Proceedings of the Linear Accelerator Conference 1990, Albuquerque, New Mexico, USA

HIGH-GRADIENT EXPERIMENT OF THE S-BAND ELECTRON LINAC

H. Matsumoto, M. Akemoto, H. Hayano, T. Naito and S.Takeda
KEK, National Laboratory for High Energy Physics
Oho 1-1, Tsukuba - shi, Ibaraki - ken 305, Japan

Abstract

The electron beam has been accelerated by the field gradient up to 85 MV/m with input peak current of 1 A and pulse width of 0.2 µsec successfully. The accelerating structure is a traveling wave 0.6 m-long constant gradient disk-loaded type at S-band. The output power of two klystrons was combined and fed into the structure. The output power of each klystron was 72 MW with 1µsec RF pulse duration at 50 Hz.

Introduction

The accelerating gradient of the Japan Linear Collider (JLC) is 100 MV/m for the X-band main linac and 50 MV/m for the S-band injector and the pre-accelerator[1]. In order to realize such a high gradient, we have started the construction of an accelerator test facility (ATF) in 1987, which is mainly composed of a 1.5 GeV S-band linac, a damping ring and a 1 GeV X-band linac[2]. As a first step, the construction of an injector part of the S-band linac has been already completed as shown in Fig. 1, which makes it possible to accelerate a single bunch beam of $5x10^{10}$ electrons and high current multi-bunches at high accelerating gradient.

Experimental studies on the upper limit of the electric field strength in conventional disk loaded structures and single cavities have been reported from several laboratories[3-8], though without the beam acceleration and mostly by standing wave structures. It was then decided to launch further studies on beam behavior under high accelerating fields in disk loaded structures.

General layout of the injector

The injector consists of a 240 kV thermionic electron gun[9], three subharmonic bunchers (119 MHz, 238 MHz and 476 MHz), single gap double prebunchers, a traveling wave buncher and an S-band constant gradient disk-loaded structure with length of 0.6 m as shown in Fig. 1. The SHB's are not used in this experiment. The SHB's, the prebunchers and the buncher are installed in the 25 Helmholtz coils whose current can be controled independently. The distribution of the axial magnetic field can be tapered from 150 Gauss to 700 Gauss so that the beam flows in Brillouin condition.

The support system of the injector consists of a 9 m long and 0.67 m wide table made of SUS316-L. The flatness of the table surface is 36 µm/9 m. All the components can be aligned easily within 100 µm accuracy.

In order to generate the maximum accelerating gradient of 100 MV/m, the output power of two 100 MW klystrons is combined and fed into the structure as shown in Fig. 2. RF output power of 200 MW with RF phase deviation and amplitude variation in the combined output was held to less than 2 degrees and 1% during any pulse, respectively. The klystron modulators[10] have been developed in KEK to drive the klystrons, SLAC 5045 and TOSHIBA E3712[11]. A small fraction of the combined power is used to feed the prebunchers and the buncher. The input RF power and the phase to the prebunchers, the buncher and the 0.6 m structure are controled by using a computer system[10].

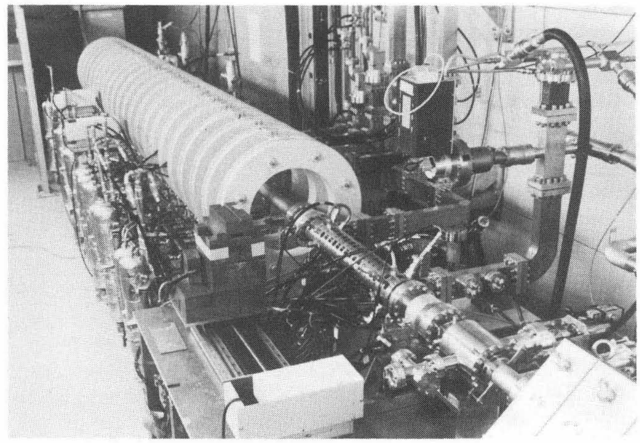


Figure 1 A photograph of the Accelerator Test Facility viewed from downstream.

