SECTION IV

BEAM DYNAMICS

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OSAKA UNIVERSITY 150-MeV S-BAND LINAC FOR HIGH-GRADIENT ACCELERATION

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Abstract A 150-MeV S-band electron linear accelerator (linac) which is characterized by the relatively high accelerating gradient and accordingly, the short overall length, has been constructed at the Institute of Scientific and Industrial Research in Osaka University. This linac consists of three accelerating waveguides (one 3 m long and two 2 m), to which rf is supplied from three 35-MW klystrons, respectively. The aging behavoirs of the accelerating waveguides and the beam characteristics have been investigated. The beam energy evaluated for zero beam-current is 123 MeV at a total input rf power of 81 MW. The accelerating gradient of 19.3 MV/m has been achieved in the 2-m waveguide.

INTRODUCTION

Recently, the small-size linacs are required in many fields such as industries and high-energy physics, as an injector of a synchrotron-radiation ring and as an electron-positron beam collider.[1,2] In our laboratory, the construction of an S-band electron linac was planned for the experiments with slow positrons, a synchrotron-radiation ring, a super-conducting electro-magnetic wiggler and a free electron laser. The beam energies necessary for these experiments are above 100 MeV. Because there was not enough area for the linac, the overall length of the linac system consisting of an electron gun, accelerating waveguides and beam-transport systems was restricted to be within 12 m. In this case, the accelerating gradient of the waveguide was to be above 20 MV/m, which is nearly the highest value for conventional linacs. The klystrons used for this linac should be of considerably high power because the accelerating gradient is proportional to the square root of the input rf power.

The linac has been completed and being operated for tests. This article represents the aging behaviors of the accelerating waveguides and the beam characteristics.

DESIGN OF THE SYSTEM

For the present linac system three kinds of klystrons were considered as candidates of high-power rf sources, 5095 (SLAC), TH 2094 (Thomson) and PV-3035 (Mitsubishi). The last one was adopted from the facts that the first one was not on the market and the second one was expensive. The PV-3035 klystron (peak rf-power, 35 MW) had been developed by improving the perveance of PV-3030 by about 10%.

In order to realize the short linac, we examined three cases in composing the accelerating waveguides (constant-gradient type) and the klystrons. Figure 1 shows the beam-loading curves calculated for the three cases, A, B and C. The case A can give the highest beam-energy but the overall length is comparatively long. For the cases B and C the beam-loading behaviors are nearly the same. The latter system has a hybrid coupler combining rf from two 35-MW klystrons. We chose the system B because of the simplicity in the composition.

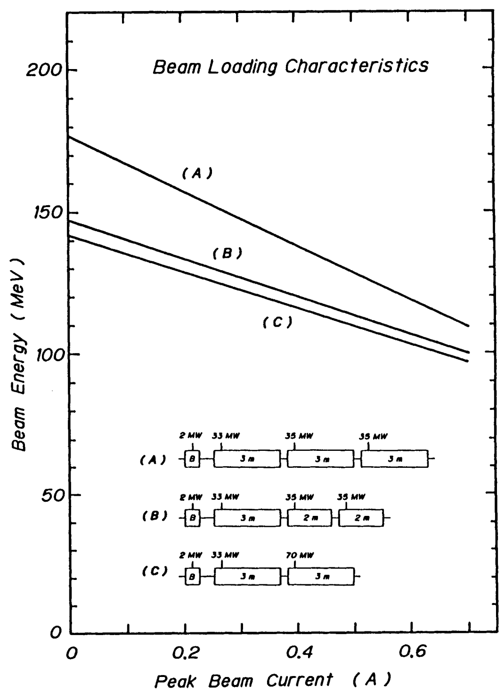
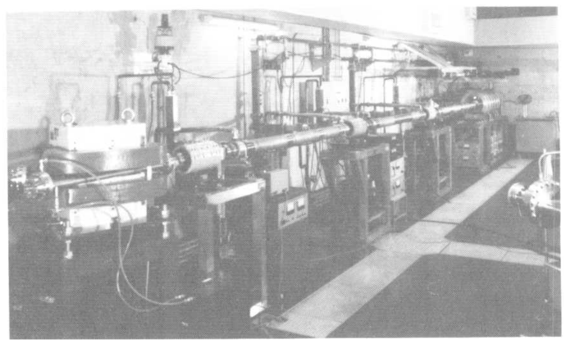


FIGURE 1 Beam-loading curves.

