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X-BAND ACCELERATING STRUCTURE FOR JAPAN LINEAR COLLIDER

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Abstract

The main linac for the Japan Linear Collider adopts X-band accelerating structures. This high frequency and therefore, a small accelerating structure for a long linac causes severe wake field problems against emittance preservation. To overcome the problems especially in multi-bunch operation, a damped structure with two slots in each disk is designed whose external Q value of the severest mode (TM110-π) is damped down below 25. The evaluation of the other higher modes are also described.

Introduction

The key issue of a high energy linear collider such as the Japan Linear Collider (JLC)[1,2] is to get a high energy beam with very low emittance using a reasonable amount of wall plug power. The JLC adopted 11.424GHz X-band accelerating structure operated at a gradient of 100MV/m for the main linac to get a 500GeV beam per a linac within several kilometers using a wall plug power of less than 200MW. This high operating frequency and the resulting small beam aperture were chosen to reduce a wall plug power. However, the wake field becomes very large for the structure with such a small beam aperture. Therefore, special cares should be taken to maintain the longitudinal and transverse emittance along the linac. To increase the luminosity without increasing total wall plug power much, 10 bunches are accelerated in an RF period in the JLC. Then, the longitudinal and transverse emittance of each bunch should be preserved by reducing the effect of the long-range wake fields.

In this paper, the basic parameters of the disk-loaded structure are first presented as the starting point to study an actual accelerating structure. Then the present paper describes a method to cure the multi-bunch wake field problems while details of the design consideration of a single bunch wake field are treated elsewhere.[3]

Basic parameters

Typical parameters[4] related to the accelerating structure of the main linac for JLC are listed in Table 1. If certain functional expressions[5] of the wake field are assumed, the energy spread of ±0.3% necessary for the BNS damping to reduce the single bunch transverse emittance growth can be obtained for the structure with $a/\lambda = 0.14$ in the case of JLC.[3] The disk thickness of 2mm was chosen to locate the ratio of the surface field to the accelerating one near broad minimum.[4] The parameters related to the wall loss were assumed to be the same as those calculated.

Table 1 Parameters of JLC linac

Accelerating gradient	G	100 MeV/m
Particles in a bunch	N	$1.0 * 10^{10}$
Bunches in a train	b	10
Bunch spacing	T_b	1.4 nsec
RF frequency	F_{rf}	11.424 GHz
2π/3 mode, Constant impedance, Travelling wave		
Beam aperture	a/λ	0.14
Disk thickness	t	2 mm
Total attenuation	τ	0.5
Shunt impedance	r	93 MΩ/m
Group velocity	v_g/c	0.02525
Elastance	s	1010V/pC/m
Structure length	Ls	0.697 m
Filling time	T_f	92 nsec
Power for a structure	Ps	121MW

All the structure-related parameters are those calculated by SUPERFISH.[6]

Evaluation of wake field

The dispersion curves of the structure with $a/\lambda=0.14$ were calculated using a frequency domain code URMEL[7] and shown in Fig. 1. The passbands in the following discussion are named following those in the figure. Because a component above the cutoff frequency of the beam pipe escapes out of the structure at a speed of its group velocity, the actual wake field should be evaluated taking this effect into account. The amounts of the wake fields were actually evaluated for a realistic multi-cell structure with a beam pipe radius the same as the beam hole radius of the accelerating cell using a time-domain code TBCI,[8] because it is difficult to evaluate them using URMEL for a long structure. Obtained wake fileds were fourier-transformed to discuss wake field problems by dealing with the wake field from the viewpoint of the higher modes of the structure. It was found that the wake field below cutoff frequency of the beam pipe is saturated as the number of the cells increases above 16. Fig. 2 shows the fourier transform of the wake fields for the 64-cell structure. The amplitudes of the typical higher modes thus obtained are presented in Table 2.

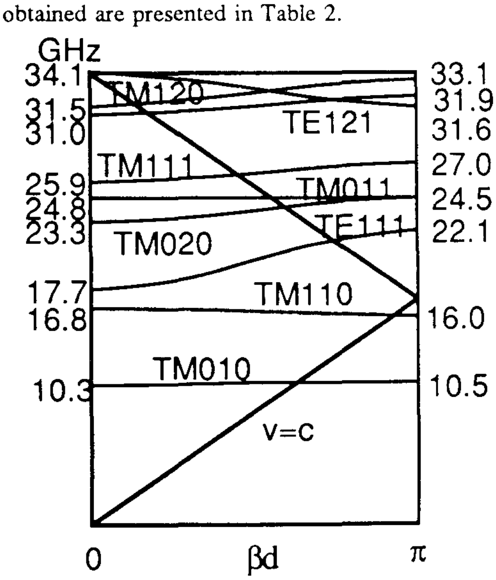

Fig. 1 Dispersion curves for disk-loaded structure for JLC.

