DEVELOPMENT OF THE FLAT-TOP ACCELERATION SYSTEM FOR THE RCNP AVF CYCLOTRON

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Abstract

A new flat-top acceleration system has been developed for an RCNP K140 AVF cyclotron to reduce the energy spread of a beam and to improve beam transmission to an RCNP K400 ring cyclotron. A flat-top cavity with a length of 700 mm and an outer diameter of 170 mm is capacitively coupled to a main resonator. A maximum peak harmonic voltage of 5 kV can be produced on a dee electrode by feeding power from a 10 kW transistor amplifier. A wide range of harmonic frequencies from 50 to 80 MHz is covered by the flat-top system. Three kinds of harmonic modes, fifth, seventh and ninth harmonics, are available to produce a flat-top voltage waveform in the whole fundamental frequency range between 6 and 18 MHz. The existing main resonator of the AVF cyclotron has been modified to avoid the interference by the parasitic resonance mode generated in the transversal direction of the dee electrode. Development of the flat-top accelerated beam is now in progress. The beam intensity of a high quality 300 MeV proton beam has been remarkably increased by a factor of four. The energy spread of the 300 MeV proton beam, transferred to the Grand Raiden in achromatic mode, has been improved to $\Delta E/E = 1 \times 10^{-4}$.

INTRODUCTION

The K400 ring cyclotron provides the high quality beam with the energy spread $\Delta E/E$ of the order of 10^{-4} by using a flat-top acceleration system for high resolution experiments in nuclear physics [1]. The energy resolution of $\Delta E/E = 5 \times 10^{-5}$ was achieved by a dispersion matching method applied to the beam transport to the spectrometer “Grand Raiden” [2, 3]. The ultrahigh resolution was, however, accomplished at the sacrifice of the beam intensity by cutting a beam in the center region of the AVF cyclotron to provide a high quality injection beam for the ring cyclotron. In order to improve the beam quality and hence to increase the beam transmission to the ring cyclotron, a flat-top acceleration system has also been introduced for the AVF cyclotron under the upgrade program of the RCNP cyclotron facility [4, 5].

The AVF cyclotron, commissioned in 1973, has a single dee electrode with an opening angle of 180 degrees [6]. A main resonator is equipped with a coaxial cavity of movable–short type and a power feeder coupled to the main cavity capacitively. The fundamental frequency range from 6 to 18 MHz is covered by the main resonator system.

The design of the flat-top acceleration system was optimized based on the model test using a 1/5-scale resonator [7]. The flat-top acceleration system was installed in JFY2004, and its commissioning started in 2005. In this paper, performance of the flat-top acceleration system and a recent result of flat-top accelerated beam development are described.

THE FLAT-TOP ACCELERATION SYSTEM

Flat-top cavity

A schematic layout of main and flat-top resonators of the AVF cyclotron is shown in Fig. 1. An additional flat-top cavity of coaxial movable-short type is capacitively coupled to the main resonator at the opposite side of the main power feeder for fundamental-voltage production. The flat-top cavity has a length of 700 mm and an outer diameter of 170 mm. A full stroke of the shorting plate of the flat-top cavity is 100 mm. A coupler electrode and an inner conductor of the flat-top cavity are shown in Fig. 2. A gap between the coupler electrode and an inner tube of the main cavity can be changed from 0 to 155 mm. Fine adjustment for 50 Ω impedance matching is accomplished by a tuner with a full stroke of 40 mm.