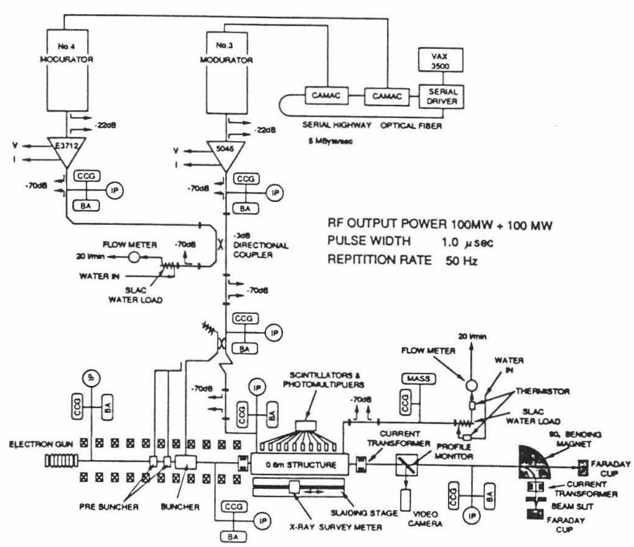


Figure 2 A schematic diagram of the experimental setup

Experimental Setup

The 0.6 m structure is a $2\pi/3$ traveling wave constant gradient type with 17-cells, input and output couplers. The disks and cylinders were machined from OFHC blocks with diamond bite. The surface roughness of the beam hole is less than 0.2 µm and that of the flat surface is less than 0.02 µm. The vacuum tightness and a good electrical contact are obtained by brazing process in hydrogen atmosphere.

The parameters of the structure to obtain the gradient of 100 MV/m at input RF power of 195 MW are given in Table 1. From these parameters, the accelerating field without beam can be calculated in the following way:

$$E_{acc}\,(MV/m) = 7.16 \times \sqrt{P_{in}\,(MW)} \qquad (1)$$

where P_{in} is the input RF power in MW.

TABLE 1
Parameters of the 0.6 m structure

Phase Shift/Cell	2π/3	Constant Gradient
Structure Length	66.5	cm
Iris Diameter 2a		
in	1.8998	cm
out	1.5900	cm
Cavity Diameter 2b		
in	8.172	cm
out	8.124	cm
Resonant Frequency f	2856	MHz at 36.5°C, VAC
Quality Factor Q	11600	
Shunt Impedance r	62	MΩ/m
Attenuation Constant α	0.48	Neper/m
Average Group Velocity vg/c	0.00445	
Filling Time Tf	0.475	μsec

The RF power of both the forward wave and reflected wave was monitored by dual Bethe-hole couplers with a coupling ratio of -70 dB. The transmitted power through the 0.6 m structure was monitored by also a Beth-hole coupler and terminated by the SLAC RF water load. The momentum of the accelerated beam is measured with a magnetic spectrometer. The peak current and pulse shape of the beam were monitored by two current transformers at the upstream and downstream of the 0.6 m structure. A beam profile monitor using a luminescent ceramic is mounted downstream of the 0.6 m structure.

Experimental procedure and result

The injector including the waveguides are pumped down to 5×10^{-9} Torr by five 60 l/s ion pumps and three 160 l/s ion pumps. The vacuum pressure is monitored by the cold cathode gauges (CCG) and the BA gauges. CCG's are used for the interlock system of the vacuum during the RF operation. The interlock level is set at 2×10^{-7} Torr. The vacuum pressure of the injector has been kept around 2×10^{-8} Torr.

After processing the accelerating structure up to 60 MV/m, the structure was exposed in atmosphere for one week to replace the experimental setup. Then it was evacuated again and reprocessed starting from several MV/m to 70 MV/m for 170 hours as shown in Fig. 3 before the beginning of the beam acceleration.

