

POST-INJECTOR CYCLOTRON BEAM BUNCHING SYSTEM AT RCNP

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Summary

The beam buncher to be used between the injector cyclotron and the ring cyclotron has been designed and tested. The buncher system is arranged at optically proper positions to focus the longitudinal phase space at the injection orbit of the ring cyclotron.

The buncher resonator is a quarter wave variable frequency (60~104 MHz) coaxial type. A  $\pi$ -mode drift tube and the coaxial tuner made of polished copper is mounted on a cylindrical housing made of OFHC. RF power is fed into the resonator through an adjustable capacitor to be matched to the 50  $\Omega$  coaxial feeder from the grounded-grid power amplifier (4CW 25,000A). A preliminary power excitations and beam tests have been made.

Introduction

The main component of the cyclotron cascade project at RCNP, Osaka University, consists of a variable energy six-separated spiral sector cyclotron (ring cyclotron) following the now operating AVF cyclotron.

The RF system of the ring cyclotron is based on the coupled three acceleration cavities (30~52 MHz) and a single-gap flat-topping cavity (90~156 MHz).

The maximum design operating energy is 400 MeV for protons at a resonator frequency of 52 MHz on harmonic number H=6. For the acceleration of heavier ions, harmonic number H=10 will be used<sup>1,2</sup>. The injector AVF cyclotron operates with single dee on fundamental mode for light ions (5.5~19 MHz) and on harmonic numbers H=3 and H=5 for heavier ions.

To inject longitudinally focused beam into the ring cyclotron, a post-injector cyclotron beam buncher system is essentially required in the achromatic beam line between the cyclotrons. The bunching is achieved by beam velocity modulation given by a synchronized higher harmonics RF voltages to make acceleration/declaration at two gaps of the buncher electrode. A schematic concept of the cyclotron cascade project is shown in Fig. 1.

This paper describes a basic study of buncher requirements and fabrication of resonator and an RF amplifier of higher harmonies operation. Preliminary test results are also described.

Buncher Requirements

The design energy resolution of the ring cyclotron output beam is  $10^{-4}$ . To achieve this, the bunch length must be less than  $\pm 4^\circ$  in RF phase even with use of a flat-topping cavity. This corresponds to a bunch length of 0.45 nsec at the highest frequency, and is reasonable for the neutron TOF measurements. This requirement must be met at the injection orbit because an isochronous cyclotron remains essentially constant phase during acceleration. The bunch length of the beams from the injector cyclotron is around 1 nsec for protons with adjustments of phase slits at the central region whereas 2 nsec or something worse without phase slits. For heavier ions, the beam width is more wide depending on acceleration frequency. The debunching due to energy spread of the injection beam in the course of about 80 m injection beam line must also be compensated.

The post-injector cyclotron buncher system will be provided to longitudinally focus the beam at the injection orbit of the ring cyclotron.

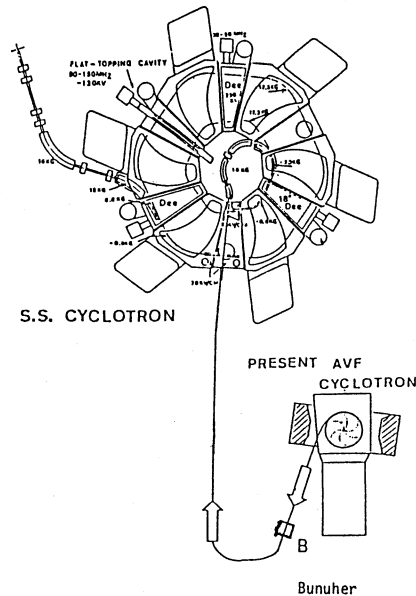


Fig. 1. A schematic concept of the RCNP cyclotron cascade project.

The condition for the bunching of the beam from the injector cyclotron is

$$A = \frac{\ell}{2\pi q L h} E \quad \text{for a 2 gap drift tube}$$

where

- A is modulating amplitude
- q is the charge state of the ions
- L is the drift length from a buncher to a focus point
- h is the buncher harmonic number to the injector RF frequency
- $\ell$  is the beam separation length
- E is the injection ion beam energy

The modulating amplitude required is reduced by a factor of harmonic number h which enables the design to a practical peak voltage for the maximum injection energy of 65 MeV protons.

