High Power Test of HOM-Free Choke-Mode Damped Accelerating Structure

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Abstract

High-power test of a damped accelerating structure using the choke-mode cavity has been performed. The structure was processed by pulsed S-band RF power up to 120 MW, and accelerating gradient of 50 MV/m was achieved. The structure demonstrated excellent high-power capability, and no HV break-down nor serious dark-current flow was observed after the processing. Electron beam was accelerated in this structure, and a design energy gain of 26 MV was observed. The beam-induced wake-field was measured using a pick-up antenna. Its spectrum indicated effective damping of HOM-power in this structure.

Introduction

In the future e^+e^- linear colliders, multibunched beam operation is essential to get high luminosity. For the same reason, the spot size at the interaction point must be quite small, for example a few nanometer in vertical and a few hundred nanometer in horizontal. To achieve this small spot by 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 by piling up many copper disks. Since there are spacing between disks, the beam induced wake-fields (or HOM : higher-order modes) can easily get out from the cavity by propagating through the slot, 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 loaded in the slot. Since the choke has sharp notch-filter response, the selected mode, the accelerating mode in this case, is trapped. On the other hand, all of the HOM power can go out without large reflection at the choke. Therefore, this structure shows quite effective damping on HOMs for wide frequency range[1]. If we apply this structure to the main linac for the linear collider, emittance degradation problem due to the long-range wake field will be perfectly eliminated.

However, since the choke has a narrow gap, a question arose, "multipacting discharge or a high voltage breakdown can happen in the gap?" Another question was "can we really establish a traveling-wave mode using this cavity?", because the choke will limit some fraction of the bandwidth. In order to answer to those questions, a hot model of the choke-mode linear accelerating structure has been fabricated, and tested by S-band pulsed high-power rf.

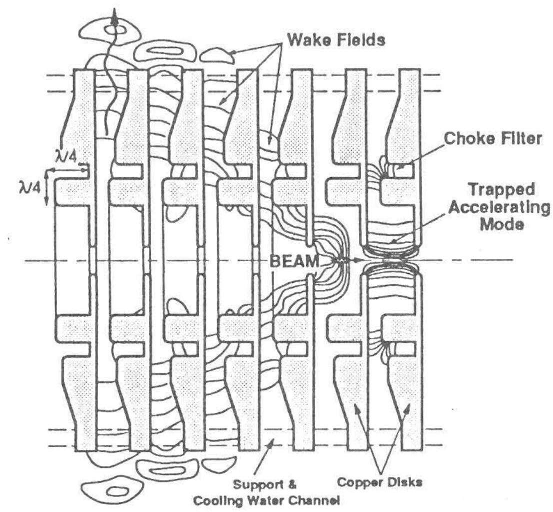

Fig. 1 Concept of the HOM-free choke-mode accelerating structure.

Structure Parameters

The completed structure is shown in Fig. 2. The structure is made by piling up copper-disks with inserting spacers, and braised in vacuum. The detailed fabrication process and cold test are explained in ref. 3 in detail. Parameters are listed in Table-1. The structure consists of 12 regular-cells with damping slots and input and output coupler-cells. The beam hole 2a is 24 mm for all cells to form a constant-impedance structure. In order to get enough space for the choke, the $3\pi/4$ mode was used. In this mode, we can use longer space about 5 mm for the choke than that in the conventional $2\pi/3$ mode. If we input 100 MW peak rf power, the accelerating gradient of 46.1 MV/m will be generated in the structure.

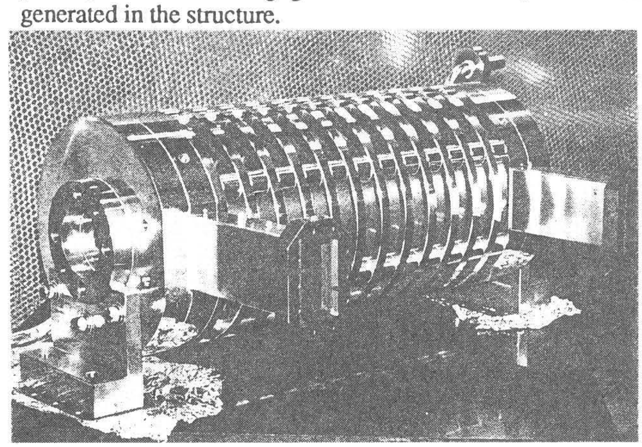

Fig. 2 Completed hot-model damped accelerating structure.

