HIGH GRADIENT EXPERIMENT BY ACCELERATOR TEST FACILITY FOR JAPAN LINEAR COLLIDER

Seishi Takeda, Mitsuo Akemoto, Hitoshi Hayano, Takashi Naito and Hiroshi Matsumoto

National Laboratory for High Energy Physics
Oho 1-1, Tsukuba, Ibaraki 350, Japan

Abstract

High gradient experiment by using a traveling wave structure in S-band frequencies is presented. Discussions are given about the dependence of dark current and structure length. As one of the parameters indicating the quality of the structure, the multiplication factor η has been proposed.

Introduction

For the e^+e^- linear colliders in TeV energy region such as the Japan Linear Collider (JLC), the accelerating gradient will be one of the important parameters affecting the over all design of main linacs. The gradient determines the accelerating structures, RF frequencies, peak power, AC power, total length and cost. The gradient of 100 MV/m is desirable to construct a 1 TeV linear collider with the reasonable length of 10 km. For the existing high energy linacs, the gradients are 10 to 20 MV/m, and 2.856 GHz is utilized as the standard RF frequency. The experimental studies on the maximum attainable accelerating gradients in standing-wave structures have been performed by several authors.[1-2] The experimental results show that the measured maximum surface electric field E_{smax} is a function of frequency for 1.5 to 4 μs RF pulse length,

$$E_{smax} \cong 195 \mid f(GHz) \mid^{1/2}.$$

For the traveling wave structures, the ratio of the surface field and accelerating field is 1.9 to 2.2. The maximum accelerating gradient E_{amax} at the RF breakdown limit is estimated to be 150 MV/m at 2.856 GHz. The higher RF frequencies are preferable to obtain high gradient. The frequencies of 11.424 GHz in X-band have been chosen for main linacs for the JLC project. The peak power of 120 MW is required to produce the gradient of 100 MeV/m in 0.7 m-long X-band traveling structure for the JLC main linacs. A prototype X-band klystron has been developing to generate 30 MW peak power with 1 μs pulse duration.[3]

RF Sources for High Gradient Experiment

Experiments reported several authors[1-2] utilize the standing wave structures of one or a few cavities since the extremely high power RF sources are unavailable. However, the understanding of dark current phenomenon in long traveling structures is necessary to determine the maximum gradient that can be obtained and used realistically. In order to produce the gradient of 100 MV/m, the required peak power per unit length is 300 to 350 MW/m at S-band frequencies and 150 to 175 MW/m at X-band frequencies. At present, such extremely high peak power can be obtained at S-band frequencies.

Experimental Set-up

Figure 1 shows the experimental set-up. The peak power of 100 MW can be produced by a 67 MW SLAC-5045 klystron or 85 MW Toshiba-E3712 klystron at 450 kV cathode voltage and 1 μs pulse duration. The peak power of 200 MW can be produced by means of a 3 db coupler combining the rf power from two klystrons. The accelerating gradient of 100 MV/m can be obtained in 0.6 m-long traveling structures at 200 MW rf input.

The 0.6 m long constant gradient disk-loaded structure with 17 cells and 2 couplers. The diameter of disk aperture 2a is decreased from 19.0 to 15.9 mm along the structure. The average shunt impedance is 61.2 MΩ/m and figure of merit Q is 11,600. The attenuation constant τ is 0.37 and the filling time t_f is 0.47 μs. The material of the structure is 1st class OFHC. The surface roughness of both the disks and cylinders are 0.02 μm except the rounded irises where the surface roughness is 0.2 μm. The gradient of 100 MeV/m can be obtained at 200 MW RF input. The result of simulation by SUPERFISH shows that the peak surface electric field around the rounded iris is about 2.0 times higher than the average accelerating gradient. The klystron modulators are operated at 50 Hz repetition rate and the average power dissipation in the structure is estimated to be 5.2 kW. The cooling water flow through the pipe drilled in the cylindrical wall. The structure without water jacket gives rise to precise alignment of the structure. The axis of disk apertures can be estimated by measuring the position of the outer wall of the structure.

Faraday cups and current transformers are utilized for measuring the dark current at both the downstream and upstream of the structure. The energy spectrum of the dark current is measured by an analyzer magnet.

The X-ray bursts due to the dark current are measured by ten plastic scintillators installed on the surface of the structure and photo multipliers and a 8 channel oscilloscope.

RF Processing

The gradient was increased by rf processing controlled the rf power to maintain the vacuum pressure below 1 x 10^{-7} Torr by a computer system. The accelerating gradient was achieved to 35 MeV/m after 60 hours of rf processing. The field emitted current except low energy region decreased after 90 hours, and gradient of 50 MeV/m could be attained after 200 hours. The total dark current generated in the structure is measured by the Faraday cup. The field enhancement factor β estimated from modified Fowler-Nordheim plots decreases from 90 to 66 by the rf processing of 300 hours. The accelerating gradient of 90 MV/m could be obtained at 160 MW rf input after 800 hours of rf processing.

