COMMISSIONING OF C-BAND STANDING-WAVE ACCELERATOR*

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Abstract

A C-band standing-wave electron accelerator for a compact X-ray source is being commissioned at ACEP (Advanced Center for Electron-beam Processing in Cheorwon, Korea). It is capable of producing 4-MeV electron beam with pulsed 50-mA. The RF power is supplied by the 5-GHz magnetron with pulsed 1.5 MW and average 1.2 kW. The accelerating column is a bi-periodic and on-axis-coupled structure operated with π/2-mode standing-waves. It consists of 3 bunching cells, 6 normal cells and a coupling cell. As a result of cold tests, the resonant frequency of the accelerating column is 4999.17 MHz at the π/2-mode and the coupling coefficient is 0.92. The field flatness was tuned to be less than 2%. In this paper, we present commissioning status with design details of the accelerator system.

INTRODUCTION

The electron accelerator is widely used for industrial applications, for example, a medical diagnosis and therapy, sterilization of products, material surface processing, and a contraband detection [1]. Sterilization processing requires an average beam power of several tens of kilowatts which depends on the processing speed. The contraband detection requires 5-10 MeV with the pulsed beam current of about 150 mA [2, 3].

We are developing an electron accelerator for an X-ray source, for industrial application. It is producing 4-MeV electron beam with pulsed 50-mA, using pulsed 1.5-MW C-band RF. In this paper, we present design of the overall accelerator system and measurement results of the prototype cavity. Also we present fabrication and RF conditioning of the actual accelerating structure.

ACCELERATOR OVERVIEW

An RF source for the accelerator is a 5-GHz CPI magnetron. 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 the WR187 waveguide network, which is filled with atmospheric pressure SF6 gas. A pulse modulator supplies the 40-kV and 90-A pulsed power to the magnetron with 4-μs pulse length [4]. It also supplies 20-kV pulsed voltage to an E-gun. 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 [5].

A bi-periodic and on-axis coupled structure is adopted for the π/2-mode standing-wave structure [6]. 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 $\beta_{ph} = 0.7$, and later six cells are

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normal cells with $\beta_{ph} = 1$. The last one is a coupler cell attached to the tapered C-band waveguide.

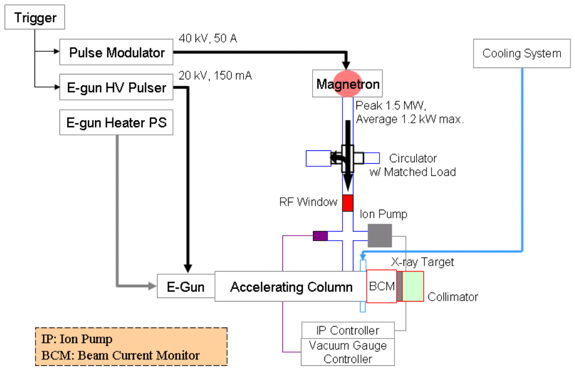

Figure 1: The schematic diagram of accelerator system.

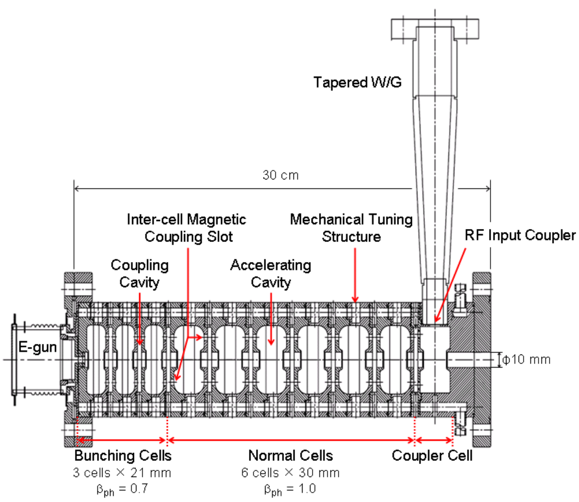

Figure 2: The cross-sectional view of the accelerating structure. The inter-cell magnetic coupling slots are skewed to this plane.

PROTO-TYPE TEST

The aluminium proto-type cavities are fabricated for confirming the cavity design [7]. With measurements of the cells, the resonant frequency of the bunching cells is 5000.000±0.661 MHz and the one of the normal cells is 4999.600±0.163 MHz.

A proto-type test of a coupler cell is conducted to decide the dimension of the RF input coupler. If the beam power P_b is 0.2 MW and the cavity dissipated power P_c is 1.3 MW, the critical coupling condition, where accelerating efficiency becomes maximized, is calculated as follows:

$$\beta^{critical} = \frac{P_{ex}}{P_c} = \frac{P_b + P_c}{P_c} = 1.15, \qquad Q_{ext} = \frac{Q_0}{\beta} = 9600, \tag{1}$$

where β is a coupling coefficient, P_{ex} is the power dissipated in the external load, Q_{ext} is the external quality factor, and Q_0 is the unloaded quality factor. The β depends on the size of the coupling hole. The Q_{ext} of the accelerating structure is measured with changing the size. As a result, the size of the coupling hole is decided 8-mm width and 17-mm length – the Q_{ext} is 9300 – as shown in Figure 3.

