RF BREAKDOWN STUDIES ON AN S-BAND DISK LOADED STRUCTURE

H. Matsumoto, Y. Fukushima, S. Horiba*, G. Horikoshi, Y. Kimura, H. Mizuno, Y. Saito, I,Sato, T. Shidara, K. Takata, S. Takeda**, N. Terabayashi*, Y. Yamazaki and M. Yoshioka***

KEK National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki, 305, Japan
* Mitsubishi Heavy Industries LTD.,
Marunouchi, Tokyo, 100, Japan
** Institute of Scientific and Industrial Research, Osaka University,
Mihogaoka, Ibaragi-shi, Osaka-fu, 567, Japan
*** Institute for Nuclear Study, University of Tokyo,
Midori-cho, Tanashi-shi, Tokyo, 188, Japan

ABSTRACT

RF breakdown tests in an S-band traveling wave accelerating structure were studied by use of a resonant ring. The accelerating structure with a surface roughness of 0.6 μm was used without any special treatment after the fabrication. The maximum field gradient on the beam axis was 104.5 MV/m with a peak field-emission current of 24 mA. This current level,however,was decreasing by the RF processing.

INTRODUCTION

An e+e- linear collider in the TeV region is one of the various proposals for future accelerators for the high energy physics. It requires traveling wave accelerating structures operating at a field gradient of about 100 MV/m or more.

Experimental results for such structures have already been reported by SLAC[1-3] and VARIAN associates INC[4-6]. In the SLAC experiment, an S-band traveling wave linear accelerator section was excited in a standing wave mode and an equivalent traveling wave accelerating field of 146.7 MV/m was attained. The peak surface field, which exists at around the beam hole on the disk, was calculated to be 318 MV/m. A single cell cavity was used in the VARIAN experiment. The accelerating field was 66.3 MV/m and peak surface field was 239 MV/m.

Though those experiments with structures in standing wave modes may give measures of the behavior of a structure operated at an extremely high gradient, direct tests on a structure operating in a traveling wave mode is preferable in order to obtain informations for the final design of the traveling wave linac. This report describes experimental results of a 5-cell S-band structure operated in the $2\pi/3$ traveling wave mode.

EXPERIMENTAL SET-UP

The schematic diagram of the experimental set-up is shown in Fig.1. The test accelerating structure was inserted in a resonant ring driven by a klystron with a peak power of 30 MW and with a pulse width of . The waveguide is made of OFHC copper extruded into a cross section of 72.1 mm in width and 34.0 mm in height. The klystron output power is fed into the ring through a 6.04 dB coupler of a 2-hole type.

The ring has a stub tuner section and a phase shifter to suppress the power which runs in the reverse direction. The circulating power Pc was monitored by two directional couplers of a Bethe-hole type with a directivity of -80 dB, which are located just before and after the accelerating structure.

The whole ring is pumped down to 5×10^{-8} Torr by a 500 l/s sputter ion pump at the main directional coupler. The ring has also an auxiliary pumping system with a turbo molecular pump and a mass-analyzer for monitoring of residual gases during the RF processing of the test cavity.

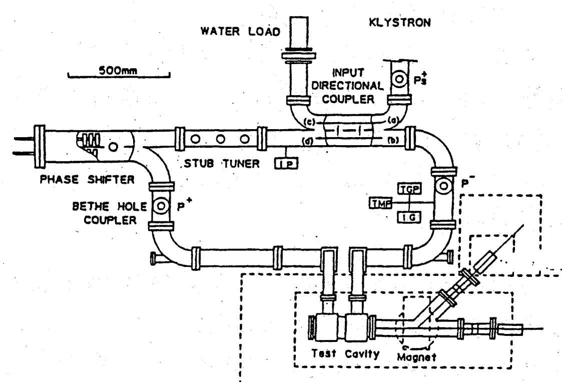

Fig. 1: A schematic diagram of the experimental set-up

The accelerating structure consists of a 3-cell regular section, an input and an output coupling cells as shown in Fig.2. The regular cell is a conventional disk-loaded structure. The disk and cylinder were machined from OFHC blocks with a surface finish of about 0.6 μm. Those parts were then stacked together with a high pressure in order to obtain a good electrical contact between them and electroplated with copper on the outer surface to a thickness of 10 mm. The vacuum tightness is obtained by the electroplated layer without any brazing process[7,8].

