COMMISSIONING OF L-BAND ELECTRON ACCELERATOR FOR INDUSTRIAL APPLICATIONS *

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Abstract

An intense L-band electron linear accelerator is now being conditioned at Cheorwon Electron-beam Service Center (CESC) for industrial applications. It is capable of producing 10-MeV electron beams with 30-kW average beam power. For high-power capability, we adopted 1.3 GHz, and the RF source is a 25-MW pulsed klystron with 60-kW average RF output power. The accelerating structure, with a built-in bunching section, is a disk-loaded waveguide with constant-impedance operated in the $2\pi/3$ mode. It is to be operated under the fully beam-loaded condition for high average power with the 6-μs pulse length and the 350-Hz repetition rate. In this paper, we present details of the accelerator system and commissioning status.

INTRODUCTION

Recently, demands on the electron linear accelerator are increased for industrial applications [1]. In using electron beam 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. We present the design details shown 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	7 μs
Repetition Rate	350 Hz
Averaged RF Power	60 kW
E-gun High Voltage	- 80 kV
Pulsed E-gun Current	1.6 A
Beam Pulse Length	6 μs
Beam Energy	10.7 MeV
Output Beam Current	1.4 A
Beam Transmission Rate	90%
Averaged Beam Power	35 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/1°C

RF SYSTEM

The Thales klystron tube (TV2022D) generates 25-MW pulsed RF with 7-μs pulse length and 350-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.

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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. EEV thyratron tube (CX2412X) is used for the switch.

The pulsed power is applied to the klystron through the 1:13 pulse transformer. Finally, the klystron beam voltage is 264 kV and the beam current is 230 A. Figure 1 shows results of the high-voltage pulse test without the input RF. It has a pulse flat-top longer than 7 μs for the stable output RF.

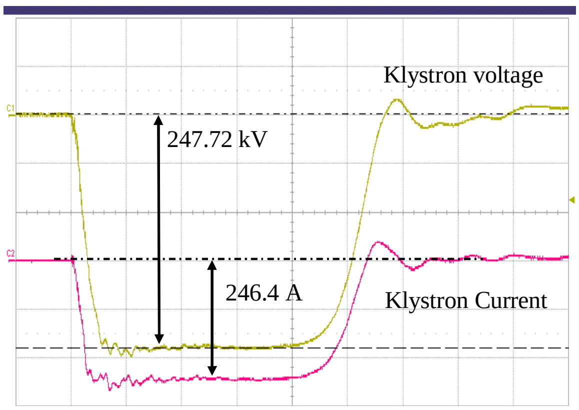

Figure 1: High-voltage pulse test with the klystron (horizontal: 2 μs/div).

The output RF power from the klystron is transmitted to the accelerating column through a WR-650 waveguide network. The material of the waveguide is aluminium and it is filled with 1.5-atm SF_6 gas. Thales RF windows, (TH20141A) break the gas-filled region of the waveguide from the evacuated region of the accelerating column. Since the accelerating structure is operated with a travelling-wave, the output is connected to the water-load.

ACCELERATING COLUMN

The accelerating column consists of 5 bunching cells and 26 normal accelerating cells. Since it is a travelling-wave accelerating structure, the first bunching cell and the last normal cell contain the input and output couplers. The phase velocities of the bunching cells are gradually increased from 0.65c to 0.98c as shown in Table 1.

The accelerating column is a disk-load waveguide. Each cell has a resonant frequency of 1.3 GHz at 2π/3 mode. The attenuation coefficient of each cell is shown in Table 1. Since this accelerating column is operated under the fully beam-loaded condition, the attenuation coefficients are designed to be as in Table 1 [4]. Correspondingly, the net attenuation through the column is -1.5 dB without electron beam. The reason why the attenuation of the bunching cell is smaller than the normal cell is for effective capturing of low-energy beam at the entrance of the column [5].

