THE FLAT-TOPPING SYSTEM FOR THE RCNP RING CYCLOTRON

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A variable frequency (90~150MHz) single gap cavity flat-topping system was developed for RCNP ring cyclotron to realize high beam energy resolution and single turn extraction. Extremely high stability is required for relative phase between the acceleration and flat-topping voltage. Typical phase excursion of the cavity voltage is less than 0.1deg./100hrs. Voltage variations are less than 0.01 and 0.05% for the acceleration and flat-topping, respectively.

1 Introduction

The RCNP Ring cyclotron was constructed to provide high quality beam for experimental studies of the nuclear physics. The first beam of 300MeV protons was successfully extracted from the ring cyclotron in autumn 1991. Since the first extraction, various efforts for improving the beam quality and the beam extraction efficiency have been done. Energy spread of 0.02% and pulse width150psec was achieved on target of high resolution spectrograph and neutron TOF ,respectively. The specification of the RCNP ring cyclotron is shown in Table 1.

Table 1: Specification of the RCNP Ring Cyclotron.

Maximum energy		
	p	400MeV
	d	200MeV
	^{3}He	510MeV
	α	400MeV
	light heavy ions	400Q^2/A
RF system		
Acceleration		
	Single gap cavity	3sets
	Frequency	30~52MHz
	Maximum voltage	550kV
	RF power	250kW/cavity
	Beam aperture	30×2310mm
	Acceleration gap	200~300mm
	Voltage stability	10^{-4}p-p/p
	Phase stability	0.1deg.
Flat-topping		
	Single gap cavity	1set
	Frequency	90~156MHz
	Maximum voltage	140kV
	RF power	50kW
	Beam aperture	30×2130mm
	Acceleration gap	50mm
	Voltage stability	5×10^{-4}p-p/p
	Phase stability	0.1deg.

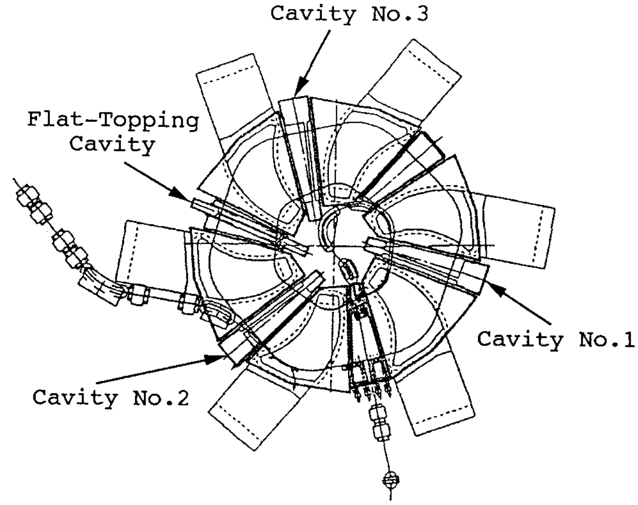

Figure 1: The schematic plane view of the ring cyclotron.

Three single gap acceleration cavities and a single gap flat-topping cavity are used to accelerate high quality beam. The frequency range of the acceleration system is 30~52 MHz. The frequency range of the flat-topping system is 90~156 MHz, which corresponds to the third harmonic of the acceleration frequency. Radial voltage distribution of the flat-topping cavity is similar to that of the acceleration cavities 1). The flat-topping effect is homogeneous throughout radius from injection to extraction. The beams in different phases can be accelerated through very similar trajectory. The temperature of the cooling water for the cavities are controlled within 0.1deg. variation by a PI temperature regulator to get high stability of the RF system. The filament power supplies, bias power supplies and screen grid power supplies for the power amplifiers are also stabilized. Typical phase excursion of the cavities is less than 0.1deg./100hrs. Voltage variations are less than 0.01 and 0.05% for the acceleration and flat-topping, respectively. The acceleration cavities and flat-topping cavities are shown on a schematic view of the Ring Cyclotron in Fig.1

