COMMISSIONING STATUS OF 10-MeV INTENSE ELECTRON LINAC*

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Abstract

An intense L-band electron linac is now being commissioned at ACEP (Advanced Center for Electron-beam Processing in Cheorwon, Korea) for irradiation applications. It is capable of producing 10-MeV electron beams with the 30-kW average beam power. For a high-power capability, we adopted the traveling-wave structure operated with the 2π/3-mode at 1.3 GHz. The structure is powered by a 25-MW pulsed klystron with 60-kW average RF power. The RF pulse length is 8 μs while the beam pulse length is 7 μs due to the filling time in the accelerating structure. The accelerating gradient is 4.2 MV/m at the beam current of 1.45 A which is the fully beam-loaded condition. In this paper, we present details of the accelerator system and commissioning status.

INTRODUCTION

Recently, there are increased demands on electron linear accelerators for industrial applications [1]. In using electron beams as irradiation sources, the higher beam energy is favorable since the penetration depth is larger. However, the electron beam energy is limited by about 10 MeV due mainly to neutron production. For the clinical X-ray systems, a low current and a low repetition rate are required. The X-ray source for the container inspection requires 5-10 MeV with a few kilowatts of the average beam power [2]. On the other hand, the food or waste sterilization system requires relatively high average beam power to which the process speed is proportional [3].

A high average-power electron accelerator is being developed in the institutional collaboration with PAL/POSTECH and KAPRA. The accelerator is installed at ACEP and it will be used for not only for sterilizing foods and medical products, but also reforming materials. The accelerator is required to provide an average beam power of 30 kW at the beam energy of 10 MeV. In order to treat such a high-power, an L-band RF system and accelerating column is adopted due to thermal stability compared with an S-band. A travelling-wave accelerating structure is adopted for industrial purposes due to the following reasons. It needs no circulator necessary for the standing-wave structure. It makes the system simpler and less expensive. Also the RF power coupling is insensitive to the beam-loading effect. The design details are presented in table 1 and test results in the following sections.

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Table 1: Accelerator Parameters

Accelerator Parameters	
Operating Frequency	1.3 GHz
Pulsed RF Power	25 MW
RF Pulse Length	8 μs
Repetition Rate	300 Hz
Averaged RF Power	60 kW
E-gun High Voltage	- 80 kV
Pulsed E-gun Current	1.6 A
Beam Pulse Length	7 μs
Beam Energy	10 MeV
Output Beam Current	1.45 A
Beam Transmission Rate	90%
Averaged Beam Power	30 kW
Shape of Accelerating Cell	Disk-loaded
Operating Mode of Accelerator	2π/3 mode
RF Filling Time	0.8 μs
Operating Temperature	40°C ± 1°C
Averaged Accelerating Gradients	4.2 MV/m
Beam Loading Factor	- 4.7 MeV/A
Temperature Shift Factor	- 2.3 MeV/1°C

RF CHARACTERISTICS

The Thales klystron tube (TV2022D) generates 25-MW pulsed RF with 8-μs pulse length and 300-Hz pulse repetition rate. It is powered by a matched pulse modulator, composed of a set of inverter power supplies, a pulse forming network and a thyratron switch.

The inverter power supplies are totally 8 units, each of 45 kV and average 30 kW. The PFN has 15 stages, each with a 50-nF capacitor and a 2.2-μH inductor. The EEV thyratron tube (CX2412X) switches pulsed power of 45 kV and 3 kA. The klystron tube with perveance of 1.6 μPerv amplifies RF power to 25 MW when the beam voltage is 270 kV. The beam voltage is applied to the klystron with a 1:13 pulse transformer [4].

The L-band accelerating column is a travelling-wave structure, composed of 31 cells including 5 bunching-cells [5]. It is operated with 2π/3-resonant-mode at 1.3 GHz. After fabrication of the column, we measured the RF reflection, a ratio of the reflection RF power to the input, and the RF transmission, a ratio of the output to the input. Figure 1 shows the measured values of them in both of low- and high-power conditions. The reflection is less than -20 dB, enough to protect the klystron tube from the reflection power. The transmission is almost -1.5 dB compared with the design value of -1.47 dB. The RF filling time corresponding to the RF transmission is almost 0.9 μs as shown in Figure 2 (a). The input and reflection RF power is measured at the waveguide bi-directional coupler placed on the input coupler. The output RF power is measured on the output coupler.