Table 2: Characteristics of bunching and normal cells

Cell	Phase velocity /c	Group velocity /c	Attenuation coefficient (Neper/m)
1st buncher	0.65	0.0170	0.0538
2nd buncher	0.75	0.0167	0.0489
3rd buncher	0.88	0.0165	0.0442
4th buncher	0.92	0.0164	0.0431
5th buncher	0.98	0.0163	0.0415
Normal	1.00	0.0089	0.0623

The actual column was fabricated by IHEP, China with final dimensions confirmed by prototype test with aluminium cavities [4]. In this test, we measured the resonant frequency of each cell and the RF power coupling of the input and output coupling cell. According to the low-power measurement of the actual column, the transmission is -1.7 dB and the reflection is -20 dB at 1.3 GHz. The cell-to-cell phase shift was also measured detuning each cell in order. The cumulative phase shifts are within ±2° with respect to 120°, as shown in Figure 2.

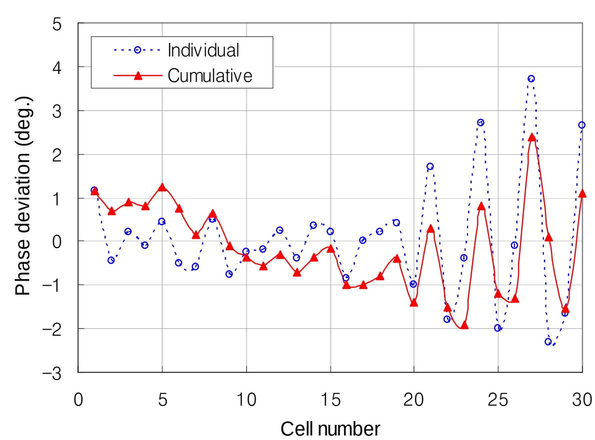

Figure 2: The cell-to-cell phase shifts with respect to 120°.

ELECTRON GUN

A diode-type pierce gun is used for an electron source. The perveance is 0.13 μPerv and the diameter at the beam waist 1.5 mm from the anode head. This gun is powered by an 80-kV pulsed power supply. The power supply uses the 0.1-μF charging capacitor and two sets of solid-state switches, corresponding to ON/OFF. The electron beam was emitted from the gun with the pulsed power supply as shown in Figure 3. The measured perveance is 0.12 μPerv.

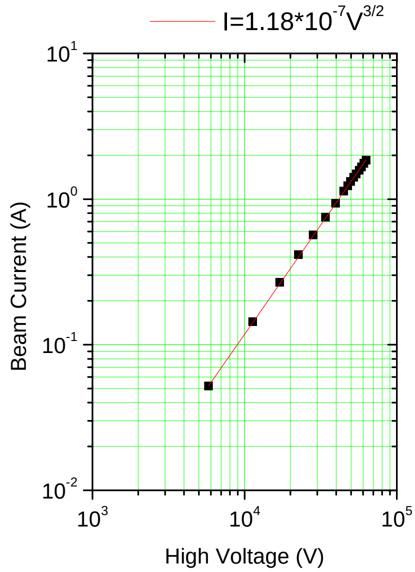

Figure 3: The E-gun beam current as a function of the applied high-voltage.

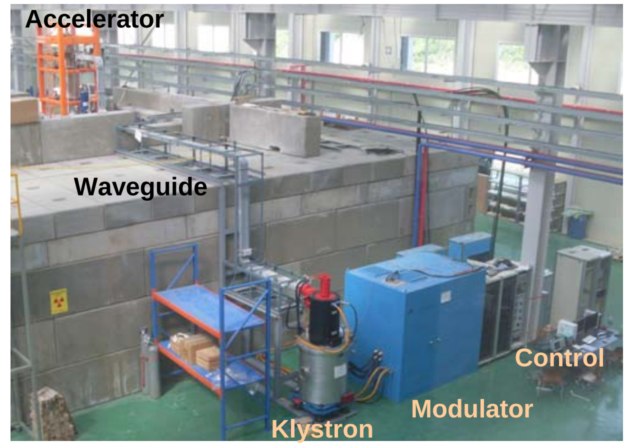

Figure 4: The overall view of the accelerator system.

COMMISSIONING STATUS

The RF system and the beamline were installed at CESC. The infrastructure, e.g. the cooling system and the shielding block, was ready at the site. Figure 4 shows the overall view of the accelerator system in the site. The accelerating column is placed on the second floor of the shielding block. The beam will be irradiated toward inside the shielding block where the target object is moving on the conveyor belt. The accelerating column is now being conditioned with gradually increasing RF power. The cathode of the electron gun has been activated, and the e-beam conditioning is now being conducted.

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