

HOM-FREE LINEAR ACCELERATING STRUCTURE FOR e^+e^- LINEAR COLLIDER AT C-BAND

T. Shintake, ¹K. Kubo*, H. Matsumoto, and ²O. Takeda

KEK: National Laboratory for High Energy Physics, Oho, Tsukuba, Ibaraki 305 Japan

¹SLAC: Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309 USA

²Toshiba Co., Yokohama, 230 Japan

HOM-free linear acceleration structure using the choke mode cavity (damped cavity) is now under design for e^+e^- linear collider project at C-band frequency (5712 MHz). Since this structure shows powerful damping effect on most of all HOMs, there is no multibunch problem due to long range wakefields. The structure will be equipped with the microwave absorbers in each cells and also the in-line dummy load in the last few cells. The straightness tolerance for 1.8 m long structure is looser than $30\ \mu\text{m}$ for 25% emittance dilution limit, which can be achieved by standard machining and braising techniques. Since it has good vacuum pumping conductance through annular gaps in each cell, instabilities due to the interaction of beam with the residual-gas and ions can be minimized.

I. INTRODUCTION

In the future e^+e^- linear colliders, multi-bunch beam operation is essential to get high luminosity. For the same reason, the spot size at the interaction point must be focused into quite small dimension, typically a few nanometer in vertical and a few hundred nanometer in horizontal. To achieve this small spot with multi-bunch beam, it is very important to accelerate low-emittance beam in the main-linac without deteriorating its emittance. Therefore, the wake-field problem in the linear accelerating structure is one of the most important R&D issue to realize the linear collider.

To solve this problem, the choke mode cavity was devised by the author[1]. The concept of this structure is explained in Fig. 1. This structure is made of many copper disks. There are gaps between disks, the beam induced wake-fields (or HOM: Higher-Order Modes) can easily get out from the cavity through the gap, and all of HOM oscillations disappear before the successive bunched beam coming. In order to trap only the accelerating mode inside the cavity, the choke is attached in the gap. Since the choke has sharp notch-filter response, only the selected mode, the accelerating mode in this case, is trapped. On the other hand, all of the HOM power can get out smoothly without reflecting at the choke. Therefore, this structure shows quite effective damping on all HOMs for wide frequency range. If we apply this structure to the main linac for the linear collider, emittance degradation problem due to the long-range wake field can be perfectly eliminated.

In order to demonstrate feasibility of this structure, a hot model of 0.5 m long constant-gradient structure at S-band was fabricated[2,3] in 1993. The completed structure was installed in ATF injector linac at KEK. The high power processing was smoothly performed, finally an average accelerating gradient of 50 MV/m was obtained with 120 MW input power[4]. There was no difficulty on processing due to high voltage break down or multipacting discharges. Also, the beam acceleration test was performed, and the energy gain of 26.2 MeV was observed at 104 MW input power, which was good agreement with the design value. With this success, the high power capability of this structure was fully proved.

The next step of the R/D program has been started in 1995, a C-band model of this structure is now under developing, in which HOM absorbers will be loaded in each disks and also in-line dummy load will be integrated at the last few cells. In this paper, status of this R/D is reported.

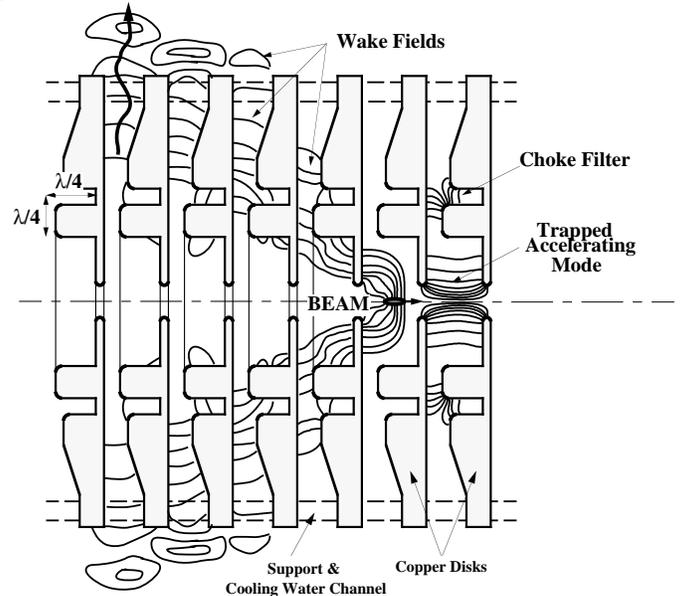


Fig. 1: Conceptual drawing of HOM-free linear accelerating structure using choke mode cavity.

II. C-BAND STRUCTURE DESIGN

We have proposed C-band rf system as one of the best solution to realize the large scale main linac for the e^+e^- linear colliders at 500 GeV to 1 TeV c.m. energy scale with minimum R/Ds and lower construction cost[5,6].