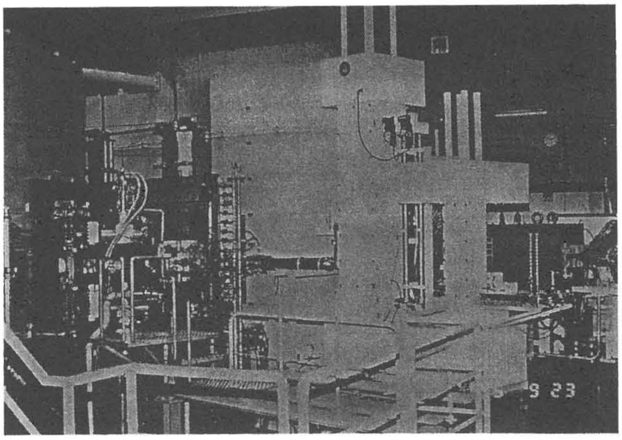

Figure 2: Photograph of the flat-topping cavity and the rf power amplifier.

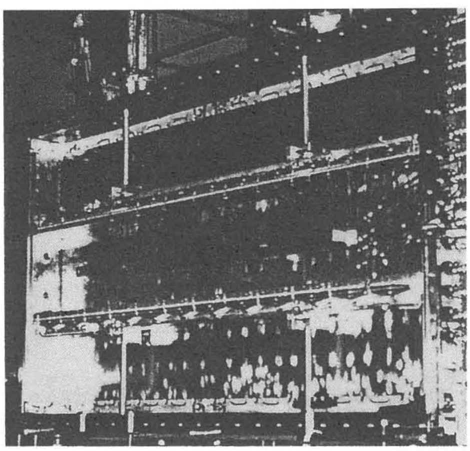

Figure 3: Photograph of the inside of the flat-topping cavity.

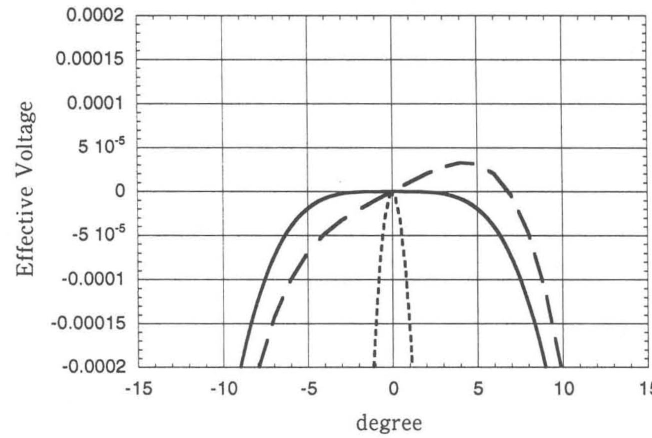

Figure 4: Effective acceleration voltage vs. rf phase.

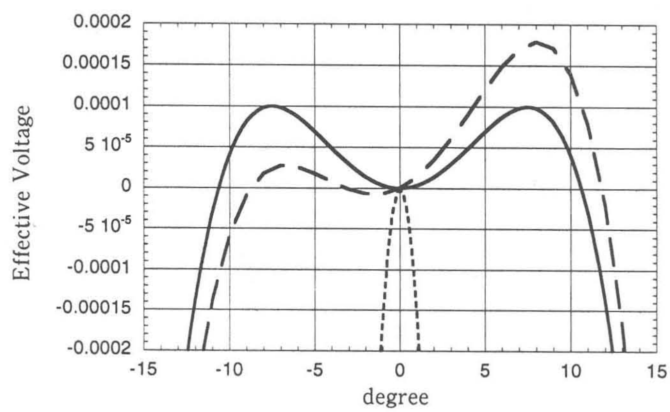

Figure 5: Effective acceleration voltage vs. rf phase. Deceleration voltage is 0.1137Vacc.

2 FLAT-TOPPING SYSTEM

A single gap resonator is used for the flat-topping cavity. Fig.2 shows a photograph of the flat-topping cavity and the power amplifier. Fig.3 shows a photograph of inside of the flat-topping cavity.

