POST-INJECTOR CYCLOTRON BEAM BUNCHING SYSTEM

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Summary

A model of the beam buncher to be used between the injector cyclotron and the ring cyclotron has been designed and tested. The buncher system consists of two bunchers 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 (90 ~ 130 MHz) coaxial type. A π-mode drift tube and the coaxial tuner made of polished copper is mounted on a cubic beam chamber made of pure aluminium. RF power is fed into the resonator through an adjustable capacitor to be matched to the 50 Ω coaxial feeder from the grounded-grid power amplifier (4CW 10,000A). A preliminary power test has 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 (SSC) following the now operating AVF cyclotron.

The RF system of the SSC is based on the coupled three acceleration cavities (30~50 MHz) and a single-gap flat-topping cavity (90~150 MHz).

The maximum design energy is 400 MeV for protons at a resonator frequency of 50 MHz operating on harmonic number H=6. For the acceleration of heavier ions, harmonic number H=10 will be used[1,2]. 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[3].

To inject longitudinally focused beam into the SSC, a post-injector cyclotron beam buncher system is essentially required in the achromatic beam line between the injector cyclotron and SSC. The bunching is achieved by beam velocity modulation given by a synchronized higher harmonics RF voltages to make acceleration/deceleration 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 fablication, with materials on hand, of a model of a buncher resonator and an RF amplifier of higher harmonies operation. Preliminary test results are also described.

Buncher Requirements

The design energy resolution of the SSC output beam is 10^{-4}. To achieve this, the bunch length must be less than ±4° 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, 50 MHz, and is reasonable for the neutron TOF measurements. This requirement must be met at the injection orbit of the SSC because an isochronous cyclotron remains essentially constant phase during acceleration. The bunch length of the beams from the injector cyclotron is

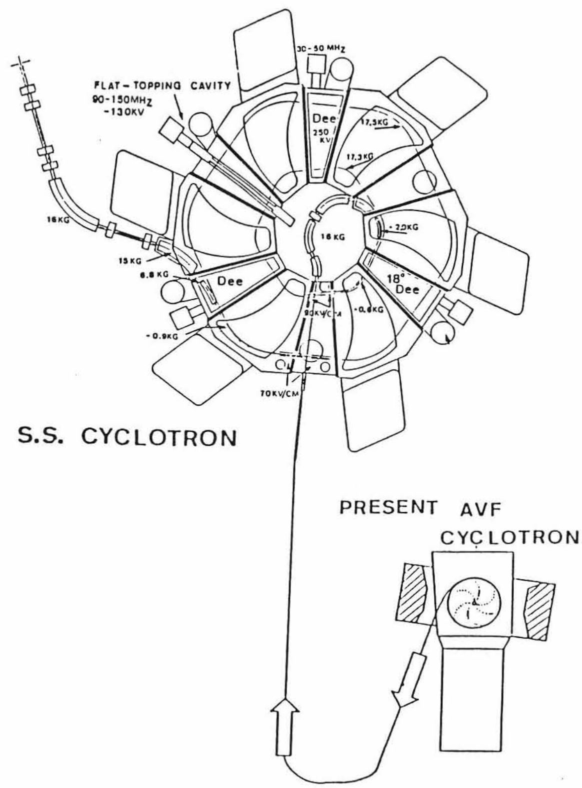

Fig. 1. A schematic concept of the RCNP cyclotron cascade project.

around 1 nsec for protons with adjustments of phase slits at the central region and something worse for heavier ions. The debunching due to energy spread of the injection beam in the course of about 70 m beam line between injector and SSC must also be compensated.

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

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

$$A = \frac{\ell}{2\pi qLh} E \qquad \text{for a 2 gap drift tube}$$

where

A is the 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
ℓ 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.

The energy dispersion introduced by the beam modulation is correlated with the beam phase, the two bunchers will be installed in the beam line at optically proper positions which are in studying. A practical solution of the choice of the harmonic number h would be 6, for example, which corresponds the requirement of a buncher performance to be around 170 kV excitation in the maximum frequency (120 MHz) for the conditions of the project.