Dark Current Measurement

The transient analysis of the dark current has been reported.[4] The experimental results show that the bursts of both the current waveform and X-ray are detected simultaneously with the RF front arrival to the output coupler. It seems to be considered that the RF breakdown due to multipactoring is produced near the coupler iris.

Figure 2 shows the energy spectrum of total dark current. The main portion of the total dark current is generated in the output coupler. However, the dark current from the structure can be obtained by eliminating the low energy components of the energy spectrum.

Figure 3 shows the field enhancement factor β estimated from modified Fowler-Nordheim plots. For the total dark current, enhancement factors (β = 66) agree with the measurement by means of Faraday cup. The field enhancement factor in the structure except output coupler is evaluated to be 39.

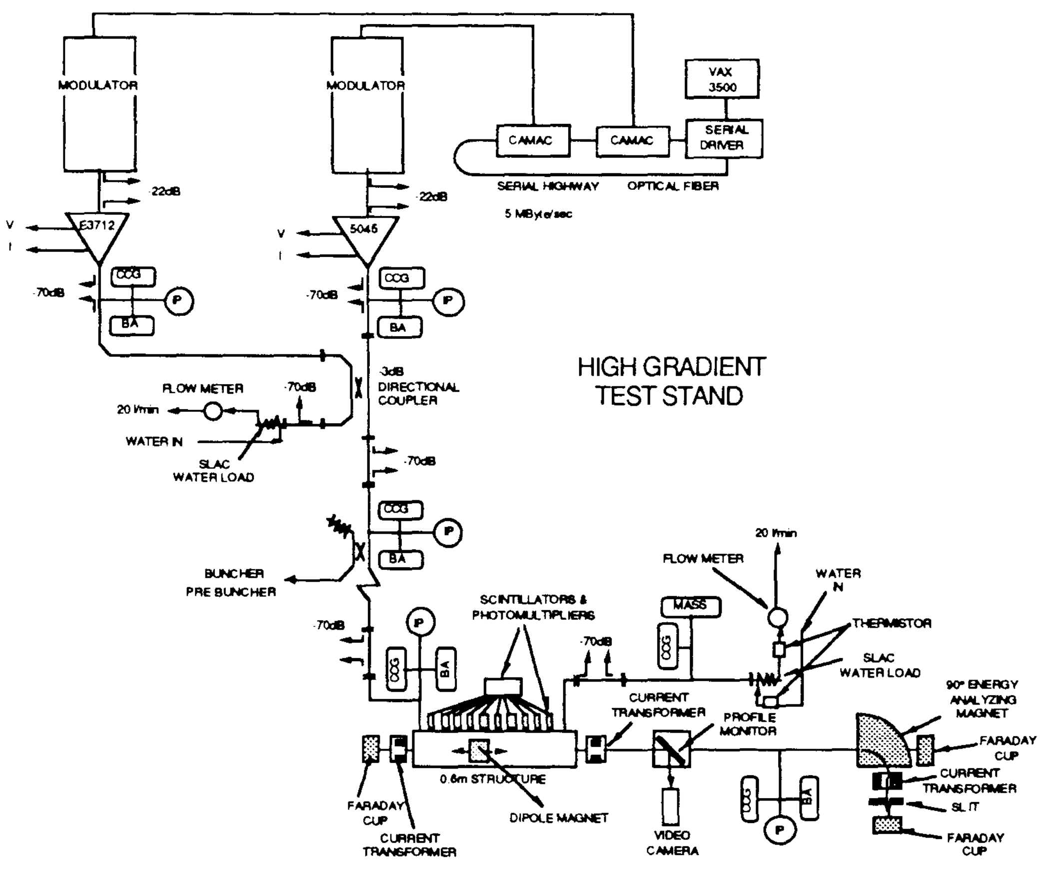

Figure 1. Diagram of the experimental set-up.

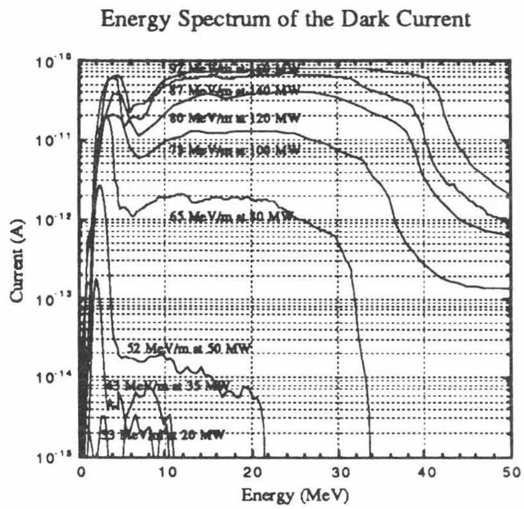

Figure 2. Energy spectrum of the total dark current.