Resonant frequency is changed by sliding the upper and lower tuner plates of the cavity. Each sliding tuner is supported by two rods. Each rod can be driven independently so as to get up-down symmetry of the cavity. Finally the rf leakage thorough the beam aperture is minimized. The sliding tuners have silver contacts with leaf springs. The contacts are pressed to the side walls (1.5kg/contact) by pneumatic pressure. The surfaces of the walls are tend to be stained with carbon by multi-pactoring discharge, and the stein causes bad contact . To make good contacts the contact pressure is increased by 25% from an initial design.

For effective operation of the flat-topping system , voltage and phase stability is very important. Figs.4 and 5 show beam energy gain versus beam phase refer to acceleration voltage, with and without flat-topping. The beam phase acceptance for $|dV|/V < 10^{-4}$ is 1.62deg. without flat-topping. The phase acceptance is expanded to 15.1deg. with the flat-topping system where flat-topping voltage is 1/9Vacc. As shown in the fig.4, if the phase of the flat-topping voltage shifted 0.1deg. from optimum value, the peak energy gain increases 4×10^{-5} and the peak position shifts about 5 degrees. The maximum phase acceptance of 19.9deg. can be get using flat-topping voltage of 0.1137Vacc as shown in fig.5. A detailed discussion about phase acceptance is discussed in elsewhere 2). The phase setting resolution and the phase stability better than 0.1deg. are required for the phase control system.

Fig.6 shows a block diagram of the RF system. A heterodyne metod with 0.455MHz intermediate frequency is used in phase control circuits and auto tuning servo circuits of the cavities. The phase stability depends on stability of the signal generator & divider, phase control circuits and coaxial cables. The phase of the rf signal is compared on the intermediate frequency. The reference IF phase signal is delayed by an integrated circuit (IC) voltage to time delay convertor. The input voltage of the IC is controlled by DAC in 0.03 deg steps. The temperature of these control circuits are

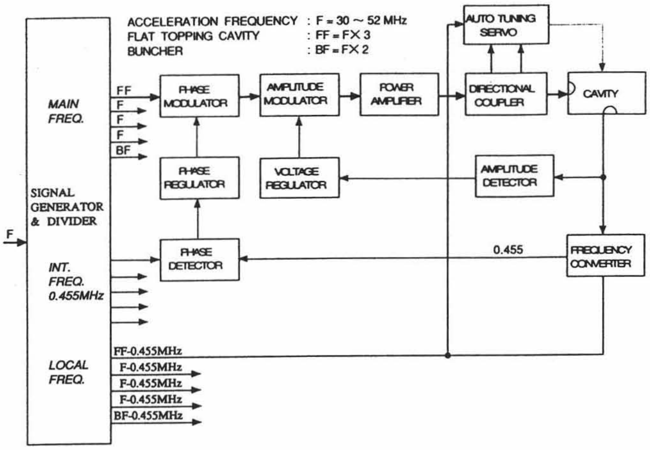

Figure 6: Block diagram of the flat-topping RF system.

regulated within 0.01deg.. With the temperature regulator, the IC delay generator is usable as precise digital phase shifter for a system which is required high stability. The signal generator & divider generates the phase standard signals. The stability of the signal generator is important for phase stability. To insure phase stability, temperature of the circuit for the signal generator & divider is also regulated. The long rf cables between the elements of rf system are outside of the feedback loop of the phase regulator. It is difficult to maintain the cables under the constant temperature, a foam polyethylene insulation cable is used for the system. The temperature coefficient of propagation velocity of signal of the cable is excellently small compared with cables using solid polyethylene or tetrafluorethylene insulator 3).