First beam acceleration was started at 50 MV/m and the accelerating gradient was increased up to 70 MV/m without any serious problem. However, it took considerably long period to reduced the rate of the breakdown and dark current at 70 MV/m since the structure was not processed above the level. The accelerated beam current was 0.9 A and pulse width was 0.2 μsec. Figure 4 (a) shows the pulse shape of RF and beam current. The second peak appearing in curve (2) of Fig.4 is due to the dark current. Figure 5 (a) is momentum spectrum of the accelerated beam. Since the emittance of the dark current is large, only a small peak is observed around 3 MeV/c in the Fig. 5 (a). The beam profile seen on the profile monitor is shown in Fig. 6. In this profile, the core part and the outer ring correspond to the accelerated beam and the dark current, respectively. Accelerating gradient was raised to 80 MV/m after one day processing. After futher RF processing for 120 hours, the beam was accelerated at 85 MV/m which is the maximum gradient in the present experiment. The current was 0.9 A and the pulse was 0.2 μsec. Figure 4 (b) and Fig. 5 (b) show the pulse shape of RF, beam current and momentum spectrum. At these gradients above 80 MV/m, dark current is very heavy and RF breakdown takes place frequently as is given elsewhere[13].

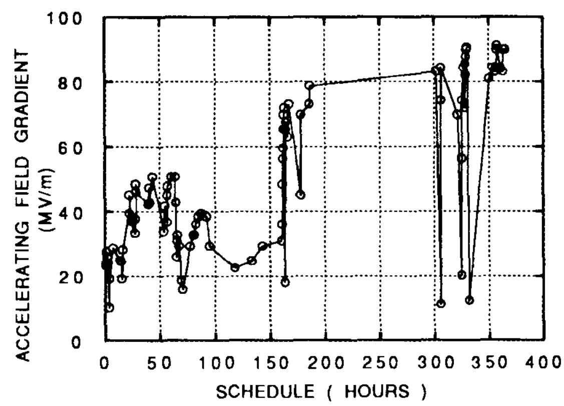
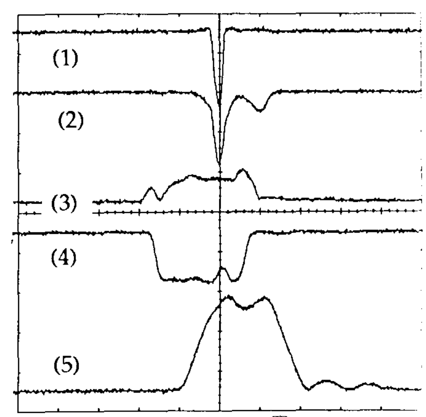
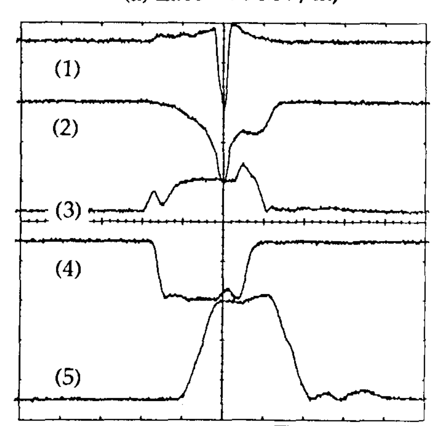


Figure 3 RF processing history for the 0.6 m structure.

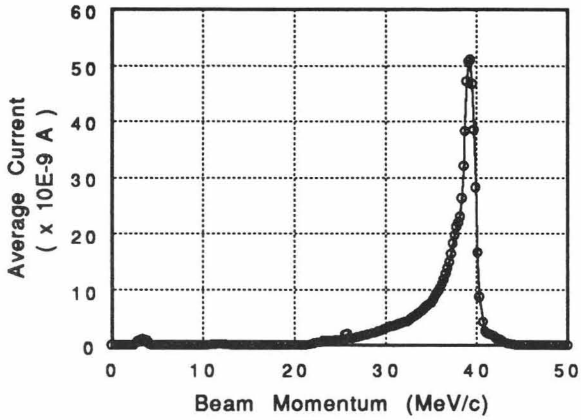


(a) Eacc = 70 MV/m,

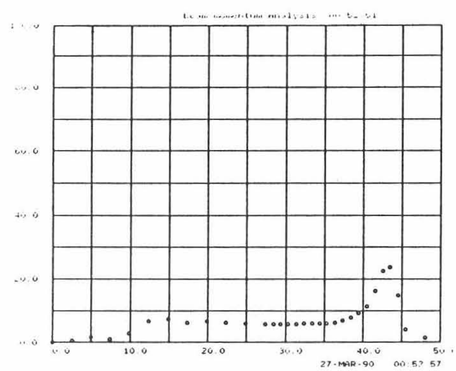


(b) Eacc = 80 MV/m

Figure 4 Pulse shape of RF and beam current.
1) Input and 2) output current of the 0.6 m structure, 3) reflected RF from the prebuncher, 4) transmitted RF of the buncher and 5) the 0.6 m structure.