Buncher Structure

A π-mode drift tube mounted on a quarter wave resonator and RF power amplifier have been made as a test model of the buncher to study the resonator characteristics of the high frequency side in the whole band. Figure 2 shows a cross section of the buncher resonator.

The drift tube length ($1/2\beta\lambda$ = 50 cm) has been determined from the extraction radius of the injector cyclotron and the buncher harmonic number h to be 6 adopted. A copper outer cylinder 50 cm in diameter and a central stem 20 cm in diameter are coaxially welded through a doughnut type end plate. The demountable drift tube made of polished copper is supported by the central stem with screws as shown in Fig. 3. The system is mounted on a cubic beam chamber of pure aluminium. The frequency is tuned by a copper sliding short plate with silver plated Be-Cu spring contacts. Two capacitors faced to the drift tube (not shown in the figure) are used for fine tuning and a pick-up monitor.

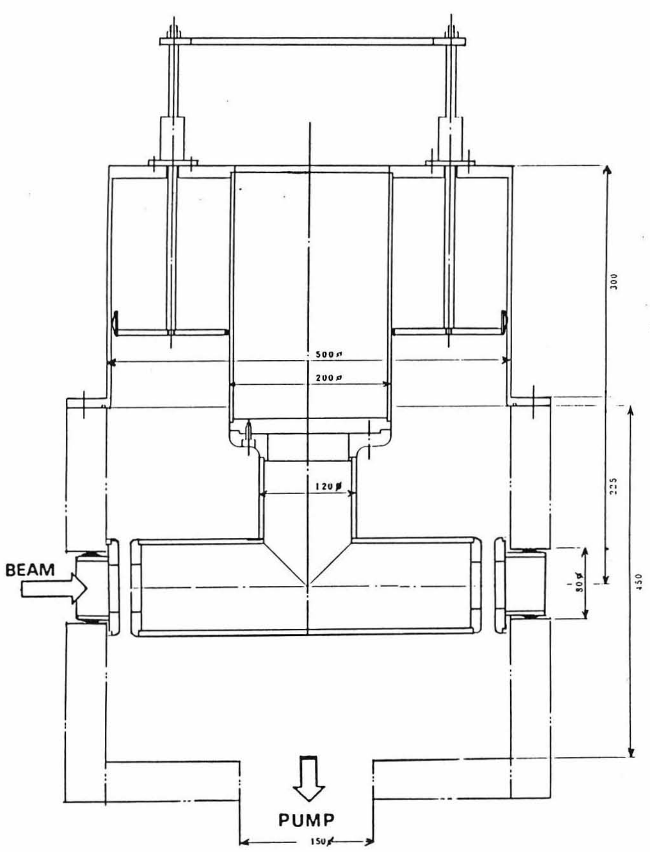

Fig. 2. Cross section of the quarter wave buncher resonator.

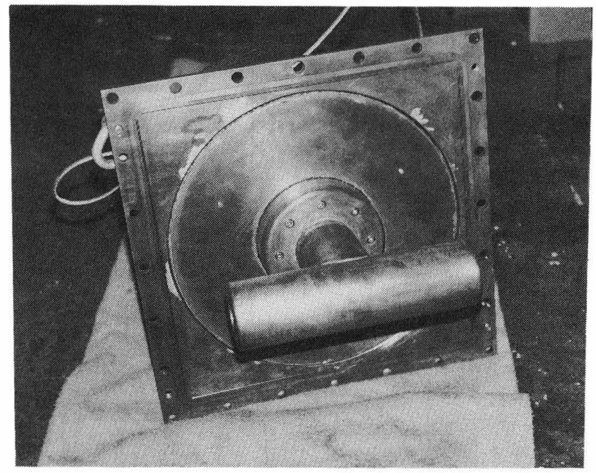

Fig. 3. Photograph of the drift tube mounted on the central stem.

The central stem and the sliding short are cooled by water whereas the drift tube and the outer cylinder are not for the moment. The buncher is evacuated through a bottom suction of the aluminium chamber. RF power is fed into the buncher through a capacitive coupling supported by a 8 cm diameter coaxial feeder. The vacuum seal at the coaxial feeder is made by teflon support.