3 BEAM TUNE UP PROCEDURE

The initial tune up of the Ring Cyclotron parameter ,strength of injection elements,injection phase, main coil current, and trim coil currents, is done without flat-topping. After beams are tuned up without using the flat-topping system, flat-topping voltage is applied. The voltage of the acceleration cavities are adjusted to hold same energy gain and symmetry of the beam orbit. The voltage of the neighboring cavities No.2 and No.3 is increased. An accuracy need for relative voltage of cavities is relatively low compare to phase accuracy and voltage stability. The phase reference signal from the signal generator & divider contains certain offset related to property of the circuits, the absolute phase between acceleration voltages and flat-topping voltage is not indicated by the phase control system. The optimum phase of the flat-topping voltage is searched by observing a position of the accelerated beam orbit. Fig.7 shows measured radius of the beam orbit vs. the phase of the flat-topping. The phase of the flat-topping is roughly adjusted to the phase which corresponds to the the minimum energy gain or minimum orbit radius.

The next step, the phase is adjusted precisely monitoring the turn separation at the extraction region. Fig. 8 shows a typical turn pattern at the extraction region with and without flat-topping.

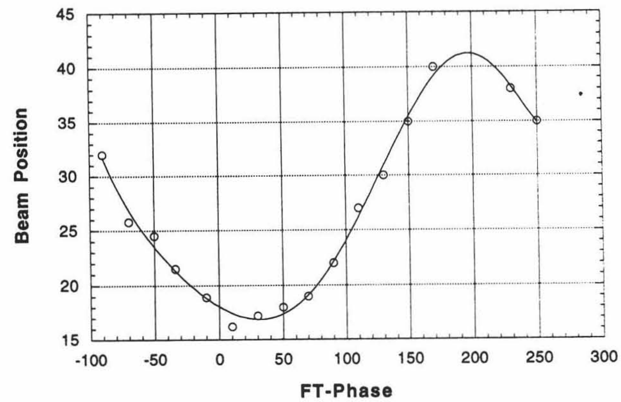

Figure 7: Relative position of the 2nd turn orbit of the accelerated beam vs. phase of the flat-topping voltage.

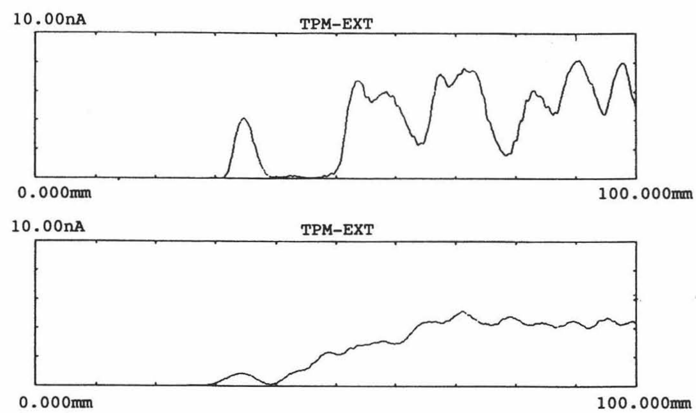

Figure 8: Typical turn pattern of 450MeV ^{3}He beam at the extraction region measured by a profile monitor.
Upper: with flat-topping Lower: without flat-topping.

Final adjustment of the phase is done within 0.1deg. accuracy to optimum phase, observing beam energy width by the spectrograph. The energy spread of the accelerated beam of Ring is dER=2dEI+dEA where dEI is the energy spread of the injection beam and dEA is the energy spread generated during acceleration. According to phase compression effect by the radial voltage distribution of the cavities, the energy spread of the injection beam is doubled at extraction 4). The flattopping system is not a system to improve beam quality, but minimize dEA. The final beam quality depends on quality of the injection beams.

Fig.9 shows a long term drift of the phase of an acceleration voltage.

