mm. The absolute value of the transverse wakefield is shown in Figure 4. The initial slope of the damping pattern is considered to show the Q_{ext} of the TM_{110}-0 mode. It was roughly estimated to be 9.3. Since the Q_{ext} of TM_{110}-0 mode obtained by Slater's tuning method was 8.9, these were consistent with each other.

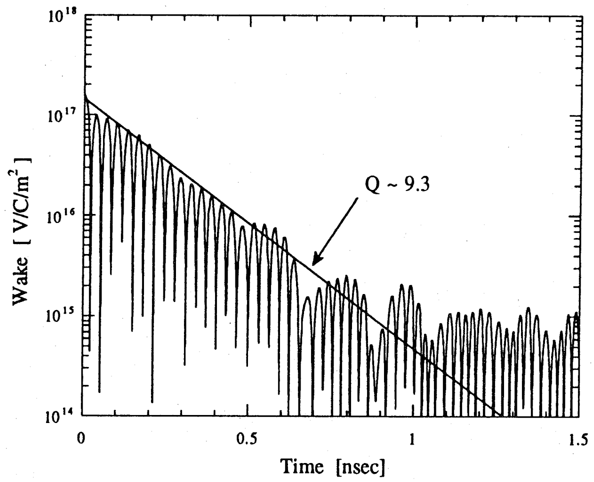

Figure 4. Damping of the transverse wakefield excited by a bunch (σ_z=5mm). Boundary condition for TM_{110}-0 mode.

V. CONCLUSION

The Q_{ext}'s of the transverse and longitudinal higher order mode synchronous to the beam in the periodic structure were evaluated. The Q_{ext}'s of the transverse mode were almost lowered below the required value for the JLC X-band linac. The longitudinal higher order modes were also heavily damped in this structure. A time domain simulation showed the consistency with Slater's tuning method.

VI. REFERENCES

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