LINAC SYSTEM

A photograph and a schematic diagram of the linac system are shown in Figure 2. A master rf-source is a synthesized oscillator of a stability less than 1 x 10^{-9}. The pulsed rf generated by a booster klystron, TH 2436 (Thomson), at a peak power of 1.5 kW for a duration of 3 μs is divided and then supplied to the three 35-MW klystrons, separately. The conventional accelerating-waveguides of constant-gradient type (Mitsubishi Electric Corp.) were used. The main parameters of the waveguides are listed in Table I.

The high-voltage (280 kV) pulses supplied to the klystron at a duration of 4 μs are formed by a conventional line-type modulator which consists of a 16-sectional pulse-forming network, a ceramic hydrogen thyratron



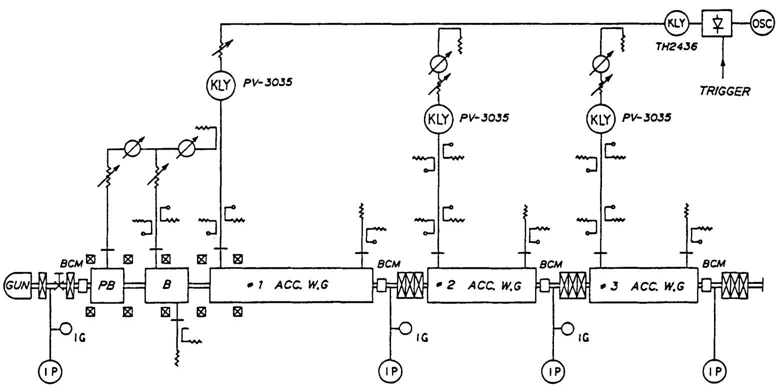


FIGURE 1 S-band linac system.

TABLE I Parameters of the accelerating waveguides.

Nominal Operating Freq.	2.856 GHz
Accelerating Mode	$2\pi/3$
Attenuation Coefficient, I_0	0.153 Nepers/m
Figure of Merit, Q	12,600
Group Velocity, v_g/c	0.0147
Shunt Impedance, r	53 MΩ/m

(CX1525, EEV) and a pulse transformer (Pearson). In order to make the modulator compact, the main part of the charging-and-discharging circuit involving a De-Qing circuit was set in an oil tank. The flatness at the peak of the high-voltage pulse is less than 1%.

The electron gun involving an EIMAC Y-796 cathode-grid assembly has been designed on refering to the injector of SLC.[3] As a grid pulser one with an FET amplifier is used for pulse durations from 0.1 to 2.5 μs, and an avalanche pulser for 10 to 100 ns. At a cathode voltage of 100 kV injection currents higher than 2 A can be obtained for a pulse duration of 1.5 μs.

The six Helmholtz coils are placed in the region from the buncher waveguide to the 1st accelerating waveguide at an interval of 230 mm, as shown in Figure 2. The strength of the magnetic field is 320 gausses at the center.

Triplet quadrupole-magnets, a beam-current monitor, a beam-profile monitor and an ion pump (evacuation speed, 320 l/s) are placed between the accelerating waveguides. Vacuum pressures are less than 10^{-8} Torr under operation.

AGING BEHAVIORS OF ACCELERATING WAVEGUIDES

The aging of the accelerating waveguides was made as follows. After installation the waveguides had been evacuated about one week at room temperature. Then, rf was supplied to the waveguide at 10 pps repetition of 3 μs pulses, the input rf power being gradually increased under vacuum pressures less than 10^{-7}

