DESIGN OF A SECOND-HARMONIC BUNCHER FOR RILAC

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Abstract

A second-harmonic buncher for the variable frequency heavy-ion linac (RILAC)[1] is planned to be installed between RILAC and a pre-injector (Cockcroft). More efficient bunching of DC beam at the injection point of RILAC is expected to be obtained by adding the second-harmonic buncher to the existing buncher of a fundamental frequency.[2] The designed buncher system is described.

Introduction

RIKEN Ring Cyclotron (RRC)[3] can accelerate various kinds of ions ranging from proton to uranium in a wide energy region. One of two injectors of RRC is RILAC, which is used to inject mainly heavier ions. RILAC consists of an ECR ion source, a Cockcroft (500 kV), and a variable frequency linac (17 - 45 MHz). RILAC can accelerate ions whose charge to mass ratio is from 1/28 to 1/4. To bunch a DC beam from the Cockcroft, a fundamental-frequency buncher (a total peak voltage of 6 kV) has been placed at 4.1 m upstream from the entrance of the linac in the injection beam line.

This plan aims to increase a beam intensity by adding a second-harmonic buncher to the existing buncher. It is to be noted that a beam buncher with a sawtooth-like wave-form has successfully been performed for the other injector of RRC, AVF cyclotron.[4] The second-harmonic buncher will be placed near the fundamental one. Its characteristics is given in Table 1. The buncher needs operational frequency range from 34 to 90 MHz because that of RILAC is from 17 to 45 MHz. The calculation showed that the total peak voltage required in the second-harmonic buncher is 3 kV at the maximum.

Table 1

Characteristics of the second-harmonic buncher

Frequency range	34-90 MHz
Harmonics	2
Number of gaps	2
Maximum peak voltage per gap	1.5 kV
Voltage stability	$\pm 1 \times 10^{-3}$
Phase stability	±0.5 °
Width of each gap	10 mm
Separation of gaps	27.5 mm
Aperture of beam transmission	30 mm

Resonator

The resonator of the buncher is of a coaxial quarter-wave-length type with its shorting plate fixed. It has two gaps and is π-mode. The separation of gaps is 27.5 mm. The resonant frequency is tuned only by a variable vacuum capacitor installed at the open end of the resonator. A cross sectional view of the resonator is shown in Fig.1. The length of the resonator including the variable vacuum capacitor is about 50 cm. The inside diameter of the outer conductor of the coaxial part is determined to be 13 cm because there is no more room due to existing beam apparatuses in the beam line. A ceramic insulator is used for support of the capacitor as well as for vacuum seal.

Resonant frequencies, shunt impedances, power losses, and Q-values calculated with transmission-line approximation are shown in Fig.2. The capacitance of the variable vacuum capacitor has to be varied from 15 to 225 pF to cover the frequency range. The maximum current of the capacitor is 120 A (peak) at 34 MHz. The shunt impedances calculated at the drift tube gap are varied from 20 kΩ at 34 MHz to 80 kΩ at 90 MHz. The maximum power loss is about 70 W at 34 MHz when the peak gap voltage is 1.5 kV. Q-values are from 2000 to 3300. The maximum current density at the shorting plate is 20 A(peak)/cm.

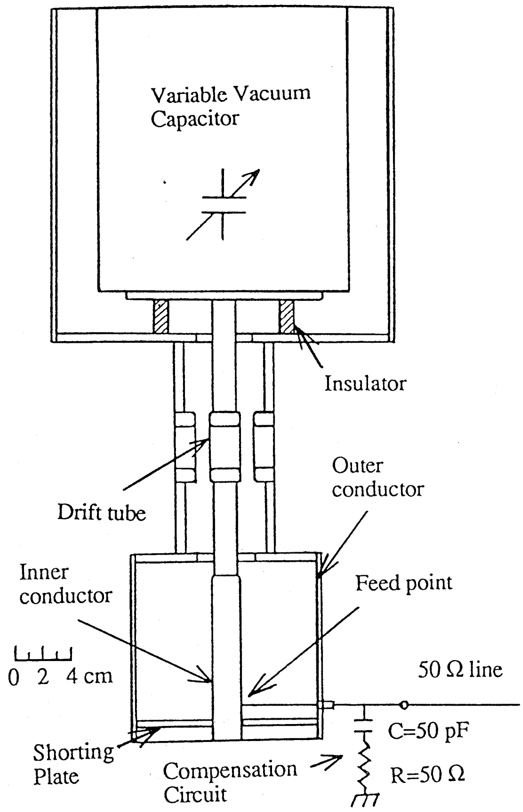

Fig.1 Cross sectional view of the second-harmonic buncher and a coupling circuit.

Power feeding

RF power is fed directly to a feed point on the inner conductor of the resonator (Fig. 1). The ratio of the voltage at the drift tube gaps to that at the feed point is nearly constant (~14) in the frequency range. Consequently the feed point has to be driven by a peak voltage of 110 V to get the maximum gap voltage required. Input impedance of the resonator at the feed point rapidly increases with frequency as shown in Fig. 3 curve (a). The position of the feed point, 1 cm from the short end, is selected to achieve nearly good impedance matching to a 50 Ω power feeder at the lowest frequency, where the maximum RF power is required. In the high frequency region, where RF power requirement is small, poor voltage standing wave ratio (VSWR) reaching 6.7 is improved within 1.3 by making a simple compensation circuit absorb surplus RF power (Fig. 1 and Fig. 3 curve (b)).

