COMMISSIONING OF 10-MEV L-BAND ELECTRON LINAC FOR INDUSTRIAL APPLICATIONS *

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Abstract

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

INTRODUCTION

Recently, there are increase 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 CESC 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. It makes the operation of system easier. The design details are presented in table 1 and test results in the following sections.

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 MEASUREMENT

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 8 units in total, 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

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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.

The L-band accelerating column is a travelling-wave structure, composed of 31 cells including 5 bunching-cells [4]. It is operated with 2π/3-resonant-mode at 1.3 GHz. As a result of the low-power measurement of the column, the transmission coefficient of the cumulative phase shift per cell is phase advance of each cell is 120°±2° as shown in Figure 1.

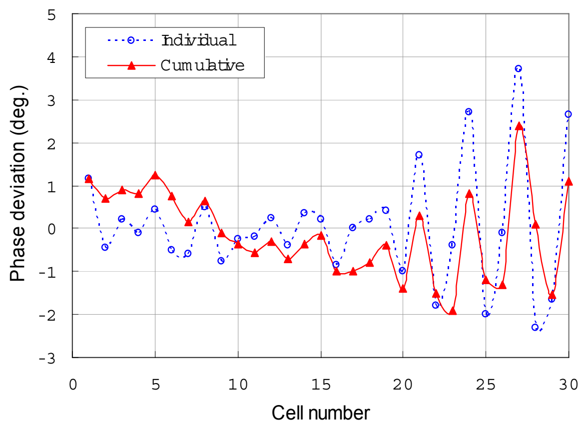

Figure 1: The cell-to-cell phase shifts with respect to 120°.

With an 8-μs pulse length, the klystron supplied peak RF power up to 25 MW. Figure 2 shows the klystron beam voltage, the resulting forward RF power into the accelerating column, and the transmitted RF power out from the column. The transmission is -1.6 dB consistent with the low-power measurement value of -1.5 dB, measured by using a network analyzer. The RF filling time in the column is 0.9 μs.

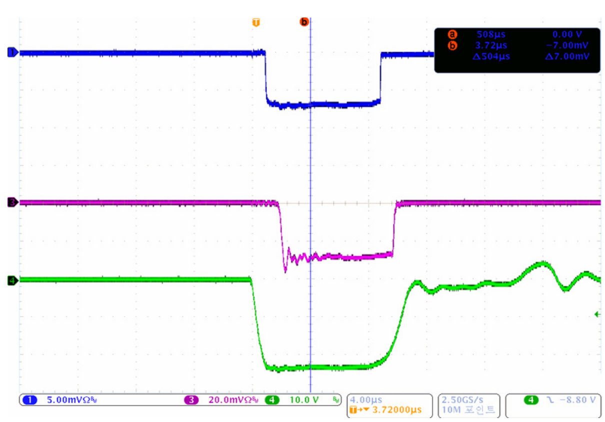

Figure 2: RF power waveform, from top: forward RF power into the column (23 MW), transmitted RF power out from column (16 MW), and klystron beam voltage (260 kV).

BEAM ACCELERATION

A diode-type Pierce E-gun is used for an electron source, which is capable of emitting 3 A with 80-kV negative high-voltages. For an initial test of electron beam acceleration, the beam emission current was 1.6 A with the E-gun HV of 60 kV. The forward RF power into the accelerating column was 20 MW. With pre-buncher optimization, the accelerated beam current was 1.1 A which is measured at the downstream beam current transformer.

When the electron beam is accelerated by RF power, an electron is able to reach to the end of the accelerating column approximately in 10 ns. Since the RF filling time is almost 10^3 times longer than the electron flight time, the electron beam was injected to the column immediately after the RF power had been filled through the column as shown in Figure 3.

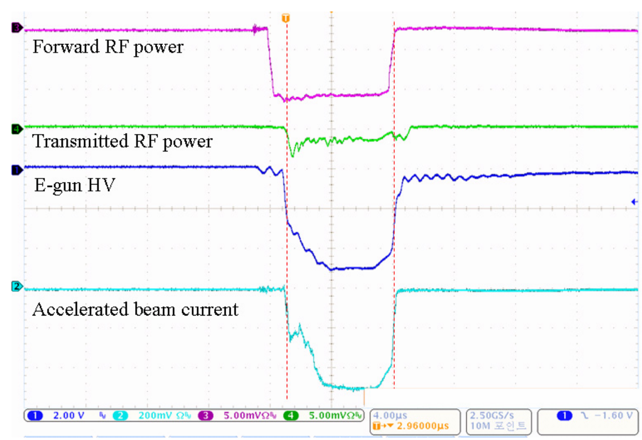

Figure 3: The synchronization of the RF and beam pulses (horizontal: 4 μs/division).