Cold Tests

To adjust the gap length, cylindrical sliding noses made of copper are inserted into both ends of the beam guiding holes of the chamber wall. Spring contacts are soldered to the noses for sliding use. Cold tests were made with gap lengths ranging from 2 cm to 4 cm. The tuning range covers 90 to 135 MHz with 2.5 cm gap. Figure 4 shows the estimated characteristics of the resonator where peak current at sliding short and power loss are assumed to 100 kV excitation. The Q values are measured by the resonance width at 3 dB below the resonance frequencies. The measured Q are around 7,000 for the frequency range. The miscellaneous resonances at higher frequencies are also investigated.

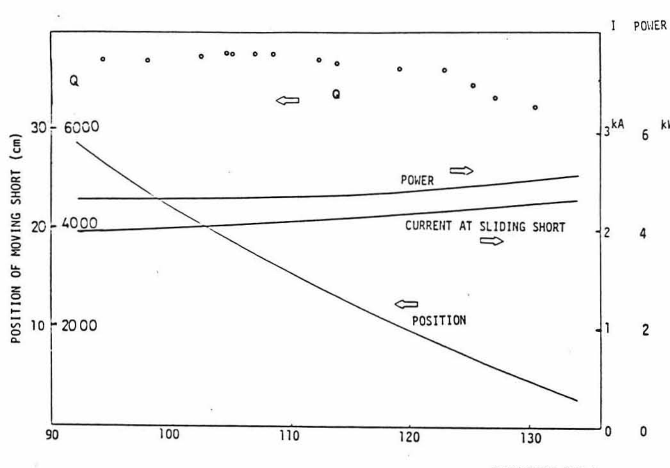

Fig. 4. RF characteristics of the model buncher. The peak current at sliding short and RF power loss is the value assumed to 100 kV excitation.

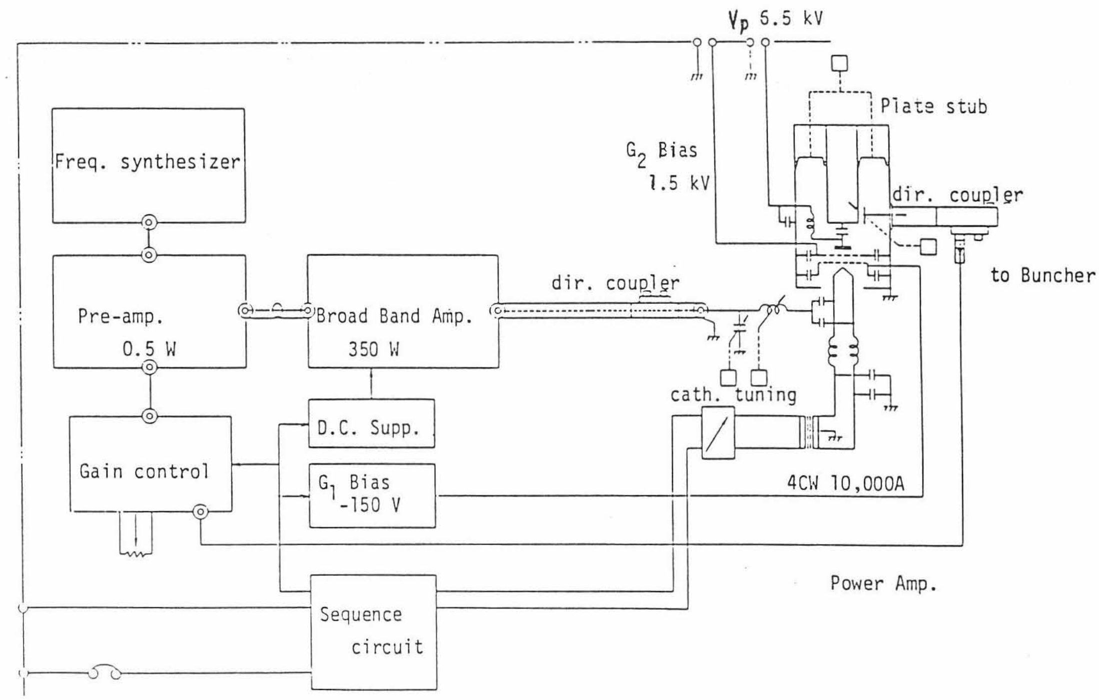

Fig. 5. Block diagram of the amplifier system.

