COMMISSIONING OF L-BAND INTENSE ELECTRON ACCELERATOR FOR IRRADIATION APPLICATIONS*

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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 in collaboration with POSTECH (Pohang University of Science and Technology) and KAPRA (Korea Accelerator and Plasma Research Association). It is capable of producing 10-MeV electron beams with average 30-kW. For a high-power capability, we adopted the L-band traveling-wave structure operated with a $2\pi/3$ mode. The RF power is supplied by the pulsed 25-MW and average 60-kW klystron with the matched pulse modulator and the inverter power supplies. The accelerating gradient is 4.2 MV/m with the beam current of 1.45 A which is fully beam-loaded condition. The solenoidal magnetic field is 700 Gauss to focus the electron beam and suppress the BBU instability. In this paper, we present commissioning status with details of the accelerator system.

INTRODUCTION

There are increased demands on electron accelerators used for industrial applications such as the irradiation processing, the X-ray imaging, and medical applications [1]. In any case, the beam energy is restricted by 10 MeV due to neutron production. For irradiation processing, the electron beam energy is determined by the depth of irradiation targets and the higher beam power is favorable which increases the process speed. On the other hands, X-ray sources for the industrial CT or the radio-surgery requires 5 – 10 MeV electron beams with average power of a few or sub-kilowatts [2]. RF linacs are favored for these applications due to compactness of the accelerating structure.

The electron accelerators for the irradiation processing can be classified by acceleration methods: DC accelerators, RF linacs, and re-circulating accelerators. DC accelerators have better power efficiency compared with the others. However the energy is practically limited due to breakdown in industrial applications [3]. Re-circulating accelerators such as the Rhodotron® are capable of up to several hundred kilowatts [4]. However, since these accelerators require magnetic fields for re-circulation depending on the beam energy not the beam power, RF linacs is more favorable for a few tens of kilowatts. The maximum beam power by the RF linac was 25 kW with S-band RF [5].

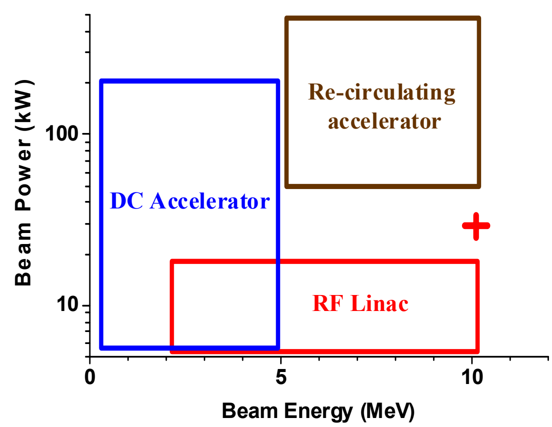

Figure 1: Favorable accelerators on beam energy and power for the irradiation processing, the red cross: our machine.

PAL/POSTECH developed a 10-MeV, 30-kW RF linac in collaboration with KAPRA. In order to treat high power, the L-band RF system and accelerating structure are 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. Also the RF power coupling is independent of the beam current. To achieve highest power efficiency, the accelerator is operated with almost a fully beam-loaded condition.

*Work supported by KAPRA and POSTECH BK21 Program.
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ACCELERATOR DETAILS

A 1.3-GHz klystron provides pulsed 25-MW, average 60 kW RF power to the accelerating column with 8-μs pulse length and 300-Hz repetition rates. Eight inverter power supplies and a matched pulse modulator supply 275-kV and 260-A pulsed power to the klystron. Each inverter generates the charging voltage of 45 kV and average 30 kW. A pulse forming network in the pulsed modulator consists of 15 states of a 50-nF capacitor and a 2.2-μH inductor. A thyratron tube switches on the modulator circuit and 1:13-transformer steps up the voltage before the klystron [6].

The accelerating structure consists of 31 cells, the five front cells are for bunching whose phase velocities increase gradually up to the velocity of light [7]. It is resonated with $2\pi/3$ mode at 1.3 GHz. The RF filling time is 0.8 μsec. When the input RF power is 25 MW, it is a fully beam loaded condition with the beam current of 1. 45 A. The temperature of RF cavities in the accelerating structure is maintained within 40 ± 1 °C. Detailed accelerator parameters are listed in Table 1.

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	$2\pi/3$ 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/°C

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 Fig. 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 Fig. 2 (c) due to the regenerative BBU (Beam Break-Up) instability [8]. 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.