A flat-topped dee voltage waveform can be generated by superimposing a harmonic voltage on the fundamental one [8]. Main parameters of the RF system are listed in Table 1. An RF power from a 10 kW transistor amplifier is transmitted to the flat-top resonator through a coaxial waveguide WX39-D. Input impedance is adjustable by changing the capacitance of a feeder capacitor between 5 and 250 pF. Impedance matching of a 50 Ω transmission line from the flat-top cavity to the main resonator is

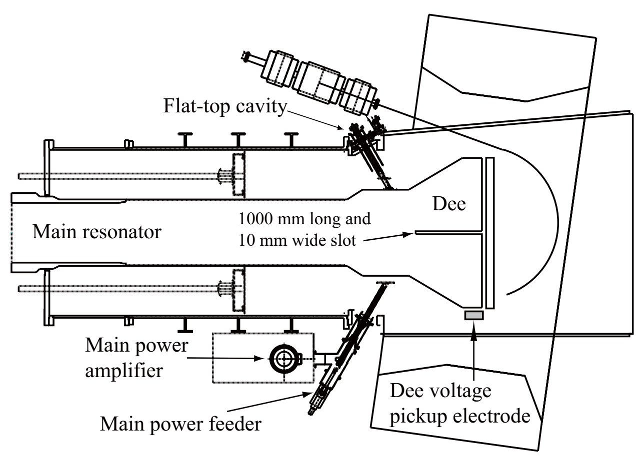

Figure 1: Layout of the RCNP AVF Cyclotron.

optimized by adjusting positions of the coupler, the

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shorting plate, the tuner and the feeder capacitor. A 50 Ω impedance matching can be achieved in a wide range of harmonic frequencies from 50 to 80 MHz. Hence the fifth, seventh and ninth harmonic modes are available for production of the flat-topped voltage waveform. Such higher order harmonic modes have an advantage of saving power for the harmonic voltage production, since the *n*-th harmonic voltage required for the flat-top waveform production is $1/n^2$ of the fundamental one [9].

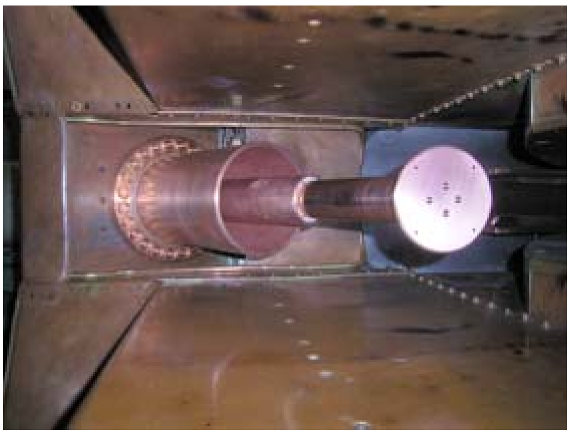

Figure 2: The coupler electrode and the inner conductor of the flat-top cavity.

Table 1: Main parameters of the RF system

Fundamental frequency	6 - 18 MHz
Maximum acceleration voltage	60 kV peak
Flat-top : harmonic number	5, 7, 9
Flat-top : harmonic frequency	54 - 80 MHz
Flat-top : maximum harmonic voltage	5 kV peak
Flat-top : maximum Q-value of resonator	2000
Flat-top : maximum RF power	10 kW
Flat-top : maximum voltage of resonator	80 kV peak
Flat-top : maximum current density	50 A/cm

Modification of Dee Electrode

A parasitic resonance mode was known to exist originally at around 76 MHz. This resonance is generated in the transversal direction of the dee electrode axis. There is some possibility of the parasitic resonance's interference with the fifth harmonic voltage production for the flat-top acceleration of higher energy protons. In order to shift the transversal resonance frequency to around 55 MHz, the original dee electrode was replaced by a new one with a 1000 mm long and 10 mm wide slot along the electrode axis as shown in Fig. 1.

New dee-voltage pickup electrodes have been installed near the acceleration gap of the dee electrode as shown in Fig. 1. The four pickup electrodes are mounted on a copper block facing the side of the dee electrode. Two pickup electrodes have been designed to have a pickup signal level ratio of $1/10^4$, used for fundamental voltage regulation and RF reference signal supply to users and control systems of a beam buncher and a beam chopper. The signal from the pickup electrode with a pickup ratio of $1/10^5$ is used for monitoring the flat-top voltage waveform at a console. Other pickup electrode provides a harmonic signal for a low-level control of the flat-top resonator.