An additional loss in this circuit increases with frequency from 30 W at 34 MHz to 80 W at 90 MHz for the maximum gap voltage, whereas the resonator's loss shows a reverse tendency ; the total loss of the resonator with the compensation circuit is kept rather constant over the frequency range. An RF power of 150 W is enough to drive the buncher and is supplied with a solid-state wide-band amplifier.

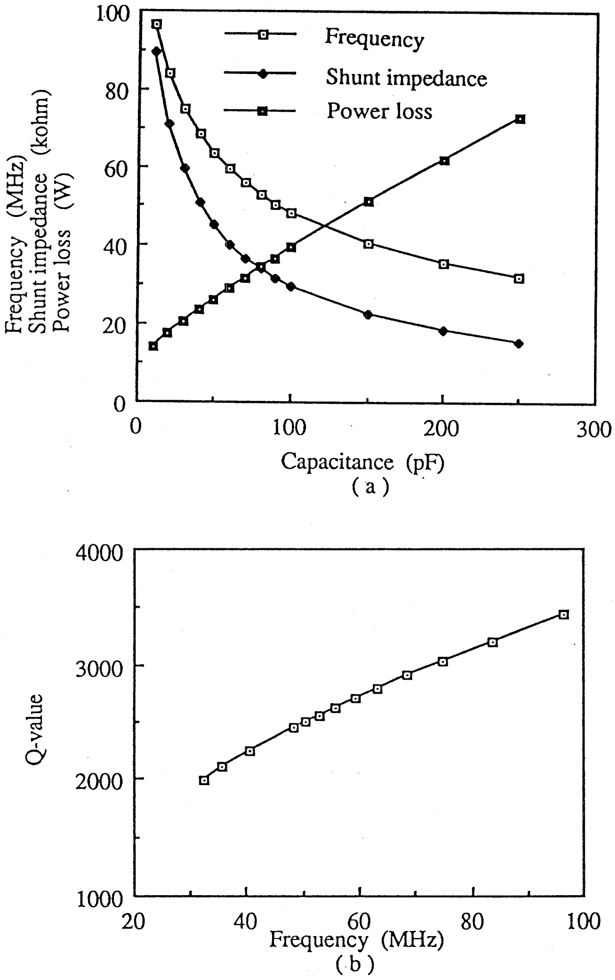

Fig.2 (a) Resonant frequencies, shunt impedances, and power losses calculated as a function of capacitance of the tuning capacitor. Power losses are calculated for the peak gap voltage of 1.5 kV. (b) Q-values calculated as a function of frequency.

RF control system

The RF system needs to keep synchronous operation between the buncher and RILAC. A block diagram of the RF control system is shown in Fig.4. The system consists of a frequency doubler, low level circuits, and a wide-band power amplifier. The RF reference signal is fed from the signal generator of RILAC. The frequency of this signal is doubled with the frequency doubler. The bunching voltage and its phase are stabilized by comparing the pickup signal from the resonator with the reference signal. The stabilities of the voltage and the phase should be within less than $\pm 1\times10^{-3}$ and $\pm 0.5\,^{\circ}$, respectively. Tuning of the resonator is made by minimizing reflected power monitored with a directional coupler.

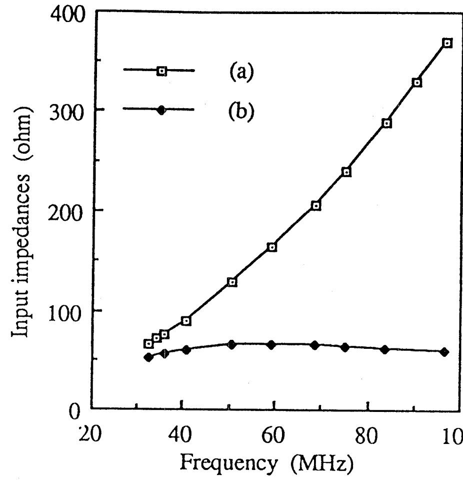

Fig.3 Input impedances of the resonator at the feed point calculated as a function of frequency. Curve (a) : without compensation and curve (b) : with compensation

Conclusion

A compact resonator for the second-harmonic buncher is designed by combining a variable capacitor and a fixed-length coaxial stub. Power feeding without adjusting mechanism will ease the operation. The buncher system will be manufactured in the near future.

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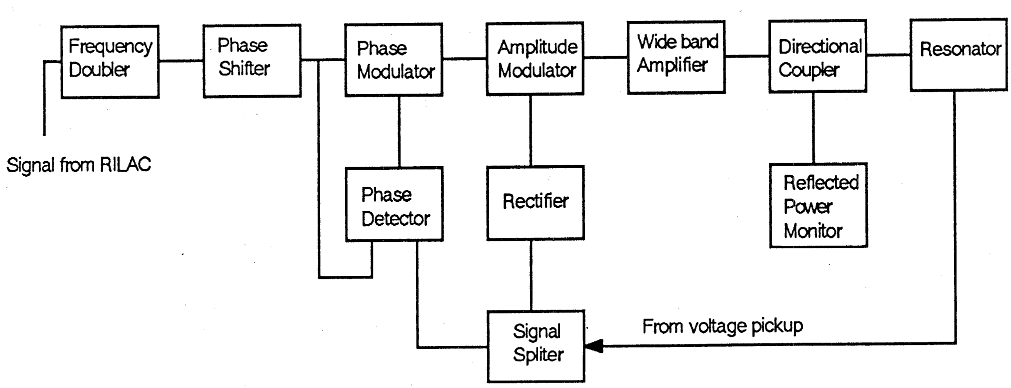

Fig. 4 Block diagram of the RF control system.