Table-1
Electrical Parameters

Operating Frequency	$f0$	2856.0	MHz
Phase Shift per Cell	βD	$3\pi/4$	
Number of Cells	N	14	cells
Impedance	CI : constant impedance		
Active Length	L	551	mm
Aperture	$2a$	24.0	mm
Quality Factor	Q0	12000	
Group Velocity	Vg/c	0.0084	
Shunt Impedance	r	42.0	MΩ/m
Attenuation Parameter	τ	0.16	
Filling Time	TF	220	nsec
Accelerating Gradient at 100 MW input			
Average Accelerating Gradient	E_a	46.1	MV/m
Energy Gain	V	25.4	MV

High Power Test

The completed structure was assembled into a vacuum tank of 550 mm inner-diameter and 850 mm length. Then the structure was installed into the beam line of the ATF injector as shown in Fig. 3. No microwave absorbing materials were equipped in the tank at this test. The rf power was fed from the klystron through a stub tuner to compensate the power reflection from the mismatched input coupler. The dark current was monitored by the Faraday cup after the analyzer magnet. The wake field power was monitored by an pickup antenna mounted on a viewing port.

Fig. 4 shows the history of the high-power rf processing. The input power reached 50 MW after 140 hours processing. The rf pulse width during this period was 1 µsec, and repetition was 12.5 Hz. Then the operation mode was switched to high peak-power compressed pulse mode. The klystron output pulse was compressed to 1 µsec width by SLED type pulse compressor. After 100 hours processing, the input peak power reached to 120 MW.

The input and output RF-pulse waveforms are shown in Fig. 5, at the input power of 40 MW. The output power shows flat waveform, which indicates no HV breakdown inside the structure. The ripples after the rise and fall of the pulse are caused by reflection from the input and output couplers, because the tuning of the input and output couplers was not optimum as described in ref. 3.

Beam Acceleration Test and Wake Field Measurement

When the input power reached to 104 MW, the beam acceleration was tested. The electron beam of 80 MeV was injected into the structure, and the accelerated beam energy was measured by the analyzer magnet. The observed energy gain was 26.2 MeV. This is quite good agreement with the expected value of 25.9 MeV.

By injecting short pulse electron beam, the wake field spectrum was measured. Since the beam induced HOM power can get out from the structure, we can directly observe it using a pick-up antenna mounted on the vacuum tank. In order to clearly observe the HOM power, the acceleration rf power was turned-off in this measurement. Fig. 6 shows the expected and measured wake-field spectrums. Since all of HOM modes in the choke-mode cavity are heavily damped, the beam induced HOM-power does not have evident resonative structure, that is, it becomes simple white-spectrum. But the choke has notch-filter response at S-band acceleration frequency, and 3rd resonance at 9.5 GHz, thus the observed HOM power spectrum should have notches at these frequencies. The pulse length of the electron beam is 1.7 nsec FWHM, and there are several number of bunches in one pulse. Thus the beam spectrum has periodic peaks at harmonics of the acceleration frequency. The expected wake field spectrum was obtained by multiplying the beam spectrum with the notch filter response of the choke and the high-pass filter response of the viewing port, whose cutoff frequency is 2.8 GHz. In the measured spectrum, the narrow resonances at 2.2 GHz are the tank resonances. Also, narrow ripples overlapping everywhere on the spectrum are caused by the tank resonances. As shown in Fig. 6, the envelop of the measured spectrum agreed with the theoretically expected spectrum. This indicates most of all HOMs are effectively damped by the slot.

Discussion & Future Plan

In this test, high power capability of the choke mode accelerating structure has been demonstrated experimentally.

The next step is to establish realistic models, that is, we will fabricate 1 to 2 meter long structures of constant-gradient at higher frequency band. We will implement microwave absorbers inside the vacuum tank, and study the HOM-damping performance.

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References

1. T. Shintake, "The Choke Mode Cavity", Jpn. J. Appl. Phys. Vol. 31 (1992) pp.L1567-L1570, Part 2, No. 11A. 1 Nov. 1992
2. T. Shintake, "Design of High Power Model of Damped Linear Accelerating Structure using Choke Mode Cavity", proceedings of 1993 Particle Accelerator Conference, Washington, D.C., U.S.A., May 1993, pp. 1048 - 1050, KEK Preprint 93-27, May 1993 A
3. A. Miura, et. al., "Fabrication of HOM Free Linear Accelerating Structure using Choke-Mode Cavity for Japan Linear Collider", contributed to this conference.

