BEAM COMMISSIONING OF C-BAND STANDING-WAVE ACCELERATOR FOR X-RAY SOURCE*

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Abstract

A C-band standing-wave electron linac for a compact X-ray source is now being commissioned at ACEP (Advanced Center for Electron-beam Processing in Cheorwon, Korea). It is designed to produce 4-MeV electron beam with pulsed 50-mA, using a 5-GHz RF power generated by a magnetron with pulsed 1.5 MW and average 1.2 kW. The accelerating structure is a bi-periodic and on-axis-coupled one operated with π/2-mode standing-waves. It is consisted of 3 bunching cells, 6 accelerating cells and a coupling cell. As a result of measurements, the beam energy is almost 4 MeV. In this paper, we present the design details and the commissioning status.

INTRODUCTION

An electron RF linac is widely used for industrial applications, for example, the sterilization of products, medical diagnosis and therapy, material surface processing, and contraband detection [1]. The Sterilization processing requires an average beam power of several tens of kilowatts which depends on the processing speed. High power accelerators prefer L-band or S-band linacs due to a cooling capacity. C-band or X-band linacs are preferred for medical purposes due to compactness. The compact accelerator system for medical therapy is developed and operated to treat cancer such as Novalics and Cyberknife [2]. The contraband detection requires 5 – 10 MeV with the pulsed beam current of almost 150 mA [3, 4].

We are developing an electron accelerator for X-ray sources. It is capable of producing 4-MeV electron beam with pulsed 50-mA, using pulsed 1.5-MW C-band RF power. In the following sections, we present design of the overall accelerator system and conditioning history. We also present measurement results of the RF power, beam current and beam energy.

ACCELERATOR OVERVIEW

The RF source for the accelerator is a 5-GHz magnetron made by CPI. It is capable of producing 1.5 MW with 4-μs pulse length and 200-Hz repetition rates. The RF power is transmitted to the accelerating column through WR187 waveguides filled with the SF_6 gas in the atmospheric pressure. A pulse modulator supplies the 40-kV and 90-A pulsed power to the magnetron [5]. It also supplies 20-kV pulsed voltage to an E-gun by a branch in the pulse transformer. The E-gun is a diode-type thermionic DC gun, capable of injecting pulsed 150-mA beam.

Table 1: The Design Parameters for the Accelerator

Operating Frequency	5 GHz
Input Pulsed RF Power	1.5 MW
Pulse Length	4 μs
Repetition Rate	200 Hz
E-gun Voltage	20 kV
Input Pulsed Beam Current	150 mA
Output Beam Energy	4 MeV
Output Pulsed Beam Current	50 mA
Output Average Beam Power	160 W
Type of Structure	Bi-periodic, On-axis coupled
Operating Mode	SW π/2 mode
Beam Aperture Diameter	10 mm
Average Accelerating Gradient	13.3 MV/m
Number of Cells	10
Inter-cell Coupling	6%
Quality Factor*	11000
Effective Shunt Impedance*	90 MΩ/m
Transit-time Factor*	0.81

*Values for normal cells.

For a compact system, the accelerating structure is attached to the E-gun directly and a pre-buncher with a drift tube is omitted, as shown in Figure 1. Furthermore, no solenoids magnet is used since the beam current is low enough to be focused by the intrinsic focusing effect of the standing-wave electric field [6].

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A bi-periodic and on-axis coupled structure is adopted for the π/2-mode standing-wave structure [7]. To increase the inter-cell coupling up to 6%, the magnetic coupling slot is bored on the wall between the accelerating cavity and the coupling cavity. The first three cells, in the Figure 2, are bunching cells with the phase velocity of 0.7*c*, and later six cells are normal cells with the phase velocity of *c* (speed of light). The last one is a coupler cell attached to the tapered waveguide.

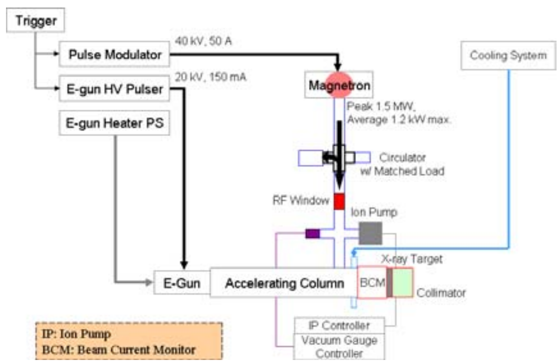

Figure 1: The schematic diagram of accelerator system.

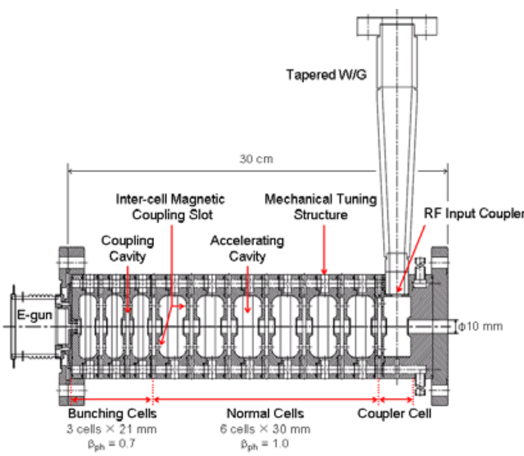

Figure 2: The cross-sectional view of the accelerating structure. The inter-cell magnetic coupling slots are skewed to this plane.

RF MEASUREMENT

With low power measurements of the fabricated accelerating column, the resonant frequency was 4998.86 MHz, the β was 0.917, and the Q_0 was 9658. The electric field is distributed with π/2-mode, and the field flatness was 0.78% with the bead test.