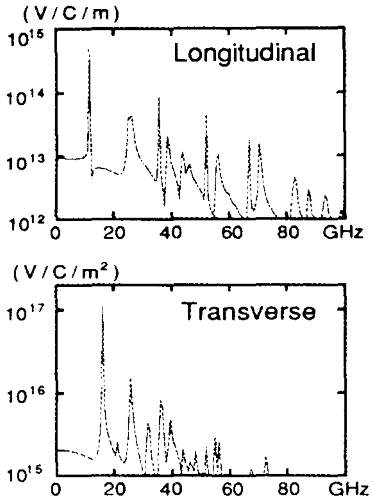

Fig. 2 Fourier transform of wake fields in structures for JLC.

Table 2 Wake field in the structure for JLC.

Mode	Frequency (GHz)	Long. Wake 10^{15}V/C/m	Qm	Q0	Qπ
TM010	11	0.5			
TM020&011	26	0.05			
TM021	36	0.09	270		
TM030	38	0.03			

Mode	Frequency (GHz)	Transv. wake 10^{17}V/C/m^2	Qm	Q0	Qπ
TM110	16	1.1	15	~0.2	20~25
TE111	21	0.03	70	16~30	~0.8
TM111	26	0.18	38		
TM120	32	0.06	72		
TM121	36	0.12	61		
TM130	39	0.05	96		

Qm: Maximum allowable Q values.

Q0,Qπ: Q values for the optimized structure.

Criteria on Q values

As shown in Fig. 2, the transverse wake field is mainly composed of the TM110 mode. By the arrival of the following bunch, the amplitude of the component decays by a factor Exp($-\omega_t T_b/2Q$), where ω_t is the angular frequency of the mode. Therefore, if the Q value of the mode is less than 15, the emittance growth originated from the injection error is limited within a factor of $\sqrt{2}$ and also the cavity misalignment tolerance increases up to 80μm for the case of JLC.[3] Maximum allowable Q values estimated in the same criterion as above are listed for the other higher modes in Table 2. If the frequency of some mode is tuned somehow, the tolerance for the mode becomes loose. However, tuning of all the components of the wake fields is actually impossible. Therefore, the reduction of the Q values for the transverse higher modes down to the values listed in table 2 is necessary.

The energy spread among 10 bunches due to the beam loading induced in the accelerating mode can be reduced by an order of magnitude compared to a single bunch beam loading and also a single bunch energy spread, while sacrificing a net accelerating gradient by about 7%. Those due to the other longitudinal higher modes can also be reduced to the same level if the amplitude of the wake field at the next bunch driven by the preceeding bunch is an order of magnitude smaller than that of the fundamental accelerating one. Among the mode listed in Table 2, the Q value of only the TM021 mode should be reduced down to 270 to satisfy the condition.

Q values of damped structure

The severest higher mode in the JLC accelerating structure against transverse emittance preservation is the component of the wake field which locates in TM110 passband. The phase differnece between the cells of the mode is very close to π. Therefore, the optimization of the geometry was performed to reduce the Q value of the TM110-π mode for the slotted disk-loaded structure, which is thought to be very effective to damp the mode.[9,10,11] The structure geometry and the parameters cited for the calculation are shown in Fig. 3. The cavity consists of two full cells with a slotted disk and two damping waveguides at the center of the cavity. The width of the waveguide wg is fixed to 11.1mm in both directions and the slot is ended at the interception of the waveguide and the accelerating cell. In an actual structure, these slots should be arranged at right angle from disk to disk as shown in Fig. 4 to make the slots effective to damp the transverse modes of both polarizations.

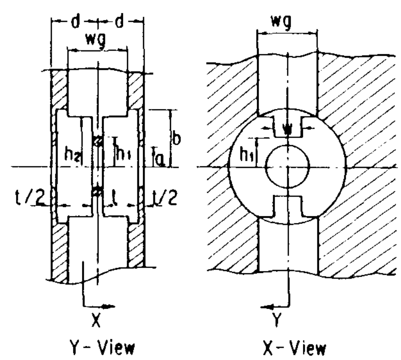

Fig. 3 Slotted structure geometry. Dimensions are as follows; a=3.6, b=10.6, t=2, d=8.75, wg=11.1 (units in mm).

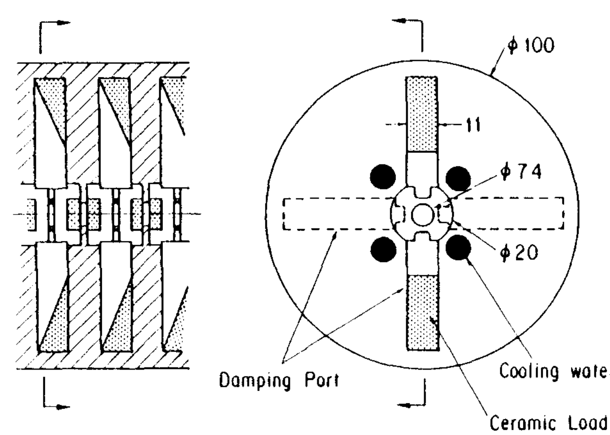

Fig. 4 Conceptual drawing of an actual damped structure.