A practical solution of the choice of the harmonic number h would be 6, which corresponds the requirement of the modulating amplitude to be around 140 kV excitation in the maximum frequency (102 MHz) for the conditions of the project.

### Buncher Structure

A  $\pi$ -mode drift tube mounted on a quarter wave resonator and RF power amplifier have been completed. Figure 2 shows a cross section of the buncher resonator.

The drift tube length ( $1/2\beta\lambda=42$  cm) has been determined from the extraction radius of the injector cyclotron and the buncher harmonic number  $h$  to be 6 and 10 adopted. A copper outer cylinder 60 cm in diameter and a central stem 22 cm in diameter are coaxially mounted through a doughnut type end plate. The demountable drift tube made of polished copper is supported by the central stem with screws. The frequency is tuned by a copper sliding short plate with silver plated Be-Cu spring contacts. The range of the tunable stroke of the shorting plate is 550 mm.

Two capacitors faced to the drift tube (not shown in the figure) are used for fine and coarse tunings. To adjust the acceleration gap length (tentatively set up to be 35 mm), sliding noses made of copper are inserted into both ends of the outer cylinder.

Together with the drift tube, the central stem is cooled by water cooling jacket. The outer cylinder, shorting plate, capacitive compensators are also water cooled. The buncher is evacuated through beam ducts of both sides. RF power is fed into the buncher from bottom of the cylinder end plate through a capacitive coupling supported by WX-77D (50  $\Omega$ ) coaxial feeder. The vacuum seal at the coaxial feeder is made by alumina ceramic window.

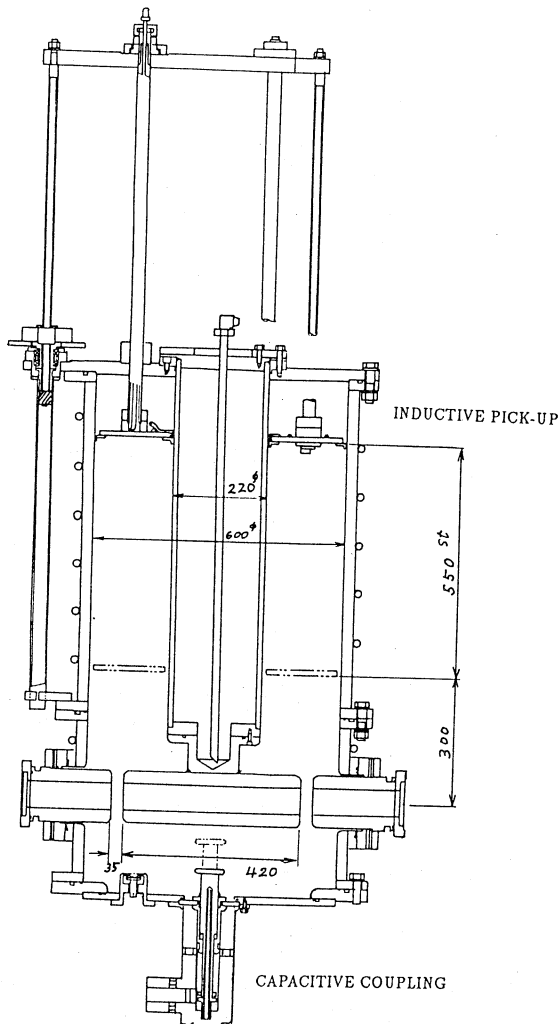


Fig. 2. Cross section of the quarter wave buncher resonator.

The inductive RF pick-up is mounted at the shorting plate. The short plate, tuner capacitors and capacitive coupling are driven by stepping motors through universal device controllers (UDC's) which control component devices assembled at local control panel. Figure 3 shows the resonator mounted on the beam line.