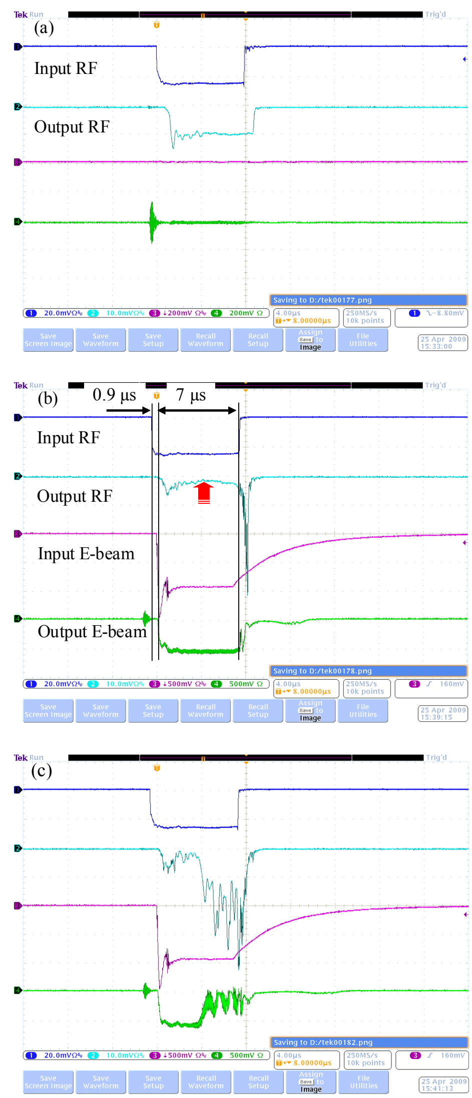

Figure 2: RF power and E-beam current waveform, (a): without beam only RF injected, (b): beam accelerated with the focusing magnetic field of 700 Gauss, and (c): beam broken up with 530 Gauss.

The accelerated electron beam is deflected in alternating magnetic fields generated by the scanning magnet. This magnet consists of two sets of coil, whose inner diameter is 100 mm, outer 340 mm, and height is 120 mm. The coil is placed 70 mm apart from each other. With 48000 ampere-turn per the coil, the electron beam is scanned uniformly as shown in Fig. 3.

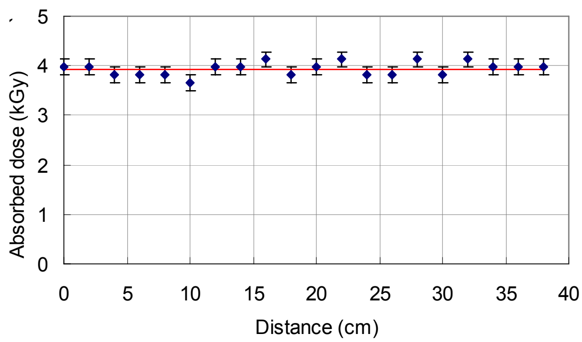

Figure 3: Dose distribution along scanning direction.

The electron beam energy is measured with two pieces of aluminum wedge. The deposit energy of the electron penetrating through the aluminum depends on their energy. A CTA (Cellulose Tri-Acetate) film dosimeter is inserted between two aluminum wedges with angle of 16.2º. The absorbed dose of the dosimeter represents deposit dose of the electron beam in the aluminum. From the range where the deposit dose becomes half in Fig. 4, the electron beam energy is supposed as 10 ± 1 MeV.

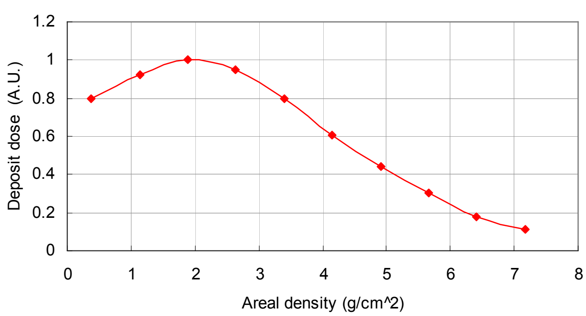

Figure 4: Deposit dose in the aluminum with penetration depth.

COMMISSIONING STATUS

The electron beam is now being accelerated with the following parameters: 20-MW RF power and 1.0-A output beam current with 7-µs beam pulse length and 153-Hz repetition rate. The beam energy is 10-MeV and the beam power is average 10 kW. Recently, we has been installed another accelerator and it is now being conditioned.

ACKNOWLEDGEMENT

This work is supported by KAPRA and POSTECH BK21 (Brain Korea 21) Program. The authors express their appreciations to Prof. Luo Yingxiong at IHEP, Beijing for useful discussions.

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