BEAM ACCELERATION RESULTS OF TEST LINAC

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Abstract

An electron linac called 'Test Linac' was constructed for nuclear physics and free electron laser experiment. The linac consists of a thermionic RF-gun, an alpha magnet, two accelerating structures, and a beam analyzing magnet. The RF-gun is one cell cavity with a tungsten dispenser cathode of 6 mm diameter. Longitudinal matching from the RF-gun to the first accelerating structure is done by the alpha magnet. The RF frequency is 2,856 MHz, and a SLAC 5045 klystron feeds RF power to two accelerating structures and the RF-gun. The initial beam acceleration results are described together with the detailed descriptions of the machine.

1. INTRODUCTION

An electron linac with a beam energy of 100 MeV has been prepared for new R&D activities such as free electron laser, neutron source, and slow positron source at PAL(Pohang Accelerator Laboratory). New experiments, such as free electron laser and compton scattering experiments, require a high-brightness electron source; this implies a high peak current (10 A to 2000 A) and a low transverse emittance (2 to 80 π mm-mrad)[1]. Also, the facility is required to study the generation of slow positron to widen the scope of material science research[2].

An electron linac called 'Test Linac' was constructed for this purpose. The linac is an RF-gun based linac of which major components are a thermionic RF-gun, an alpha magnet, and two SLAC-type accelerating structures. Though a thermionic RF-gun has some disadvantages, such as a large energy spread and a short cathode life time, it is a quite compact and relatively inexpensive source for high-brightness applications. The linac was constructed economically by utilizing the left-over components and the infrastructures for PLS. Preparation of the machine site was finished at the end of 1995. A modulator, a klystron, and an S-band waveguide network were installed at the beginning of 1996. The initial beam acceleration test was performed at the end of 1997. This paper presents the machine parameters of the test linac and describes measurement results of the initial operation.

2. MACHINE DESCRIPTION

The design beam parameters of the test linac are as follows: the beam energy is 100 MeV, the energy spread is less than 1 %, the peak current is 20 A, the beam pulse length is 6 μs, and the rms normalized emittance is less than 30 π mm-mrad. In order to achieve the design goal of the test linac, the rms normalized emittance out of the gun should be less than 10 π mm-mrad because of the effect of the chromatic aberration during the beam transport from the gun to the first accelerating structure. Machine parameters of the linac are listed in Table 1.

The linac consists of a thermionic RF-gun, an alpha magnet, four quadrupole magnets, two SLAC-type accelerating structures, a quadrupole triplet, and a beam analyzing magnet. A 2-m long drift space is added between first and second accelerating structure to insert an energy compensation magnet or a beam transport magnet for FEL research. The linac was installed at the tunnel, and its overall length is 15-m. The experimetal area at the end of linac has a dimension of about 7-m length and 5-m width. Major parameters of the installed components of the linac are listed in Table 2.

The RF-gun is one cell cavity with a tungsten dispenser cathode of 6 mm diameter. The gun produced an electron beam with an average current of 300 mA, an energy of up to 1 MeV, and a 6-μs pulse length[3]. The measured rms emittance was 2.1 π mm-mrad at an energy of 1 MeV. The alpha magnet is used to match the longitudinal acceptance from the gun to the first accelerating structure. Electron moves along a 'α'-shaped trajectory in the alpha magnet, and the bend angle is 278.6^{o}. High energy electron has a longer path length than low energy electron, thus the length of electron beam is not lengthened or is shortened in the beam transport line from the gun to the first accelerating structure.

Four quadrupole magnets are used to focus the electron beam in the beam transport line from the thermionic RF-gun to the first accelerating structure. The quadrupole triplet installed between first and second accelerating structure is used to focus the electron beam during the transport to the experimental beam line at the end of linac.

There are three beam current transformers(BCT) and three beam profile monitors for beam instrumentation. The BCT is the toroidal shape of ferrite core 25 turns-wound by 0.3 mm dia. enameled wire. The beam analyzing magnet has a bending angle of 30 degree and zero pole-face rotation.

The gallery main components consist of a SLAC 5045 klystron and an 80-MW modulator, and rf waveguide components, etc. Two branched waveguides through a 3 dB power divider from the main klystron waveguide are connected accelerating structures. A high power phaseshifter is inserted in the waveguide line to second accelerating structure. The branched waveguide through a 10 dB power divider from the main guide is connected to the RF-gun cavity via a high-power phaseshifter/attenuator and a high-power circulator. The circulator is pressurized with dry nitrogen at 20 psig. Two waveguide windows isolate the circulator from the evacuated waveguide line.