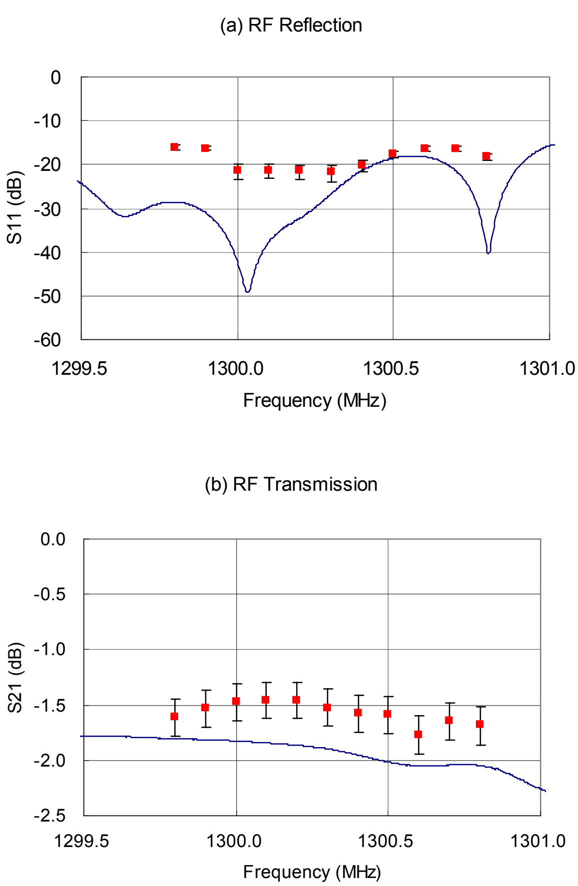

Figure 1: RF refection (a) and transmission (b) of the accelerating column, red points: measured with pulsed RF of 18-MW input power, blue lines: measured by using a network analyzer.

BEAM MEASUREMENT

A diode-type E-gun generates electron beam of 75 kV and pulsed 1.8 A max. The electron beam is injected into the accelerating column 0.9 us after the RF is injected into the column, as shown in Figure 2 (b). The input beam current is 1.8 A measured at the high-voltage line to the E-gun. The output beam current is 1.5 A measured by a BCT (beam current transformer) at the exit of the accelerating column. The beam transmission rate of the output beam current to the input is 83%.

With insufficient focusing magnetic fields by the solenoids, beam pulse shortening and higher order mode generation are observed as shown in Figure 2 (c) due to the regenerative BBU (Beam Break-Up) instability [6]. With the output beam current of 1.5 A, the focusing field is required more than 700 Gauss at the middle of accelerating column to suppress the BBU. With output beam current of 1.0 A, the field is required more than 350 Gauss.

