DEVELOPMENT OF L-BAND ELECTRON ACCELERATOR FOR IRRADIATION SOURCE*

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Abstract

An intense L-band electron accelerator is under development for irradiation applications. It is capable of producing 10-MeV electron beams of 30 kW with the fully beam-loaded condition. The accelerator is powered by a pulsed klystron of 1.3 GHz and 25 MW with the 60-kW average power. The accelerating column, a traveling-wave structure, is operated with the 2π/3 mode and is installed vertically with other beam-line components. With the beam dynamics simulation, the beam transmission efficiency is over 90% and the beam size is enough to clear the apertures. Design details and the status of installation are presented for the L-band electron accelerator.

INTRODUCTION

Recently, the interests are increased in industrial applications of the electron linear accelerators [1]. The electron beam energy is limited by about 10 MeV due mainly to neutron production. For the clinical X-ray systems, low current and 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 since the process speed is proportional to it [3].

We are developing a high average-power electron accelerator for the grain sterilizing application by the institutional collaboration between the Korea Accelerator and Plasma Research Association (KAPRA) and Pohang Accelerator Laboratory (PAL) at POSTECH. The accelerator is required to provide an average beam power of 30 kW at the beam energy of 10 MeV. In order to achieve the beam power, we use a single L-band klystron with a matched pulse power supply. For an accelerating structure, the travelling-wave structure with 2π/3 mode is adopted in which the bunching section is included for compactness. Each component of the accelerator system is described in the next section. The design detail of the accelerating column follows.

SYSTEM OVERVIEW

The Thales TV2022D klystron generates the pulsed 25-MW and average 60-kW RF power at 1.3 GHz. It is transmitted to the accelerating column through the L-band waveguide network. These waveguides are filled with SF6 gas. Since the column is a travelling-wave structure, the extra RF power is exhausted in the high-power load as shown in Figure 1. For the pre-buncher cavity, the RF power is bypassed in the cross-coupled directional coupler and transmitted through the coaxial cable with the adjusted power and phase. The pulse modulator developed at PAL supplies 264-kV and 230-A pulse power to the klystron with the pulse length of 7 us and the repetition rate of 350 Hz. Due to the high average power requirement, 8 units of 30-kW high-voltage inverter stack connected in parallel are used for the PFN charging. E-gun high-voltage pulser supplies the 80-kV and 1.6-A pulse power between the cathode and the anode of the E-gun.

Table 1: Accelerator parameters.

RF Parameters	
Operating Frequency	1.3 GHz
Pulsed RF Power	25 MW
Pulse Length	7 μs
Repetition Rate	350 Hz
Averaged RF Power	60 kW
E-gun Parameters	
High Voltage	80 kV
Pulsed Beam Current	1.6 A
Pulse Length	6 μs
Repetition Rate	350 Hz
Beam Parameters	
Beam Energy	10 MeV
Pulsed Beam Current	1.45 A
Beam Transmission Rate	91%
Averaged Beam Power	30 kW
Accelerating Structure Parameters	
Type of Structure	Constant-impedance
Shape of Cell	Disk-loaded
Operating Mode	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

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To evacuate the accelerating column and the beamline, two ion-pumps of 240 *l*/s are connected to the waveguide attached on the input and output couplers of the column. The E-gun also has a 20-*l*/s ion pump for strict vacuum condition on the cathode.

There are 5 solenoid magnets and a pair of steering magnets. To focus the electron beam by the solenoids, the first one requires 2000 A·turn while the rest requires 3-4.5×10^5 A·turn. The steering magnet tilts the beam direction up to 13° in the transverse direction with 500 A·turn.

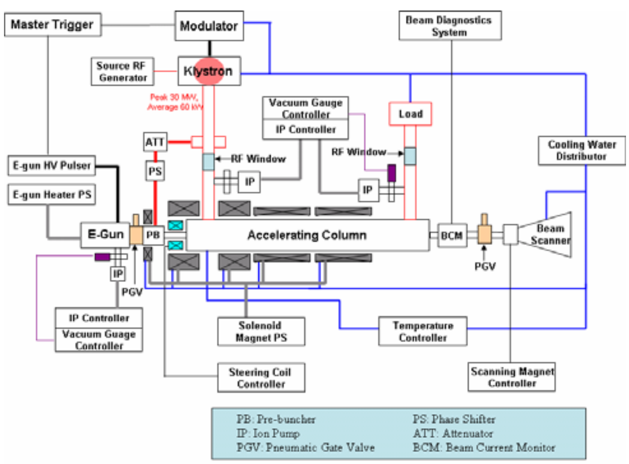

Figure 1: Block diagram of the accelerator system.

DESIGN OF ACCELERATING COLUMN

The accelerating column is consisted of 5 bunching cavities and 26 normal accelerating cavities. Since it is a travelling-wave accelerating structure, the first bunching cavity and the last normal cavity contain the input and output couplers, respectively. The phase velocity of each bunching cavity is determined as listed in Table 1.