The phase drift was less than 0.1 deg. for 10 days. The voltage fluctuations of the cavities were less than 10^{-4}. The phase drifts originate from signal generator & divider and connection cables between cavities

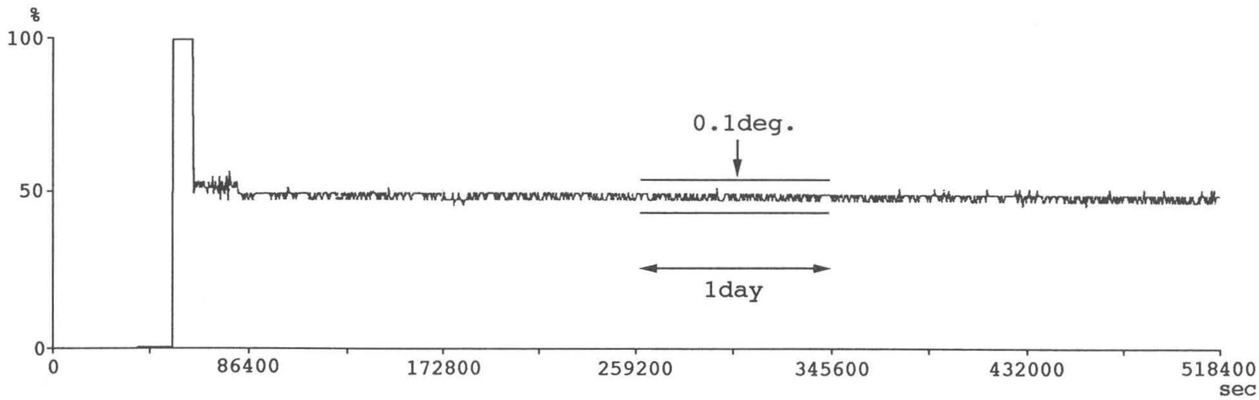

Figure 9: Long term excursion of the phase of the acceleration voltage.

and phase control circuit are not included for the monitoring system. The stability of the system was finally checked by observing the beam quality with the spectrograph.

4 RF LEAKAGE

The RF leakage power from the cavities through the beam aperture could cause serious damages to the trim coil feeds-thorough, and disturbs various electric devices. The frequency of the flat-topping exceeds the cut-off frequency of TE10 mode(70.37MHz) and TE20 mode(140.75MHz) for the beam aperture, the rf power which has vertical electric field component on median plane of the beam aperture easily leaks through the aperture. The rf leakage from the flat-topping cavity is able to propagate through the magnet chambers, and damages a trim coil far from the flat-topping cavity. The vertical component is induced by vertical asymmetrical voltage distribution. Asymmetric setting of the tuning plates and asymmetrical multi-pactoring discharge are induction factors of the vertical field on the median plane. Symmetrical setting of the tuning devices and good vacuum are important. A rf leakage monitoring system is equipped to minimize the leakage. For the protection of the trim coil feeds-through from accidental leakage, they are covered with shield plates. Fig.10 shows the shield plates and loop to pick up leaked rf power.

These protectors are also set neighbor of the acceleration cavities. Though the acceleration frequency is lower than the cut-off frequency of the beam aperture, the leakage power is large enough to damage the trim coil feed-through because of large power is fed on the acceleration cavity. A good symmetric setting and a good vacuum are also important for the acceleration cavities. Even small rf leakage can disturb beam profile monitors and beam phase monitors. The effect of the leakage is eliminated by a filter and selection of proper frequency to observe beam phase.

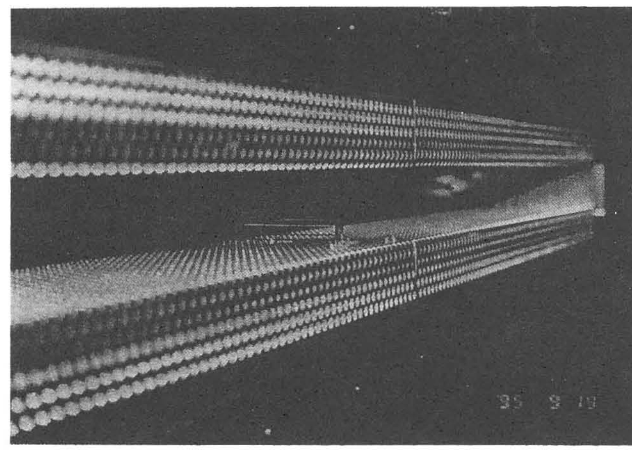

Figure 10: Photograph of the shield plates and pick up loop to detect the rf leakage.

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