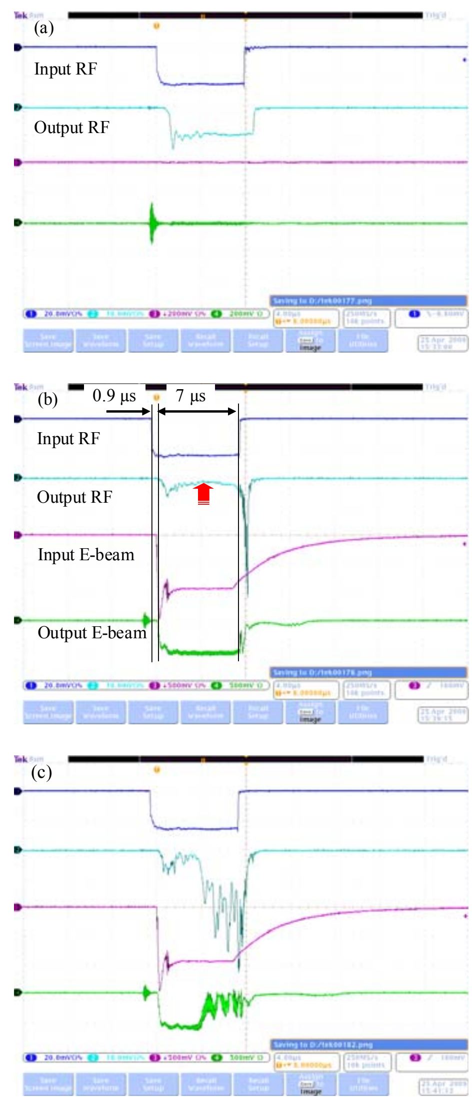

Figure 2: RF power and E-beam current waveform, (a): without beam only RF injected, (b): beam accelerated with the focusing magnetic field of 700 Gauss, and (c): beam broken up with 530 Gauss.

The beam transmission rate is optimized with the input RF power and phase into the PB (Pre-Buncher). The transmission rate with respect to the PB input power is almost saturated at 2 kW as shown in Figure 3. The transmission rate with respect to the PB phase, relative phase difference from the accelerating column, has almost flat-top when the PB phase is from the 150° to 300°, as shown in Figure 4. The nominal operation condition is 2.1-kW PB power and 210°.

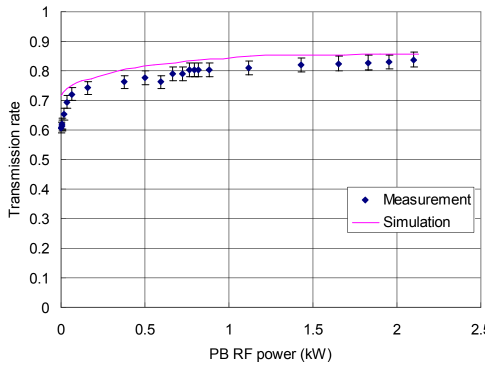

Figure 3: The beam transmission rate with the pre-buncher input power. The pre-buncher phase is 207°.

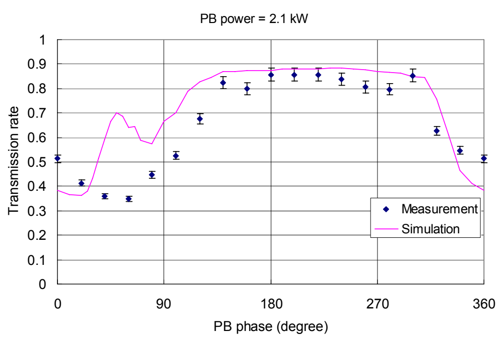

Figure 4: The beam transmission rate with the relative phase of the pre-buncher to the column. The input RF power into the pre-buncher is 2.1 kW.

Using beam scanning coils for electron beam irradiation, the beam energy is measured with irradiated image on mylar films by the beam. Figure 5 shows beam energies with respect to the input RF power and the beam current. The beam energy is proportional to the square root of the input RF power and inversely proportional to the beam current due to the beam loading effect [5].

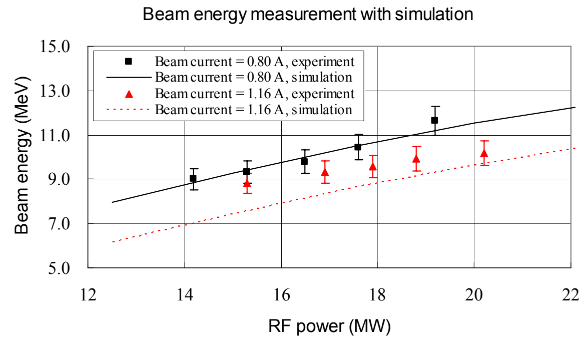

Figure 5: Measured and simulated beam energy with the RF power and the beam current.

COMMISSIONING STATUS

The beam operation is now reached up to the following parameters: 19-MW RF power and 1.0-A output beam current with 7-μs beam pulse length and 120-Hz repetition rate. The beam energy is almost 10-MeV and the beam power is 8.4 kW.

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