The designed parameter of the C-band structure is listed in Table 1, and its cross-sectional view is shown in

* Visiting from KEK

Fig. 2 The phase shift per cell is $3\pi/4$, whose unit cell length is slightly longer than the $2\pi/3$ mode, which make easy to get more room to fit the choke structure in each cell.

The average shunt impedance in this structure is 55 $M\Omega/m$, which is about 25% lower than that of conventional disk-loaded structure with same 2a, 2b dimensions. It does not mean we have to increase the input rf power by 25%. In a practical operation, the net accelerating gradient is always lowered due to the beam loading effect. This effect is smaller in lower shunt impedance structure, then the loss of the shunt impedance is somewhat compensated. In the C-band system, the pulse beam current is 0.57 A, and the beam loading effect is about 8 MV/m on the nominal accelerating gradient of 40 MV/m. To keep the same accelerating gradient in our structure of 25% lower shunt impedance, the input power has to be increased about 15%. Therefore, the power loss in the choke does not deteriorate the system efficiency so much. If we think about the big benefits of multibunch capability in this structure, this much of the power is not expensive.

Table-1 Electrical Parameters

Operating Frequency	f	5712 MHz
Phase Shift per Cell	βD	$3\pi/4$ TW
Structure Type		const. grad.
Wake field Control		Damping
Damping	Q_e	< 10
Length	L	1.81 m
Number of Cells	N	92 cells
Cell Length	D	19.68 mm
Filling Time	T_F	281 nsec
Attenuation Parameter	τ	0.53
Iris Aperture	a/λ	0.17 ~0.13
Group Velocity (%c)	V_g/c	3.5 ~1.2
Quality Factor	Q	9.5×10^3
r/Q		5.7 $k\Omega/m$
Shunt Impedance	$\langle r \rangle$	55.0 $M\Omega/m$
Accelerating Gradient at 80 MW input		
Accelerating Gradient(1)	E_a	40 MV/m
RMS Straightens Tolerance(2)		$35 \mu m/92$

1) Unloaded gradient for 500 GeV c.m. case.

2) Tightest tolerance on structure straightens over N cells.

III. MICROWAVE ABSORBERS

In the S-band high power model, we did not install the microwave absorber, because the main object in the test was demonstration of the high power capability of this new type of rf cavity. In the C-band structure design, we started R/D study on the microwave absorbers, including survey of material, its quality control, optimization of structure to meet rf matching, and brazing process.

Engineering ceramic of SiC has already been used as microwave absorber. H. Matsumoto developed the first model of waveguide dummy-load for S-band microwave in

1981, and nearly 200 units of this dummy load were successfully used in KEK PF injector linac[7]. Recently, he developed a high-peak power model which can handle 50 MW, 1 μ sec at S-band, in which disk shape SiCs($\phi 20$ mm) were directly attached on copper waveguide by brazing. T. Koseki et. al.[8] have recently applied a SiC duct to HOM-damper on beam pipe close to an rf accelerating cavity. They reported the SiC duct made by Toshiba CERASIC-B (resistivity of 20 Ωcm) strongly reduced the Q-values of HOMs in the cavity. Because of these experiences, and also its good vacuum property we will employ SiC in our structure.

We use disk shape SiC (CERASIC-B) of $\phi 15-20$ mm, directly attach them on each cell by brazing as shown in Fig. 2. The skin depth in SiC becomes 3 mm at C-band frequency, and the effective surface resistance becomes 6 Ω , which is same order as the characteristic impedance 5 Ω of TEM wave in the radial line at radius of 6 cm with 5 mm gap. Therefore the wakefields will be effectively absorbed in SiCs due to ohmic loss of the wall current.

IV VACUUM CHAMBER DESIGN

In order to simplify the vacuum chamber and reduce number of the components, we will implement the in-line dummy load in the last few cells by coating the cavity with high resistivity metal. This technique has been used long time in medical accelerators[10].

The vacuum conductance from beam line to the tank is quite large, the structure can be pumped down to very low pressure level quickly. This is quite important feature, because recent studies[9] are indicating the existence of new type instability due to wakefield like effect by trapped ions in the residual gas, which can cause emittance dilution in the main linac or in the bunch compressor.

V. CELL COOLING

Since this structure has to be used at high accelerating gradient and high repetition frequency in the liner collider, the cell cooling is one of the most important issue in practical usage. The expected maximum heat-dissipation per unit length is 3.2 kW/m. We assumed cooling water flow of 126 litter/min., and its temperature 21 deg.C, which flows along six cooling water channels of 12 mm inner diameter. We estimated heat dissipation density using SUPERFISH code, then put in these data into I-DEAS code to simulate the heat flow inside the copper-disk and heat transfer into the cooling water. According to this simulation, the maximum temperature at the top of the iris reaches 35.4 deg.C. This is quite high as compared to the traditional design of disk-loaded structure. We will implement a feedback loop which measures the rf phase at the end of the structure, and control the cooling water temperature and also the klystron input phase.