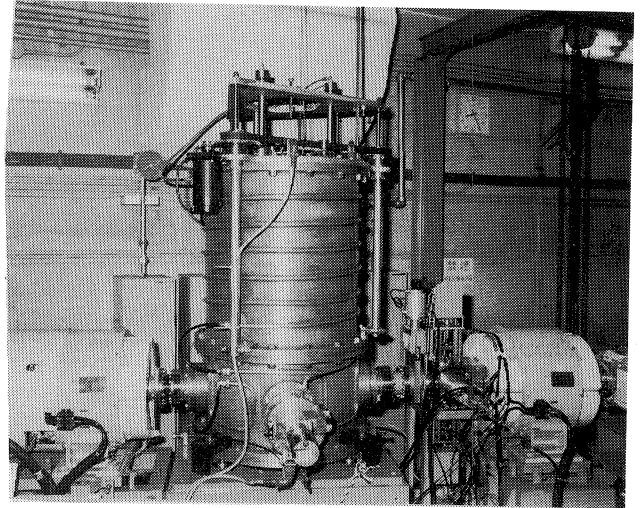


Fig. 3. Buncher resonator mounted on the beam line.

### Electric Characteristics

The characteristics of the buncher resonator have been measured by using a network analyzer. The signals from the analyzer was fed into the resonator through coupling loop and picked-up by the inductive loop. The results of the measurements are shown in Fig. 4 as a function of resonant frequency. These are roughly reproduced by the transmission-line calculations. The estimated maximum power and current density at sliding contacts at full excitation (140 kV at 104 MHz) are 10 kW and 42 Amp/cm, respectively.

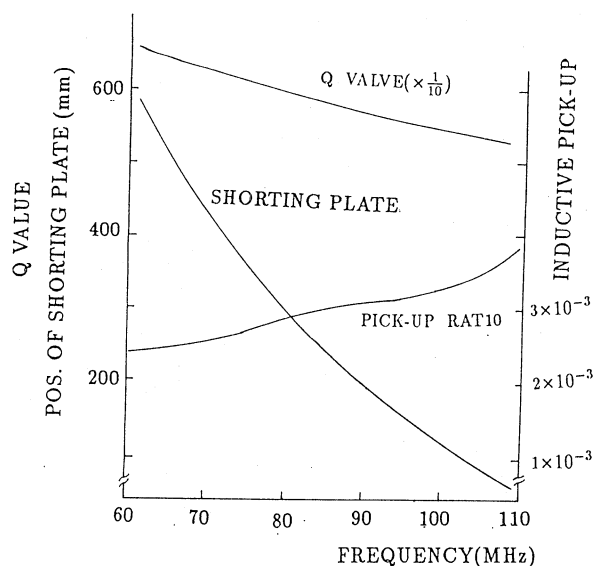


Fig. 4. Electric characteristics of the buncher.

### Amplifier and Excitation Tests

Figure 5 shows a block diagram of the buncher amplifier system. A frequency synthesizer serves as a master oscillator of the system. A pre-amplifier (0.5 W) and an intermediate broad range amplifier (400 W) is followed by a grounded-grid power amplifier. The power tube used is water cooled tetrode 4 CW 25,000 A. The plate circuit of the power amplifier is a quarter wave resonance stub with sliding short tuner (60~110 MHz). A variable capacitor at the stem of the plate stub serves as an RF coupling and DC block between anode of the power tube and power feeder. Cathode input has  $\pi$ -network tuning circuit. Tuning and coupling are monitored by directional couplers (forward/reflection power meters) both input and output stages. Maximum RF power obtained with water cooled 50  $\Omega$  dummy load is 10 kW upto 110 MHz.

The buncher is evacuated from beam passing duct and connected to the amplifier through 1.2 m long 50  $\Omega$  coaxial feeder (WX-77D). Stand alone excitation tests upto 140 kV have been made for several frequencies.

The block diagram of the RF system which distributes the RF signals to the AVF cyclotron, buncher, ring cyclotron cavities, consists of a frequency synthesizer, power divider, frequency multiplier, phase and amplitude modulators and detectors are described elsewhere<sup>2</sup>.

A preliminary beam test to confirm the bunching effect by using the injection beam line has been carried out. The time structure of the transported beam was measured by a TAC between  $\gamma$ -ray signals produced at a beam stopper placed at the ring cyclotron vault and RF stop signals from the AVF cyclotron. The flight time difference (peak position) and the beam width (FWHM) referring to buncher excitation off versus relative phase ( $\delta\phi$ ) between RF's of the buncher and AVF cyclotron is shown in Fig. 6.