Table 1. Machine parameters of Test Linac.(*achieved value)

Beam Energy	100 MeV (40 MeV*)
Beam Current	100 mA (30 mA*)
Pulse Width	6 μs (3 μs*)
Energy Spread	< 1 % (3 %*)
Repetition Rate	60 Hz max. (12 Hz*)
Norm. Emittance	< 30 π mm-mrad

3. BEAM ACCELERATION TEST

After some RF-conditioning of the accelerating structures and waveguide network, beam acceleration experiment was performed. The nominal RF power of the klystron at the experiment was 17 MW, and the RF powers fed to one accelerating structure and the RF-gun were 7 MW and 1.5 MW, respectively. The bunched electron beam at the alpha magnet was accelerated in the accelerating structures, transported to the end of the linac. The measured beam energy by the beam analyzing magnet was 40 MeV. Figure 1 shows beam current signals at the exit of the alpha magnet(BCM1) and the exit of second accelerating structure(BCM3). The measured beam currents at BCM1 and BCM3 were 90 mA and 30 mA, respectively. The length of electron beam pulse was 1.6 μs, pulse repetition rate 12 Hz, and the measured energy spread about 3% at minimum. As the beam current increases, beam energy decreases and energy spread increases.

Energy gain at the SLAC-type accelerating structure decreases as both the pulse length of the electron beam and the beam current increase[4]. When the pulse length of the electron beam is longer than the filling time of accelerating structure(=0.83 μs), the accelerating structure is fully loaded with electron beam. The beam extracted from the RF-gun is accelerated in the structure at the full loading state, thus the energy loss due to the beam loading is -38.3 times the beam current in Amperes. Therefore, the electron beam has large energy spread at the full loading state.

It was observed that low energy trace, 10% less from the peak energy, appeared on the profile screen after the analyzing magnet as the beam current increases. The front beam extracted earlier from the gun enters the accelerating structure with no RF because the rf-filling time of the gun cavity is 0.21 μs, shorter than the filling time of accelerating structure. To avoid this effect it is necessary to use a pulse-mode electric deflector or a pulse-mode magnetic deflector in front of the first accelerating structure.

Table 2. Major parameters of the installed components of the linac.

RF-gun Beam Energy after RF-gun Beam Current	 1.0 MeV 500 mA max.
Alpha Magnet Pole Radius Field Gradient, max. Good Field Region Field Well-distortion(δG/G)	 6.5 cm 1.8 T/m 14 cm < 1 %
Gun to Linac Quadrupole Pole Radius Effective Length	 20 mm 50 mm
Accelerating Structure Type Mode Frequency Length	 Constant Gradient 2/3 π 2,856 MHz 3 m
Quadrupole Triplet Pole Radius Effective Length	 22 mm 100 mm (200 mm)
Beam Analysing Magnet Bending Angle Gap Distance	 30^{o} 33 mm

In the initial beam operation, diameter of electron beam is about 20 mm at the beam profile monitor in front of second accelerating structure. Two quadrupole magnets installed in front of the first accelerating structure are not sufficient to focus the electron beam with large energy spread. Thus focusing solenoid should be added to the first accelerating structure to minimize beam loss and radiation problem.

The lowest energy spread at the accelerating structure depends on the flat-top of RF power pulse, determined by the flat-top of the klystron beam voltage. The measured flatness of the klystron beam voltage flat-top was ±1.5%. To reduce energy spread, flatness of the klystron beam voltage flat-top should be minimized to less than ±0.2%. And in order to reduce the energy loss owing to beam loading, an RF chopper may be added in front of the first accelerating structure to choose a part of electron microbunches extracted from the RF-gun. The selected microbunches can be accelerated in the accelerating structure without beam loading. By this way, the energy spread due to the beam loading can be minimized, and the charge in a microbunch can be raised.

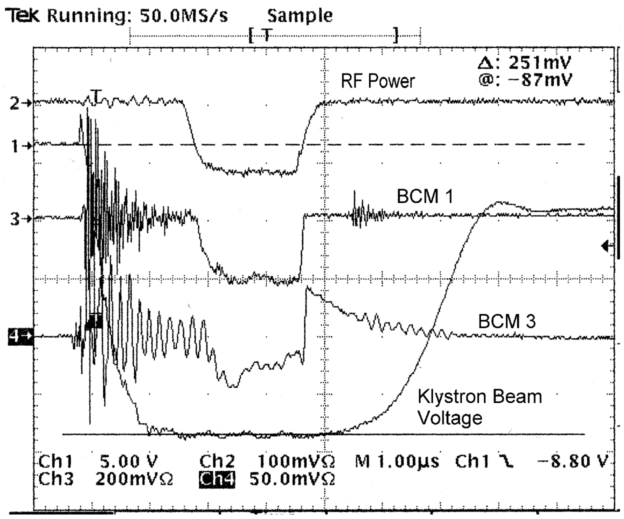

Fig. 1. Beam current signals at the exit of the alpha magnet(BCM1) and the exit of second accelerating structure(BCM3).

4. DISCUSSION

It is required to raise the beam brightness by optimizing and upgrading the linac performance for new R&D purposes. To decide the scope of high brightness applications, it is necessary to measure the beam brightness of the final beam. Beam brightness at the end of linac is determined by the emittance and the peak current of the electron beam. For the measurement of beam emittance a quadrupole magnet will be added at the exit side of second accelerating structure, and the length of the microbunch will be measured to know the peak current.

Currently the development of new high power modulator with better stability for the SLAC 5045 klystron, suitable for the FEL project, is underway. The focusing solenoid and the other linac components necessary for the better beam quality are also under preparation.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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