VI. ALIGNMENT TOLERANCE ON ACCELERATING STRUCTURE

The alignment tolerance of accelerating structures can be estimated from an analytical expression of emittance growth. Expected emittance growth due to random misalignment of accelerating structures is approximately[11]

$$\langle \Delta \varepsilon \rangle = \frac{e^2 q^2 x_{rms}^2 W_{rms}^2 \beta_0 L_a (E_f^\alpha - E_0^\alpha)}{2\alpha E_f E_0^\alpha g} \quad (1)$$

where q is total charge, x_{rms} the r.m.s. of misalignment, β_0 initial averaged beta function, L_a length of each structure, E_f final energy, E_0 initial energy, g accelerating gradient and beta-function is assumed to be proportional to E^α , where $\alpha = 0.5$. W_{rms} is the r.m.s. of the wakefield effect and

$$W_{rms}^2 \approx 0.91 \frac{W_s'^2 \sigma_z^2}{\pi} \quad (2)$$

for a single Gaussian bunch, where σ_z is bunch length. W_s' is slope of the transverse wake function which is assumed to be a linear function of distance and estimated as

$$W_s' \approx 1.35 \times 10^{19} \text{ V/C/m}^3 \quad (3)$$

for structures with the aperture radius of 7.77 mm or a/λ of 0.148. Because of the strong damping ($Q < 10$) in our structures, the multi-bunch effect due to the long range wakefield will be negligibly small compared with the single-bunch effects.

We estimated the tolerance for a bunch with 1.1×10^{10} particles and the r.m.s. length of 120 μm [6]. We assumed a linac with the same lattice as the 500 GeV (beam energy 250 GeV) NLC (Next Linear Collider, being designed at SLAC) linac[11], assuming the same beta at the same energy, except different injection energy : 20 GeV in our case and 10 GeV in NLC. The tolerance is 30 μm for each 1.8 m long structure to achieve emittance growth of less than 25%. The tolerances for various length of alignment unit are also estimated by scaling from NLC using a numerical method, which is shown in Fig. 3 comparing with the tolerances for the NLC structures[12]. Because the multi-bunch effect is negligible for our structures, the straightness tolerance of in each structure is lower than the alignment tolerance of each whole structure, which will be achieved by conventional machining and braising techniques.

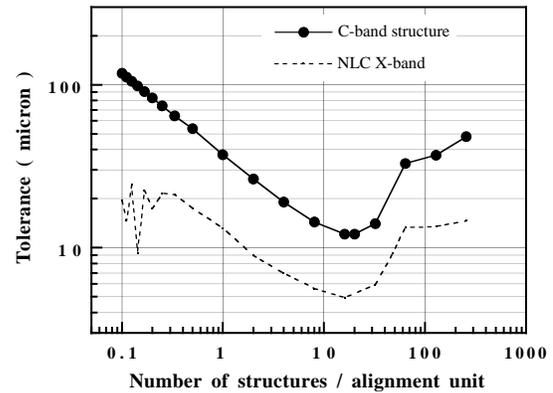


Fig. 3 Alignment tolerance for C-band HOM-free structure comparing with NLC damped-detuned structure.

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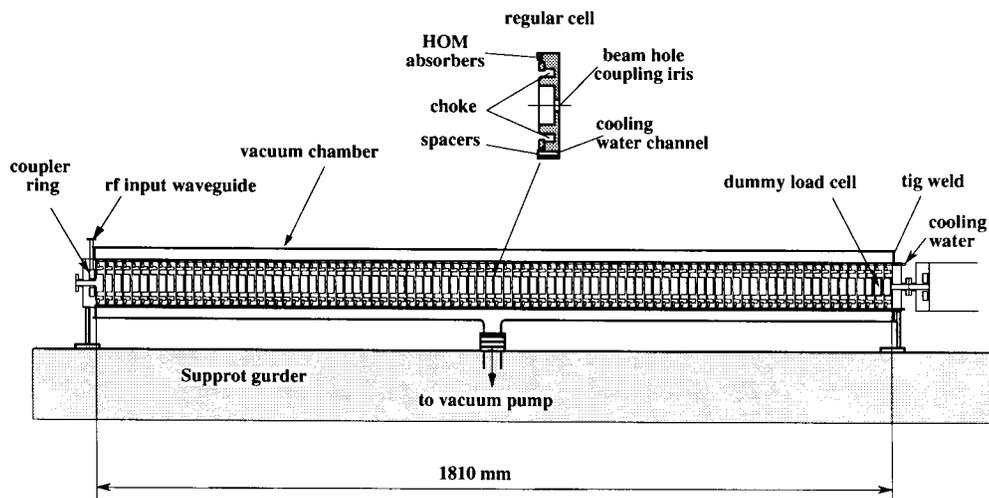


Fig. 2 HOM-Free C-band Structure