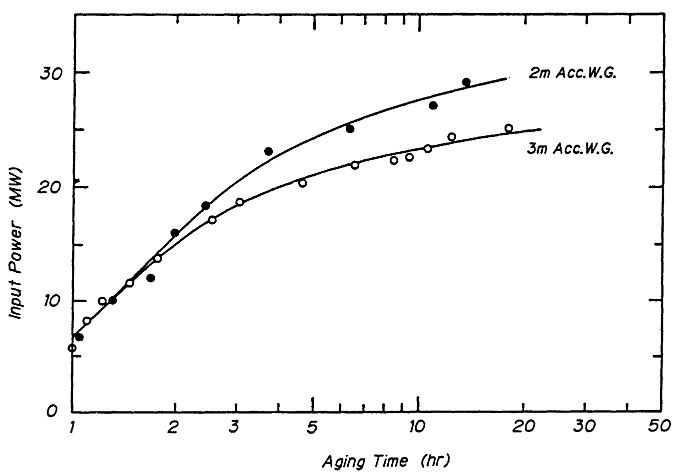


FIGURE 3 Aging behaviors of waveguides.

Torr. For the 2-m and the 3-m waveguides the relation between the aging time and the input rf power is shown in Figure 3. This figure shows the exponential increase of the aging time at the early stage of the aging process. For input powers above 20 MW frequent discharges disturbed the aging procedure. As shown in this figure, the aging time required for the 3-m waveguide is longer than the 2-m one. This may be caused by the difference in the conductance of the waveguides for evacuation.

BEAM CHARACTERISTICS

The energy spectra of the electron beams were measured with an analyzer magnet which was set at the exit of the 3rd accelerating waveguide. The beam-loading characteristics on the steady-state mode (for 1.5 μs pulses) are shown in Figure 4 for peak currents below 560 mA. This figure shows the results for the beams accelerated by using one (1st), two (1st and 2nd) and three waveguides. In the three cases the beam energies for zero beam-current are evaluated to be 48, 86 and 123 MeV, respectively. For the last case total power of the input rf has been calculated to be 81 MW (25 MW for the 1st waveguide, 30 MW for the 2nd and 26 MW for the 3rd). These results indicate that the highest accelerating gradient is 19.3 MV/m in the 2nd waveguide. The spreads of the beam energy are from 1.9 to 3.7% in fwhm: The smaller values may be obtained by the further adjustment of the PFN.

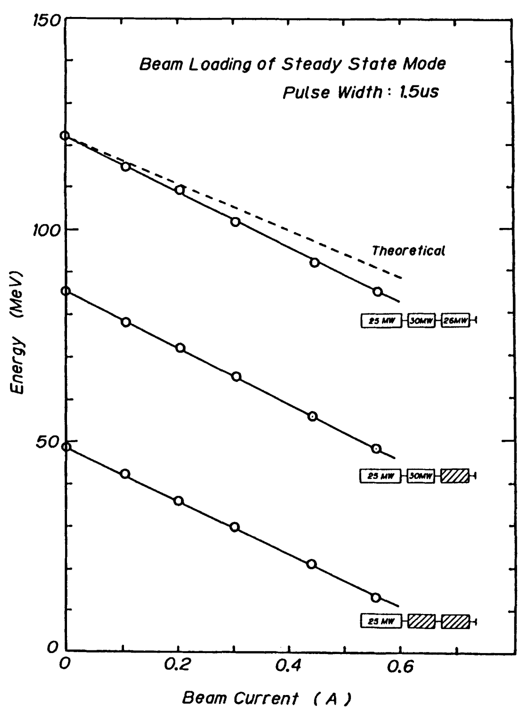


FIGURE 4 Beam characteristics.

BEAM QUALITY

One of the main components determining the beam quality is the electron gun. The emittance of the 100-keV electron beam from the gun was measured by using a multihole mask plate (pepper pot). Beams were projected onto a ceramic plate 0.1 mm thick. The beam profiles were observed from the backside of the plate with a monitor camera. The normalized beam-emittances measured were 20 and 50 πmm.mrad for the peak beam-currents of 200 and 600 mA, respectively. For the study of free electron laser the gun should be replaced by one of the lower emittance.

CONCLUSIONS

1. A 150-MeV S-band electron linac has been newly constructed, which is characterized by high accelerating-gradient and accordingly, short overall-length.
2. The linac consists of one 3-m accelerating waveguide and two 2-m waveguides, to which rf is supplied from three 35 MW klystrons, separately.
3. The aging behaviors of the accelerating waveguides have been investigated. The highest accelerating gradient and the highest beam energy are 19.3 MV/m and 123 MeV, respectively.
4. The emittance of the beam from the gun has been measured.

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