(a) Eacc = 70 MV/m,



(b) Eacc = 80 MV/m

Figure 5 Momentum spectrum of the accelerated beam.

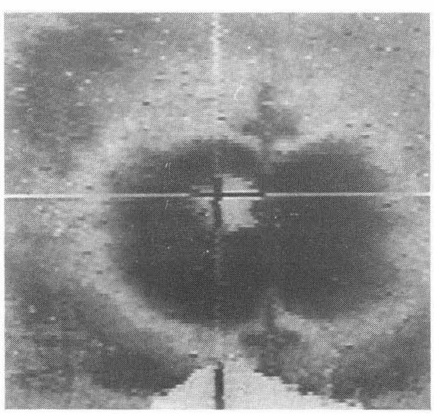


Figure 6 Beam profile

SUMMARY

We have achieved the acceleration of the electron beam of 0.9 A and pulse width of 0.2 µsec by the 0.6 m structure at the gradient of 85 MV/m. At this gradient, the dark current is very heavy and breakdown occurs frequently. However, at 70 MV/m, beam acceleration is fairly stable. It seems feasible to operate the accelerating structure at this gradient for the practical use after a reasonable processing period.

It is confirmed that the operation of 50 MV/m at S-band is quite promising. This level corresponds to 100 MV/m at X-band which meets requirement of the JLC.

REFERENCES

1. K.Takata, "The Japan Linear Collider",Proc. of the Linear Accelerator Conference (Albuquerque, USA), 1990.
2. S.Takeda, et al., "Jpan Linear Collider", Proc. of the Particle Accelerator Conference (Tsukuba,Japan) 1989.
3. G.A.Loew and J.W.Wang, "RF Break Down and Field Emission", SLAC-PUB-4845,Jan. 1989
4. E.Tnabe, "Voltage Breakdown in S-band Linear Accelerator Cavities", IEEE Trans.NS-30, No.4,(1983)3551
5. E.Tnabe, "Breakdown in High-Gradient Accelerator Cavities", Proceedings on 8th Linear Accelerator Meeting Held at Institute for Nuclear Study University of Tokyo,July 1983
6. A.H.Mceuen, et al., "High-Power Operation of Accelerator Structure at Liquid Nitrogen", IEEE Tarns. NS-32, No.5(1985)2972
7. H.Matsumoto et al.,"RF Breakdown Studies on an S-band Disk Loaded Structure", Proc. of the IEEE Particle Accelerator. Conference (WashingtonDC) 1654,1987
8. H.Matsumoto et al., "RF High Gradient of an S-band 0.6 m Disk Loaded Structure",Proc. of the Particle Accelerator Conference (Tsukuba,Japan) 1989.
9. M. Akemoto, "Electron Gun of the Accelerator Test Facility", Proc. of the Linear Accelerator Conference (Albuquerque, USA), 1990.
10. M.Akemoto et al., "Klystron Modulator with HV Common-Bus for the JLC", Proc. of the Linear Accelerator Conference (Albuquerque, USA), 1990.
11. H.Yonezawa, et al., "Development od A 100 MW S-band Klystron", Proc. of the Particle Accelerator Conference (Tsukuba,Japan) 1989.
12 H.Hayano, et al., "Control System of ATF", Proc. of the Linear Accelerator Conference (Albuquerque, USA), 1990.
13. S.Takeda et al., "High Gradient Experiment by Accelerating Test Facility for Japan Linear Collider", Proc. of the Linear Accelerator Conference (Albuquerque, USA), 1990.