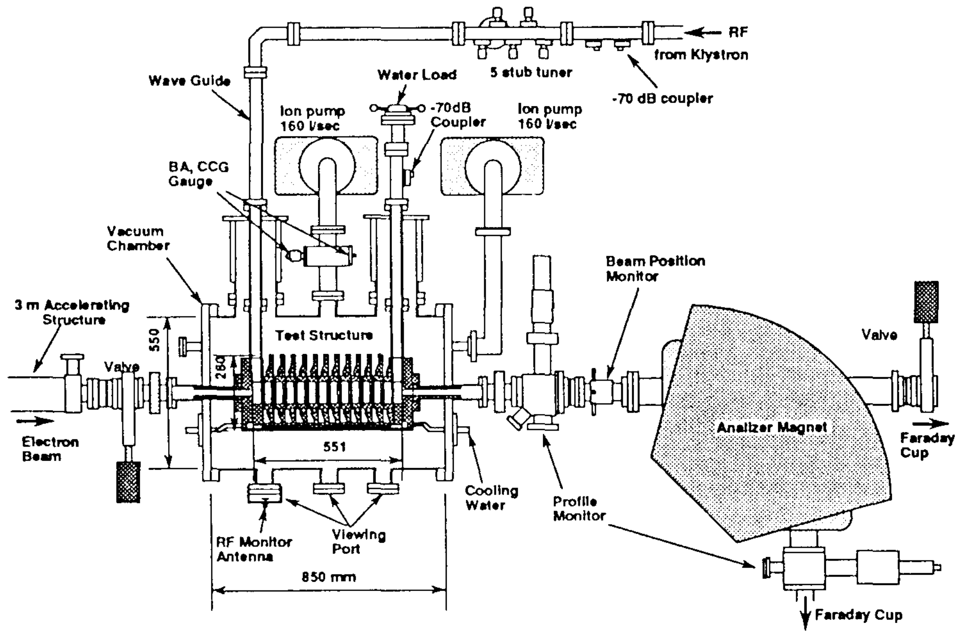


Fig. 3
Experimental setup.

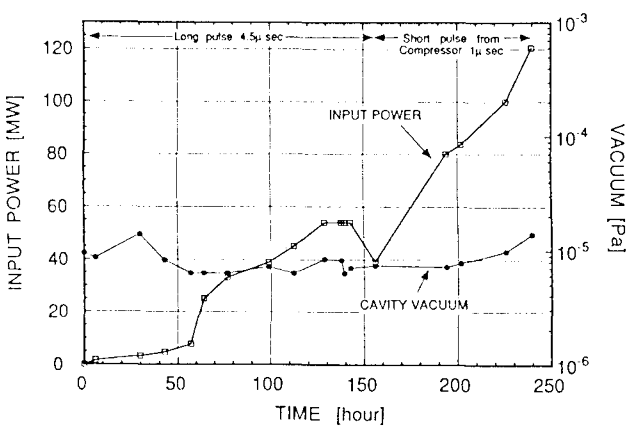
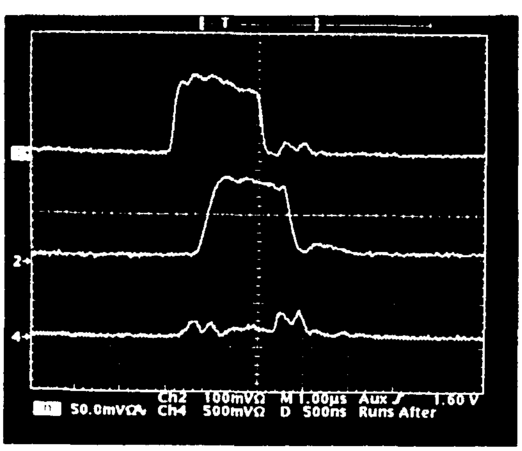


Fig. 4 RF processing history.



40 MW

Fig. 5 RF pulse waveforms of input (upper), output(middle) and input reflection (lower).

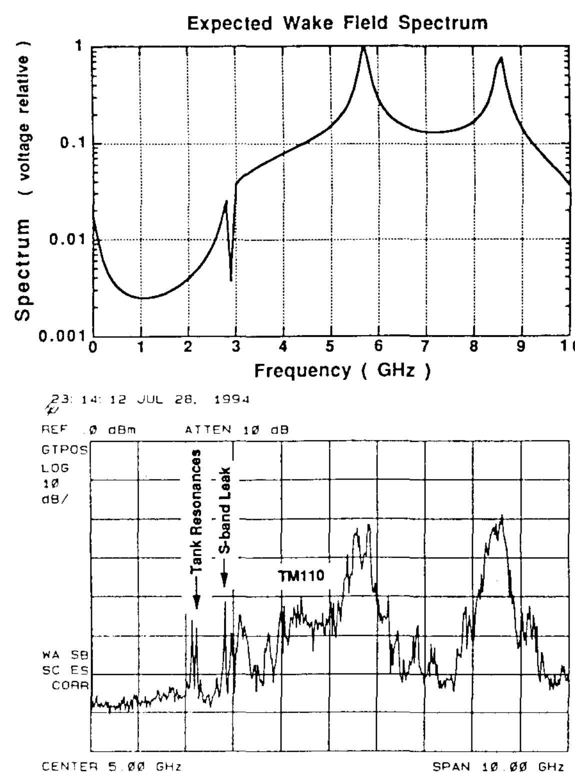


Fig. 6 Wake field spectrum.
Theoretically expected (upper) and measured (lower) spectrum.