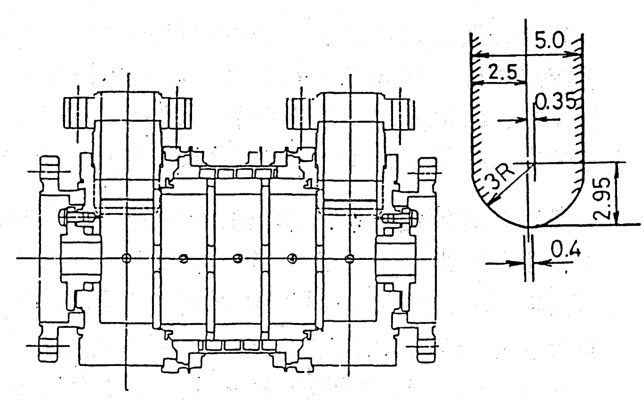

Fig. 2: Cross sectional drawings of the accelerating structure and the periphery of the beam hole: beam hole diameter 2a=1.6 cm, cavity diameter 2b=8.132 cm, pitch p=3.50 cm

The disk with a thickness of 5 mm has a beam aperture of 16 mm in diameter. The periphery of the hole is rounded with a radius of 3.0 mm as shown in Fig.2. The results of a low power measurement of the accelerating structure are summarized in Table 1. The r/Q is agreed with a SUPERFISH calculation within an accuracy of 10 %. From these values, the accelerating field Eacc is expressed as follows:

$$E_{acc}\ \mathrm{MV/m} = 9.42\sqrt{P_c\ \mathrm{MW}} \qquad (1)$$

where Pc is the forward circulating power in MW. The SUPERFISH calculation suggests that the maximum peak field on the surface Ep is 2.1 times Eacc. The evacuated structure had a resonant frequency of 2856.15 MHz at the temperature of 30 °C for traveling wave mode.

The field gradient was also evaluated by measuring the energy spectrum of electrons generated by the field emission inside the structure. For this purpose, a simple magnetic spectrometer of 45° bending angle was put just behind the test section and electrons were captured by a copper Faraday cup of 8 cm in diameter and 10 cm in length.

Table 1

Parameters of the Accelerating Structure

Phase Shift/Cell	2π/3	
Structure Length	17.5	cm
Beam Hole Diameter (2a)	1.6	cm
Cavity Diameter (2b)	8.132	cm
Resonant Frequency (f)	2856.15	MHz
Q	13330	
Shunt Impedance (r)	63.2	MΩ/m
Attenuation	0.7017	Neper/m
Group Velocity (Vg/c)	0.0032	

Resonant Ring Parameters

Coupling of Input Coupler	6.04	dB
Attenuation of Ring Circuit	1.25	dB
Resonant Ring	0.2	dB
Accelerating Structure	1.05	dB
Pulse Width	2.0	us
Repetition Rate	20	Hz

EXPERIMENTAL RESULT

The accelerating structure had first been RF conditioned up to levels of Pc = 81 MW (Eacc = 84.8 MV/m) in September, 1986. Then it was kept in atmosphere for four months. Meanwhile an improved directional coupler for the ring resonator was fabricated to obtain higher Pc. The second conditioning was held by using the new directional coupler from 9th to 28th of February, 1987. No other treatments such as baking or chemical polishing were carried out than the RF conditioning to attain high gradient.

In the conditioning, RF pulses with a width of 2 μs and repetition rate of 20 Hz were applied to the structure. During the conditioning the vacuum pressure of the structure was around 2×10^{-8} Torr. Occasionally it rose up to the order of 10^{-7} Torr or even higher as RF breakdown took place. The ultimate pressure in cold states was 4×10^{-9} Torr.

At the first conditioning, Eacc = 84.8 MV/m was attained after an integrated time of 300 hours. At the second, the same gradient was reached only in 40 hours. Another integrated time of 200 hours was necessary to attain Eacc = 104.5 MV/m which corresponds to Pc = 123 MW. This level is limited only by the maximum available power of the klystron. At this gradient, the accelerating structure could be operated quite stably for 10 hours as shown in Fig. 3.

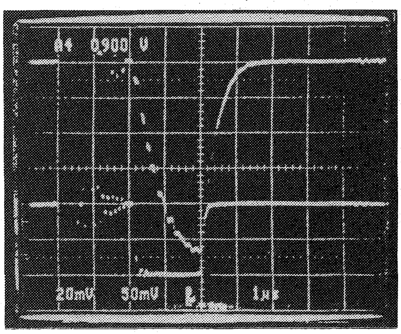

Fig. 3: A picture of the RF power in the ring built up to 123 MW (above) and RF power of the klystron(below).

Fig. 4 shows the electron energy spectra of the field-emission current at 4 different accelerating gradients. The noise level of the detector was at about 10^{-10} A. Therefore the point where the spectrum crosses this current level would correspond to the maximum electron energy for a given gradient. Actually the values obtained thus fairly agree with those calculated with eq. (1). The scallops appeared on the spectrum are supposed to be due to acceleration over a distance of integer multiples of the unit cell length of 3.5 cm, because the separation of broad peaks is about 1/5 of the maximum energy.