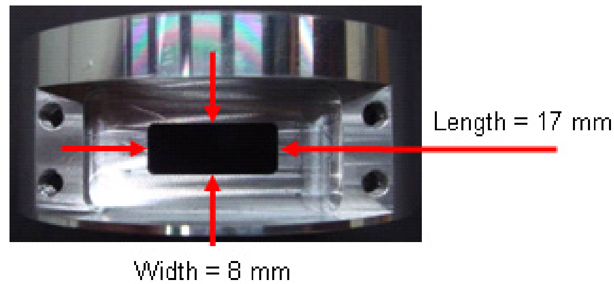

Figure 3: The RF input coupler of the coupler cell.

FABRIACATION OF ACCELERATING STRUCTURE

The actual accelerating structure with the OFHC copper is fabricated, as shown in Figure 4. With the measurement of the actual structure, the resonant frequency is 4998.86 MHz, the β is 0.917, and the Q_0 is 9658. The bead test is conducted to measure the electric field distribution. On the axis, the relation between the electric field of the accelerating structure E and the variation of the resonant frequency by the bead $\Delta\omega_0$ is as follows:

$$|E(z)| \propto \sqrt{\left|\frac{\Delta\omega_0(z)}{\omega_0}\right|}. \tag{2}$$

The electric field is distributed with π/2-mode, and the field flatness is measured with 0.78%, as shown in Figure 5.

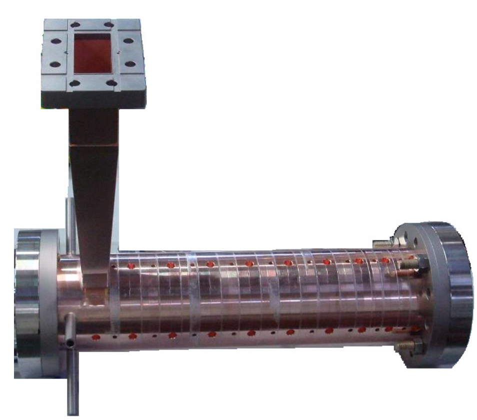

Figure 4: The actual accelerating structure with the OFHC copper.

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, as shown in Figure 5.

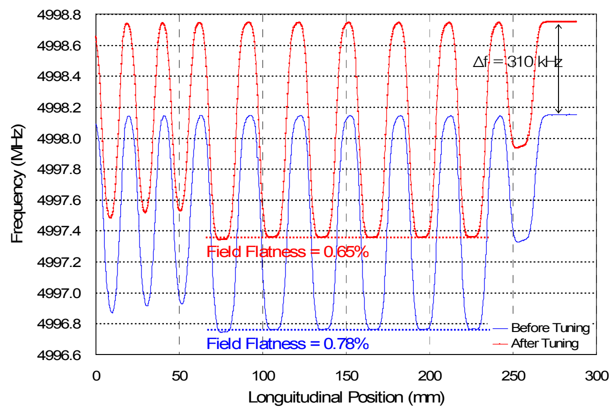

Figure 5: The result of the bead test. The blue line test is conducted before tuning, and the red line test is conducted after tuning.

RF CONDITIONING

The accelerating structure is now being conditioned with gradually increasing RF power. The operation condition is as follows: peak 550-kW RF power, 4-μs pulse length, and 10-Hz repetition rate, as shown in Figure 6. After the RF conditioning is finished, we will extract the electron beam from the accelerator and measure the electron beam energy and current. Also, we will increase the duty factor to the nominal operation parameters.

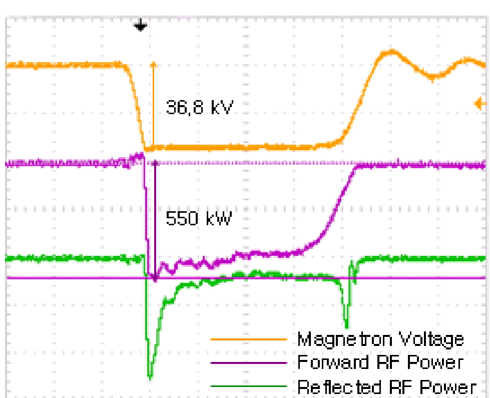

Figure 6: The operation condition of the RF conditioning

SUMMARY

The aluminium proto-type cavities are fabricated. The measured resonant frequency of the proto-type cavity is almost 5 GHz for both the normal and bunching cells. The RF input coupler is decided by measuring the Q_{ext}. The actual accelerating structure is fabricated and mechanical tuned with 4999.17-MHz resonant frequency and 0.65% field flatness. The RF conditioning is now conducted with peak 550-kW RF power, 4-μs pulse length, and 10-Hz repetition rate.

ACKNOWLEDGEMENT

This work is supported by KAPRA and POSTECH BK21 (Brain Korea 21) Program. The authors appreciate Prof. Luo Yingxiong at IHEP, Beijing for his advice on the accelerator system and the cavity design.

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