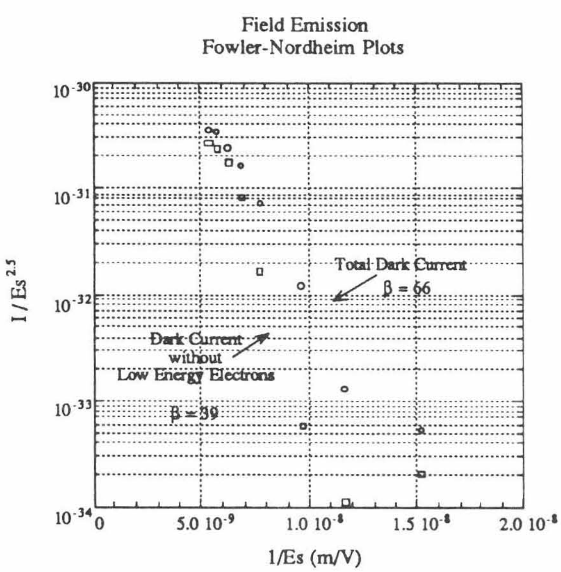

Figure 3 Fowler-Nordheim plots and the field enhancementfactor β.

Multiplication Factor η of the Dark Current

There has been an interest in the relations between the dark current and structure length. A permanent dipole magnet is set on the outside of the structure to trap the field emitted electrons from the upstream and to eliminate the downstream current at the magnet. For the dark current, the structure length can be decreased by moving the dipole magnet to the output coupler along the structure. The dark current except the low energy electrons generated in the output coupler is obtained from the energy spectrum. Figure 4 shows the logarithm of dark current against number of cells between dipole and output coupler. The figure 4 shows that the dark current Id will increase as η^N, where N is the number of cells in the structure. It is reasonable to consider that the field emitted electrons from the upstream cells are multiplied in a cell and the multiplication factor (η = 1.63/cell) is constant along the structure. It is predicted that the total dark current Id will be decreased, if the structures of low η can be realized.

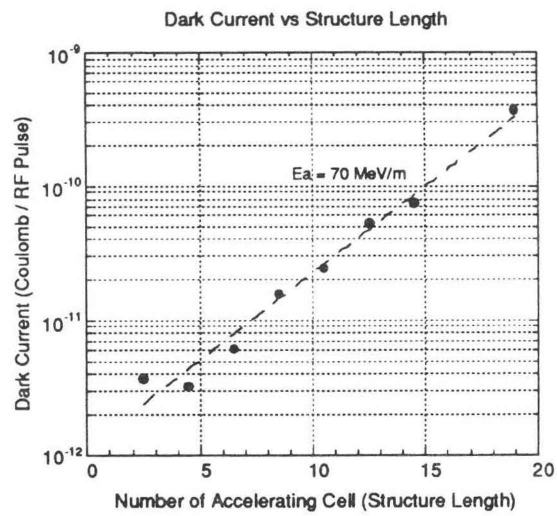

Figure 4. Dark current against the number of cells (structure length).

Acknowledgment

The authors wish to express their gratitude for the encouragement and financial support received from director general, H. Sugawara and directors Y. Kimura and S. Iwata. They also wish to express their thanks to Prof. K. Takata for the useful discussions. The experiment has been carried out by using the ATF Phase-I Linac constructed by the ATF sub-group of the JLC Study Group.

References

1. J. W. Wang and G. A. Loew, "Progress Report on New RF Breakdown Studies in an S-band Structure at SLAC," SLAC-PUB-4247, February 1987.

2. E. Tanabe, J. W. Wang and G. A. Loew, "Voltage Breakdown at X-band and C-band Frequencies," Proc. 1986 Linear Accelerator Conference, Stanford, June 1986.

3. H. Mizuno, J. Odagiri, T. Higo, M. Akemoto and H. Sakai, "X-band Klystron for Japan Linear Collider," Proceedings of this conference.

4. H. Matsumoto, M. Akemoto, H. Hayano, T. Higo, Y. Kimura, H. Mizuno, T. Shidara, K. Takata, S. Takeda, Y. Takeuchi, J. Urakawa, Y. Yamaoka and M. Yoshioka, "RF High Gradient Experiment of an S-band 0.6 m Disk-loaded Structure," Particle Accelerator **30**, 231 (1990).