By the experiment, done with the 53 MeV protons (corresponding 300 MeV at ring cyclotron), the acceleration/deceleration and beam width bunch/debunch effects depending on the relative RF phase difference are observed applying buncher voltage  $V_B=90$  kV, ( $F_B=92.5$  MHz) to 2 nsec FWHM width beam without use of internal phase slits.

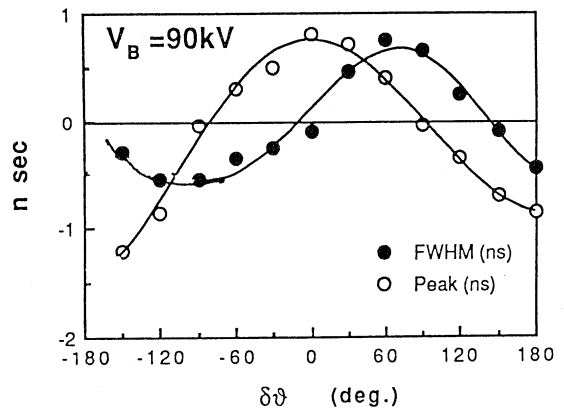


Fig. 6. Flight time difference (peak position) and beam width (FWHM) vs. RF phase difference.

### Conclusion

A quarter wave variable frequency resonator and RF amplifier system have been designed, fabricated, power tested for the post-injector beam bunching system at RCNP cyclotron cascade project. The frequency range, required excitation RF voltage, RF power are consistent with calculations. The amplitude and phase regulation, auto-tuning circuits are almost final stage of adjustments. The computer control of the auto-start of RF excitation and restart at breakdown by discharge are now under developments.

The beam acceleration tests of the ring cyclotron using the buncher system are now in progress. With adjustment of internal phase slits, limiting momentum width after buncher system, longitudinally narrow phase beam is injected into the ring cyclotron.

### References

1. I. Miura et al., in these proceedings.
2. T. Saito et al., in these proceedings.

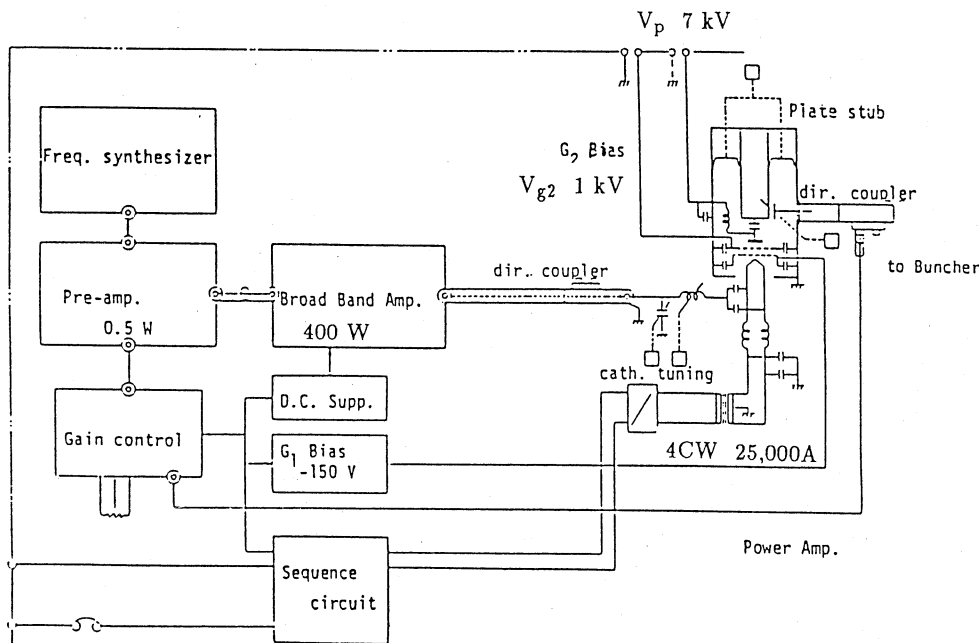


Fig. 5. Power amplifier system.