Table 1: Phase velocity and attenuation coefficient

Cavity	Phase velocity / Speed of light	Attenuation Coefficient (Nep/m)
1st buncher	0.65	0.0538
2nd buncher	0.75	0.0489
3rd buncher	0.88	0.0442
4th buncher	0.92	0.0431
5th buncher	0.98	0.0415
Normal	1.00	0.0623

Since the RF power attenuates as passing through the accelerating column, the longitudinal electric field is defined by [3]

$$E(z) = E_0 \exp(-\alpha z)\sin\phi - I r_s (1-\exp(-\alpha z)), \quad (1)$$

where r_s is the shunt impedance, $E_0 = \sqrt{2\alpha P_0 r_s}$, α is the attenuation coefficient listed in Table 1, P_0 is the input power from the RF source, and ϕ is the phase of the accelerating field. The last term represents the beam loading effect. The PARMELA simulation was conducted with the field amplitude of each cavity from Eq. (1). According to this equation, the electric field of the last cavity becomes almost zero as the beam current is increased. The accelerating column is operated with this condition, the fully beam-loaded condition.

To achieve the 10-MeV and average 30-kW electron beam, the beam energy and the beam power are calculated by the PARMELA code, with input beam current of 1 to 3 A. Figure 2 shows that the beam loading factor for the beam energy is –4.7 MeV/A. Figure 2 shows that the required beam are obtained with the input beam current of 1.6 A.

Since the beam current is high enough for the space-charge effect to be significant, the focusing magnet is required. With solenoids described in the previous section, the beam is focused effectively. The beam envelope in Figure 3 has no problem in the industrial applications.

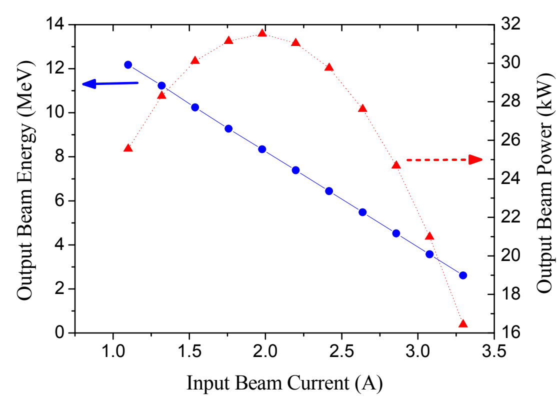

Figure 2: Output beam energy and power with the input beam current at the input RF power of pulsed 25 MW and average 60 kW.

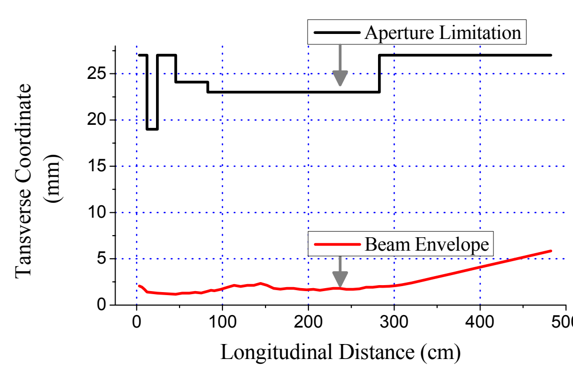

Figure 3: Beam envelope against the aperture limitation.

STATUS AND PLAN

The klystron tube with magnet was delivered from Thales, and it is installed in the klystron tank. The fabrication of the pulse modulator is finished and being tested at PAL. The accelerating column with the pre-buncher cavity, the E-gun assembly, the solenoid magnets are fabricated at IHEP, China. The waveguide components are fabricated at MEGA, US. Other components are being fabricated at POSTECH.

The accelerator system will be firstly installed at PAL for the beam commissioning. In this test, we will obtain the optimum condition of the pre-buncher input power and phase, and the magnetic field of the first solenoid, increasing the input beam current gradually. This accelerator will be finally installed at Cheorwon for the grain sterilization process as shown in Figure 4.

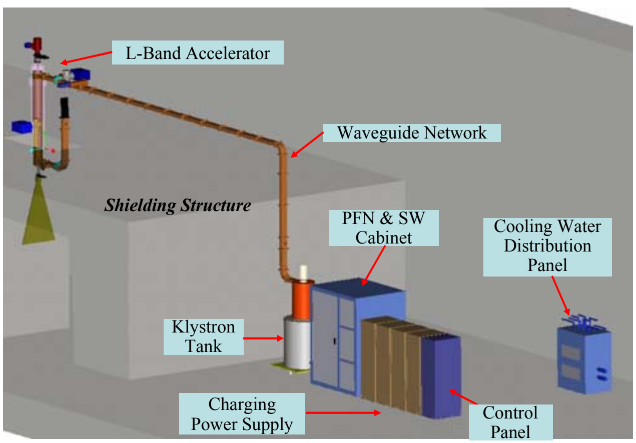

Figure 4: Drawing of accelerator setup at Cheorwon site.

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