The Q_{ex}'s were estimated using Slater's tuning curve method[12,13] where the resonant frequencies for various waveguide lengths were calculated by the code MAFIA.[14] As seen from the dispersion curves in Fig. 1, the nearest mode is TE111-0 mode, which appears in the boundary condition to calculate the TM110-π mode. This mode is separated from the TM110-π mode more than the width of the Q value if the Q value is larger than 10. Therefore, the Q_{ex} of the TM110-π mode was estimated from the steepest point of the tuning curve assuming that the Q_{ex}'s of both modes are larger than 10.

As shown in Fig. 5, the dependence of the Q_{ex}'s on the slot geometry shows a broad minimum at the slot height h=5.5 and slot width w=5.0. In this optimum geometry, the Q_{ex} is as low as 14. Even if any further modification was introduced such as slotting the disk through the beam hole or extending a disk as a ridged waveguide into some point in the damping port with or without a taper structure, the Q_{ex} was found only to increase. If the width of the damping waveguide wg is reduced from 11.1mm to 10.3mm, the minimum Q_{ex} increases to about 18. Therefore, we can expect lower Q_{ex} for wider damping waveguide port. However, the cutoff frequency of the waveguide with wg=11.1mm is already 13.5GHz and the width of the port cannot be simply widened to make the accelerating mode well confined within the accelerating cell. Therefore, this geometry is thought an optimum one at present as far as this kind of slotted structure is concerned.

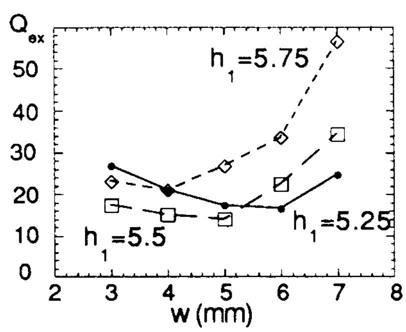

Fig. 5 Dependence of Q_{ex} of TM110-π mode on slot width w.

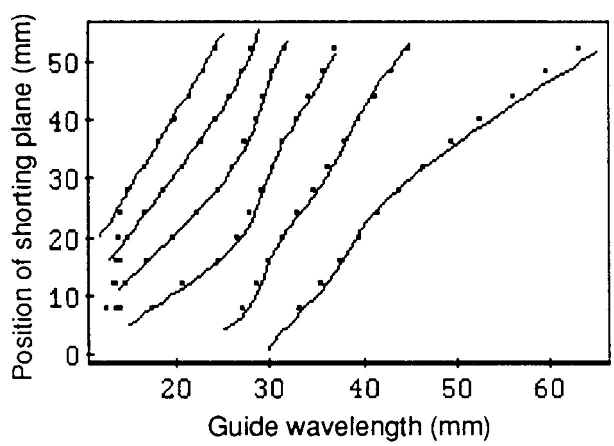

Fig. 6 Typical tuning curves. Solid curves are the results of fitting with two resonances.

For the optimized structure, the Q_{ex}'s of the higher modes were tried to evaluate. Because low Q resonances coexist in a small region of frequency, it was found important to apply the Slater's formulus

$$d = \frac{\lambda_g}{2\pi} \tan^{-1} \sum \frac{1/Q_{ex}}{(\omega/\omega_a)-(\omega_a/\omega)} + \frac{n}{2}\lambda_g$$

directly and to fit many branches of the tuning curves at once, where ω_a is a resonant frequency, d a distance from the reference plane to the shorting one, λ_g the guide wavelength and n a number of the nodes in the wave guide. Fig. 6. shows the tuning curves for the case including TM110-π mode. Solid curves are the results of the fitting with the parameters of Q_{ex}'s and ω_a's of two resonances, TE110-0 and TM110-π, and the position of a reference plane common to all branches. The disagreement at high frequency side is because of the neglect of the TM111-0 mode in the fitting. The Q_{ex}'s thus obtained are listed in Table 2.

Discussion

The Q_{ex} of less than 25 for the TM110-π mode in an optimum structure is rather high for the JLC. Therefore, other structures such as those with four slots in a disk or those of crossed guide structure[15] should probably be examined. However, it is also important to study how to analyze the tuning curves to obtain the Q_{ex} reliably enough to discuss the optimization of the geometry for the case of low Q modes with frequencies close with each other. The evaluation of the Q_{ex} of such modes as TM111, TM011 or TM020 is also needed and can be performed by a better fitting and more accurate tuning curves up to higher frequency.

The passband width of the accelerating mode for the optimized structure found 1.2% from the calculation by MAFIA. This value was smaller than that of 2.7% for the structure without damping slots and ports. This reduction is due to a magmetic coupling through the slots. The Q values of 0 and π mode in the fundamental accelerating passband were also calculated to be 0.91 and 0.76 of those without the slots and ports. This reduction of v_g and Q value considerably changes the parameters of the simple disk-loaded structure in Table 1 to the worse directions. Optimization of the geometry on the parameters of the accelerating mode should also be performed.

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