Power Test

The performance of the flat-top acceleration system has been investigated in the power tests using the following fifth harmonic frequencies; 77.084 MHz for a 53 MeV proton (to be accelerated up to 300 MeV by the ring cyclotron), 50.582 MHz for a 44 MeV deuteron (200 MeV), 58.250 MHz for a 88MeV $^3He^{2+}$ (420 MeV) and 50.720 MHz for a 87 MeV $^4He^{2+}$ (400 MeV). We have also succeeded in generating the seventh and ninth harmonic voltages at 71.008 MHz for a 87 MeV $^4He^{2+}$ (400 MeV) and 60.750 MHz for a 19 MeV deuteron (80 MeV), respectively. An example of a flat-top voltage waveform observed at 77.084 MHz is shown in Fig. 3.

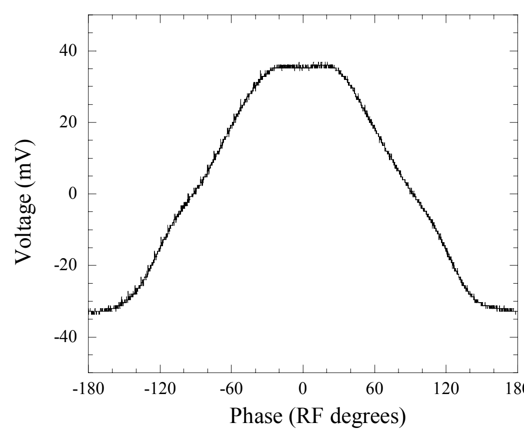

Figure 3: Example of the flat-top voltage waveform observed at 77.084 MHz with the dee voltage pickup electrode.

DEVELOPMENT OF THE FLAT-TOP ACCELERATED BEAM

Development of the flat-top accelerated beam is now in progress. In order to obtain a high quality beam with energy spread less than $\Delta E/E = 5 \times 10^{-4}$, the beam phase width has to be defined within several RF degrees by two pairs of phase defining slits. In this case, a beam buncher, placed in the injection beam line of the AVF cyclotron, plays the significant role for beam intensity keeping. The flat-top acceleration and single turn extraction from the AVF cyclotron is indispensable for production of a high quality beam.

A 300 MeV proton beam was transferred to a gold target in achromatic mode, and energies of elastically-scattered particles were analyzed with the Grand-Raiden for beam quality evaluation. The energy resolution for the

300 MeV proton beam has been estimated to be $\Delta E/E = 1 \times 10^{-4}$. The beam intensity of the high quality proton beam has been remarkably increased by a factor of four.

REFERENCES

[1] I. Miura *et al.*, “The Research Center for Nuclear Physics Ring Cyclotron”, PAC1993, Washington D.C., May 1993, p. 1650.
[2] M. Fujiwara *et al.*, “Magnetic Spectrometer Grand Raiden”, Nucl. Instrum. And Methods A422 (1999) 484.
[3] T. Wakasa *et al.*, “High Resolution WS Beam Line at RCNP”, CYCLOTRONS2001, East Lansing, May 2001, p. 458.
[4] K. Hatanaka *et al.*, “Upgrade Project of the RCNP AVF Cyclotron Facility”, CYCLOTRONS2004, Tokyo, October 2004, p. 115.
[5] K. Hatanaka, “Developments of the RCNP Cyclotron Cascade”, this conference.
[6] I. Miura *et al.*, RCNP Annual Report 1976, p.12.
[7] T. Saito *et al.*, “The Flat-Top System for the RCNP AVF Cyclotron”, CYCLOTRONS2004, Tokyo, October 2004, p. 333.
[8] J.L. Conradie *et al.*, “A Flat-top Acceleration System for the NAC Light Ion Injector Cyclotron”, Cyclotrons1995, Cape Town, October 1995, p. 249.
[9] M. Fukuda *et al.*, “Flat-top Acceleration System for the Variable-Energy Multiparticle AVF Cyclotron”, Rev. of Sci. and Instr., 74 (2003) 2293.