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 (350 W) is followed by a grounded-grid power amplifier. The power tube used is water cooled tetrode 4 CW 10,000 A. The plate circuit of the power amplifier is a quarter wave resonance stub with sliding short tuner (90~130 MHz). A variable capacitor at the stem of the plate stub serves as an RF coupling and DC block between anode of the power amplifier and power feeder. Cathode input has π-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 Ω dummy load is 8 kW upto 110 MHz and something decreasing for higher frequencies. The limitation is mainly due to the performance of the intermediate broad range amplifier and the plate power supply available.

The buncher is evacuated (from beam passing duct for the moment) and connected to the amplifier through a 50 Ω coaxial feeder (WX-77D). Figure 6 shows a complete view of the system. Excitation tests upto 130 kV have been made for several frequencies. The cooling and current contacts are to be improved to get higher excitation amplitude for the moment. The multipactoring at initial stage is partially removed by a current coil wound around the buncher.

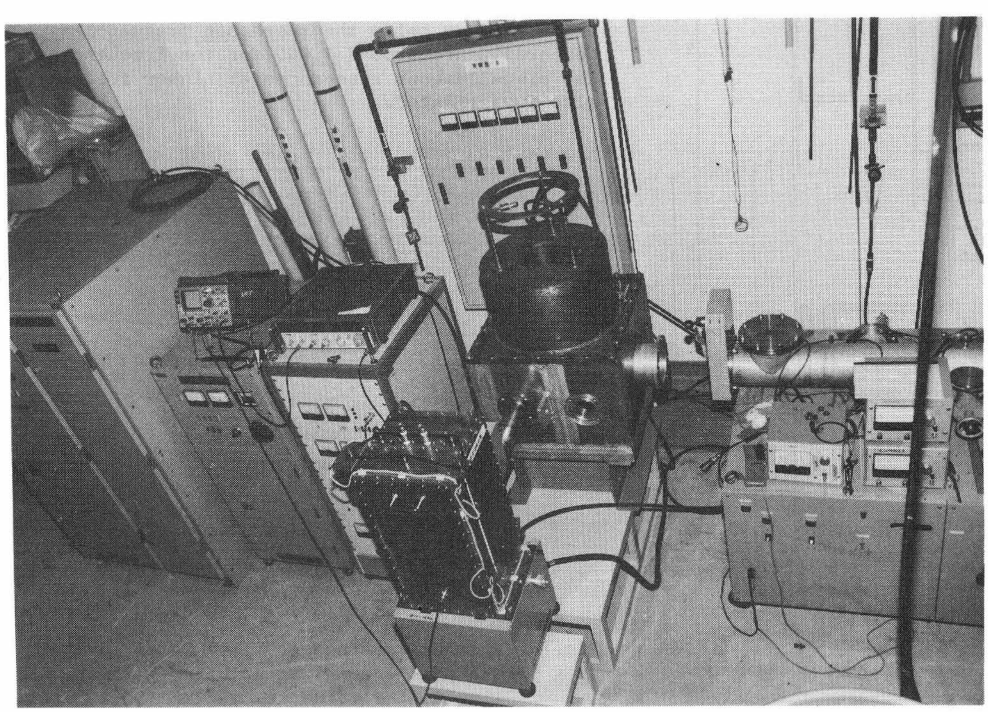

Fig. 6. View of the buncher system.

Conclusion

A model of a post-injector cyclotron buncher and a power amplifier aimed at higher harmonics operation have been fabricated. The tuning, coupling and monitoring have functioned to satisfaction. Preliminary excitation tests up to 130 kV have been made for frequency range between 90 MHz through 120 MHz.

The range of the required resonance frequency and excitation amplitude will be obtained by some modifications and improvements of the model. To realize a system to be installed, some developments such as remote control, automatic tuning, feedback for the stabilizer, which are not equipped in the model, are to be made. Phase control between the two bunchers and RF resonators of the injector cyclotron and also SSC is essential to obtain the qualified beam.

Optics of the beam transfer line to optimize the arrangements of the two bunchers for the beam handling are in studying.

Acknowledgements

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