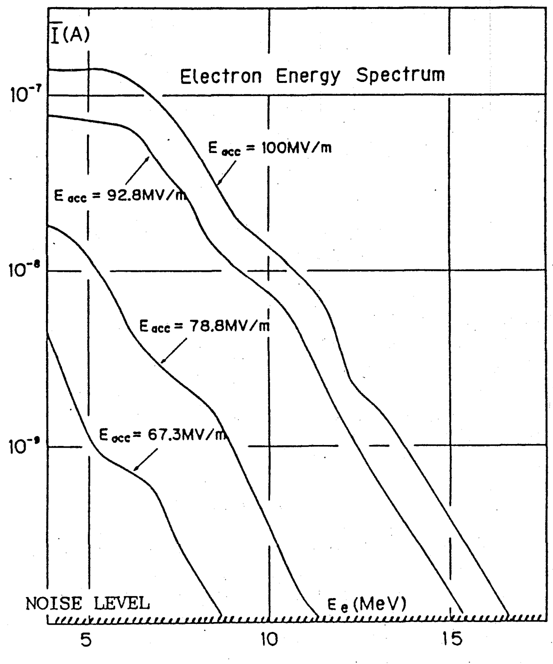

Fig. 4: Electron energy spectra at various accelerating gradients.

During the RF processing, the field-emission currents I_f at the Faraday cup on the beam axis were plotted in a modified Fowler-Nordheim diagram as shown in Fig. 5 according to the following formula:

$$\frac{I_f}{E_p^{2.5}} = C \cdot \exp\left(\frac{-1.34 \times 10^{10} \phi^{1.5}}{\beta E_p}\right) \qquad (2)$$

where c is a constant, ϕ is the work function of the copper, and β is the microscopic field enhancement factor. The three Fowler-Nordheim lines in this figure were taken on the same day. The middle and the lower lines were taken 3 hours and 11 hours after the upper line was taken, respectively. Each line has almost the same tangent of slope. This suggests that the RF conditioning reduces the effective area of the field emission. The conditioning was usually stopped every night for 12 hours and started with a slightly larger current next day.

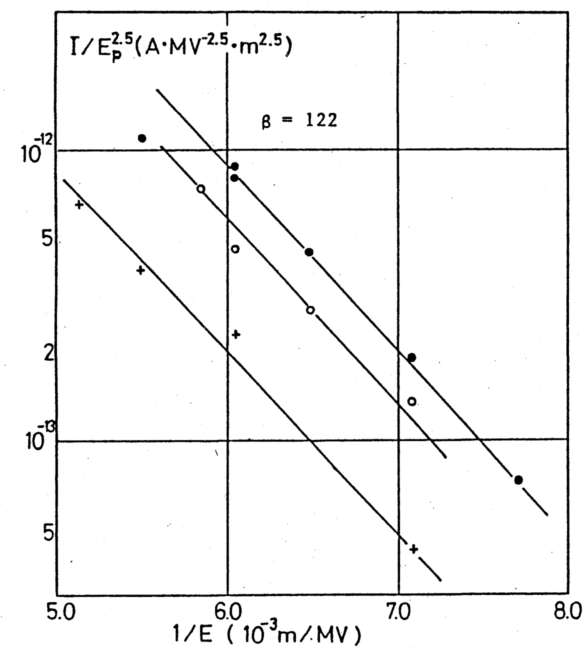

Fig. 5: Three Fowler-Nordheim plots at different times on the same day.

Fig. 6 shows the modified Fowler-Nordheim plot taken on the final day of this experiment. The slope (1) indicates the region where the surface is sufficiently RF conditioned, while the slope (2) with a larger value(β = 260) represents a newly reached domain, where the conditioning time is still about 10 hours only.

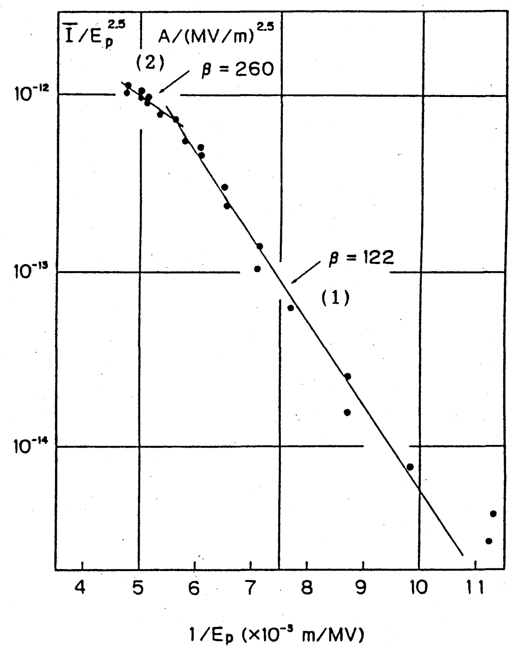

Fig. 6: Fowler-Nordheim plot on the final day of this experiment.

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