For adjusting the resonant frequency and improving the field flatness, each cavity was tuned by squeezing the cavity. Finally, the column is tuned with 4999.17-MHz resonant frequency and 0.65% field flatness.

Gradually increasing the RF power, the accelerating structure has been conditioned with the 4-μs pulse length, and the 10-Hz repetition rate. The operating RF power is 1.5 MW, and it has taken almost 50 hours to achieve the operating power, as shown in Figure 3, 4.

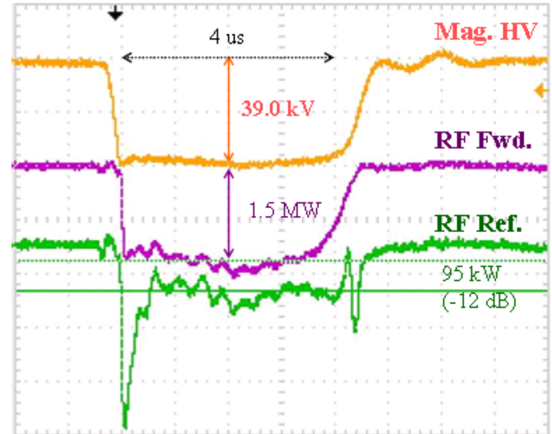

Figure 3: The forward RF power and the reflect RF power at the operating condition.

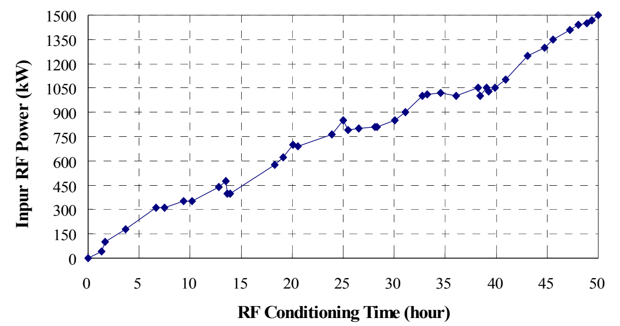

Figure 4: The history of the RF conditioning.

The parameters of the accelerating column are changed at the beginning of the RF conditioning. The resonant frequency is changed to 4994.05 MHz, the β is decreased to 0.562, and the Q_0 is decreased to 7071. The electric field distribution is little changed, and the field flatness is changed to 2.89%. According to the result of the bead test in Figure 5, peaks of the accelerating field in the accelerating cavities are reduced to almost 92%.

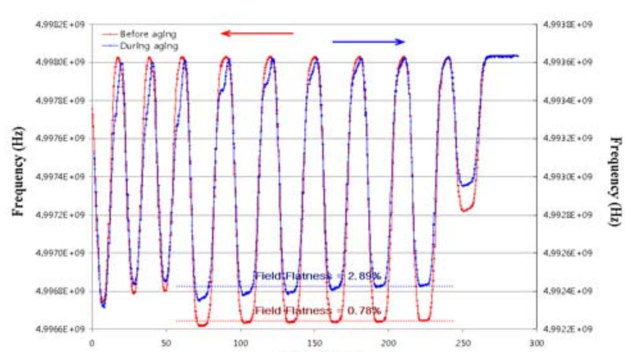

Figure 5: The comparison of the result of the bead test which is conducted before commissioning with during commissioning.

BEAM MEASUREMENT

The output beam parameters of the accelerator are measured at the condition of the 19-kV E-gun high voltage, the 150-mA input beam current, the 1.5-MW forward RF power, the 150-kW reflected RF power. The output beam current is 50 mA, as shown is Figure 6. The output beam energy is obtained by measuring the stopping range of the beam in the Al plates. The output beam energy is 3.5 – 4 MeV since the stopping range of the output beam is 8 – 9 mm, as shown in Figure 7.

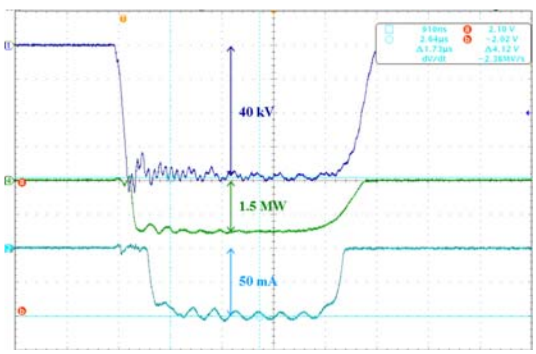

Figure 6: The waveform of the magnetron input high voltage (blue), the accelerator forward RF power (green), and the output beam current (cyan).

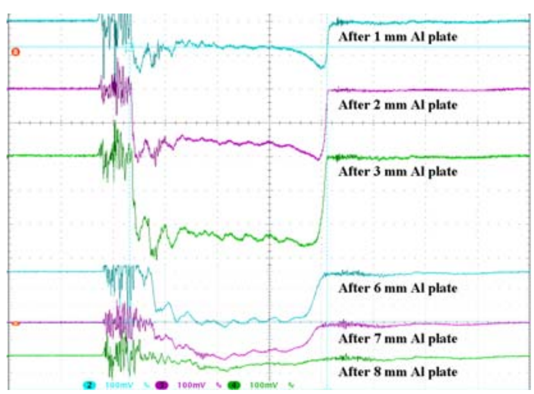

Figure 7: The waveform of the charge deposition of the Al plate.

SUMMARY

The C-band accelerating column has been fabricated and is being commissioned. After the RF conditioning, the resonant frequency and the quality factor are slightly changed. However, the accelerating fields are reduced less than 10%. At the injected beam current of 150 mA with 1.5-MW RF power, the beam is accelerated to almost 4 MeV with 33% transmission efficiency which corresponds to the design values.

ACKNOWLEDGEMENT

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