For the improvement of the beam transmission, the pre-buncher is optimized with the RF input power, called a pre-buncher power, and the relative RF phase difference from the accelerating column, called a pre-buncher phase. The changes of the transmission rate with respect to the pre-buncher phase are shown in Figure 4. At the phase of 207°, where the transmission rate is a maximum, the bunch center could slip into the synchronous phase of the RF in the accelerating column [5]. On the other hand, at the phase of 0~20° the RF could not be synchronized with the RF, therefore the transmission rate is a minimum.

With the phase of 207°, the transmission rate is saturated at the pre-buncher power of 0.7 kW, as shown in Figure 5. In the RF linac, the electrons within the acceptable phase are captured and accelerated, since the phase of the electrons can oscillate on the synchronous phase. Over the pre-buncher power of 0.7 kW, the phases of the electron beam are modulated within the acceptable phase [5].

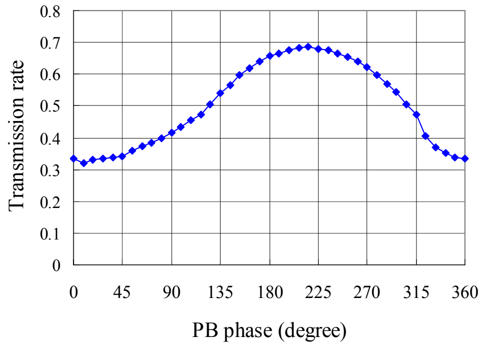

Figure 4: The beam transmission rate with the relative phase of the pre-buncher to the column. The input RF power into the pre-buncher is 0.9 kW.

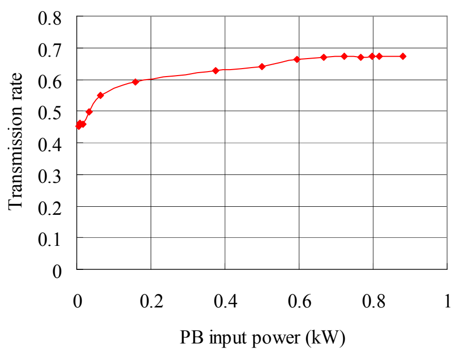

Figure 5: The beam transmission rate with the pre-buncher input power. The pre-buncher phase is 207°.

To measure the electron beam energy, we use an energy measurement tool which composed of 8-layered aluminium plates. The longitudinal length of the first plate is 13 mm as a low-energy filter and the final plate is 20 mm as a beam stopper. The length of the rest plates is 1 mm. The accelerated electron beam energy of 1.1 A with the 20-MW input RF is estimated to be 12.5 ± 0.5 MeV compared with the MCNP simulation on the deposit charge in the plates, as shown in Figure 6 [6].

COMMISSIONING STATUS

The Operation condition of the RF conditioning without the beam is now as follows: 25-MW RF power, 8-μs pulse length, and 50-Hz repetition rate. After the RF conditioning, we will increase the beam duty factor to the nominal operation parameters.

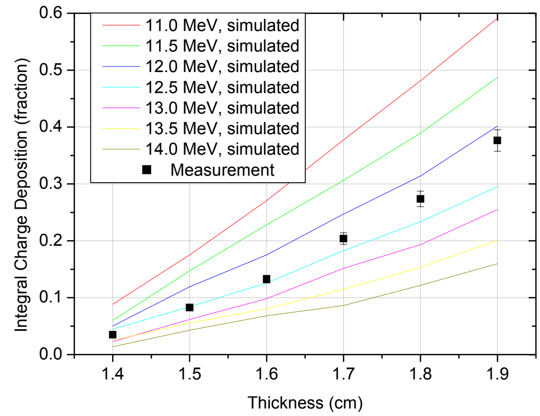

Figure 6: Integrated deposit charges for the electron beam penetrating aluminium plates, measurement values compared with MCNP simulation values.

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