MODEL TEST OF A DOUBLE-COAXIAL λ/4 RESONANT CAVITY AS A REBUNCHER

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Abstract

Parameters of a 25.5 MHz double coaxial λ/4 resonator to be used as a rebuncher in a heavy-ion linac system have been determined by cold-model tests. The resonator will be about 120 cm in length, which is much shorter than a quarter wavelength in free space, 294 cm.

Introduction

A linac complex for the acceleration of the unstable nuclei produced by cyclotron beam bombardment is under construction at Institute for Nuclear Study, University of Tokyo [1]. The ions from ISOL with a charge-to-mass ratio of 1/30 at minimum will be accelerated first by 25.5 MHz RFQ linac of sprit-coaxial type [2] up to 170 keV/u and, after charge stripping, will be further accelerated by 51 MHz interdigital-H linac [3] up to 800 keV/u. The reason of the doubled operation frequency of the interdigital-H linac is to make the tank size small and to obtain higher shunt impedance. This configuration, however, requires a rebuncher between two linacs to adjust the longitudinal beam-emittance to be efficiently accepted by the rear linac [4]. The rebuncher works also to compensate the energy loss at the charge stripper, about 7 keV/u.

Since a linearly varying electric-field is desirable for the emittance adjustment, the operation frequency of the rebuncher should be 25.5 MHz rather than 51 MHz. The necessary peak voltage at the rebuncher is about 200 kV [4]. The rebuncher with these specifications may be a single cavity with a few acceleration gaps.

The Resonator for the Rebuncher

The λ/4 transmission line resonator will be most adequate for the frequencies of some tens MHz. So-called spiral resonator is a derivative of the coaxial λ/4 resonator and is effective to make the cavity compact [5,6,7]. Anyway the length λ/4 for 25.5 MHz is very long, 2.94 m, and it will be quite difficult to support the drift tube stably at the end of the transmission line. Thus we have examined how to reduce the line length for a given frequency [8]. The most simple way will be to load the capacitance at the open end of the line or to
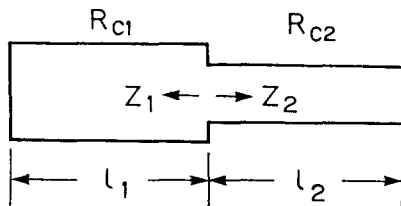
distribute capacities along the line. These methods, however, will cause a big drift tube or a complicated cavity structure, and a reduced shunt impedance.

We have therefore adopted the principle of the ridged waveguide, with which we will be able to reduce the resonator length when we compose it by connecting two lines with different characteristic impedances, as shown in Fig. 1. The input impedances as seen from the connecting point toward left and right are

$$Z_1 = j\,Rc_1 \tan(\frac{2\pi\,l_1}{\lambda})\,,$$

$$Z_2 = j\,Rc_2 \cot(\frac{2\pi\,l_2}{\lambda})\,,$$

respectively. By the resonance condition $Z_1 + Z_2 = 0$,

$$\tan(\frac{2\pi\,l_1}{\lambda}) = \frac{Rc_2}{Rc_1}\cot(\frac{2\pi\,l_2}{\lambda}).$$

When we take $l_1 = l_2 = L/2$,

$$\frac{L}{L_0} = \frac{4}{\pi}\,\tan^{-1}\left(\sqrt{\frac{Rc_2}{Rc_1}}\right),$$

where L_0 is the resonator length for homogeneous transmission line in which $Rc_2 = Rc_1$. This formula shows the reduction rate of the resonator length when the characteristic impedance of the open-side line is less than the one for the shorted-side line.

By applying above principle for a coaxial transmission line, and further by folding it at the connecting point, we obtain a double coaxial λ/4 transmission line resonator, as shown in Fig. 2. This structure will have a length which is
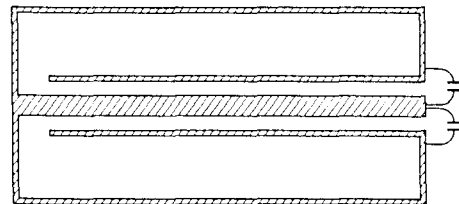

Fig. 2 A double coaxial λ/4 transmission line resonator.

fairly less than a half of the natural resonator length, 147 cm. The inner conductor length will be also reduced to the same extent, and the mechanical stability of supporting the drift tube will be much improved. The structure length will be further reduced due to the capacitance accompanying the drift tubes. We have decided to adopted this structure for the rebuncher.

Fig. 1 The transmission line composed of two lines with different characteristic impedances.

Design of the Rebuncher

In designing the rebuncher by adopting the resonator structure mentioned in the previous section, we are subject to some constraints from the actual situation : First the distance from the floor to the beam line is 120 cm, and second the dimension of the rebuncher along the beam must be short in order for the divergent beam to remain within a drift tube bore. Considering these conditions, we have determined the rebuncher cavity structure as shown in Fig. 3, which is a cross section of the half-scale cold model for the measurement of the rf
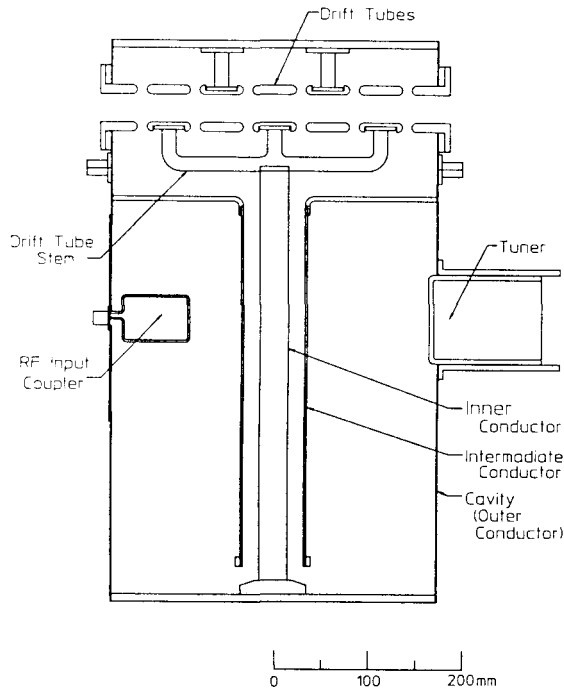

Fig. 3 The rebuncher cavity with double-coaxial structure.

Fig. 4 The effects of the six-cell rebuncher on the ion beam.

characteristics. The reasons for this structure are as follows. A simple folding of natural transmission line resonator will give the length 294/2=147 cm, which must be reduced to around 100 cm to install the rebuncher between the beam and the floor. About 30% reduction of the resonator length must be realized by the effects of the characteristic impedance change along the line and the capacitance of the drift tubes. The reduction by the characteristic impedance change increases by closer arrangement of the inner and intermediate conductor, and rough arrangement of the intermediate and the outer conductor (see Fig. 2). They are, however, restricted by the discharge limit and the diameter allowed to the rebuncher.

We need here to consider the drift tube arrangement. Since the designed velocity of the ion at the rebuncher, β, is 0.0191, the cell length $\beta\lambda/2$ is 112 mm. By the beam trace calculation, we have confirmed that the six-cell rebuncher with the drift tubes having 60 mm beam bore and having no focusing element can be employed to satisfy the present condition, as shown in Fig. 4. This configuration allows rather large diameter for the rebuncher and extends the freedom of the
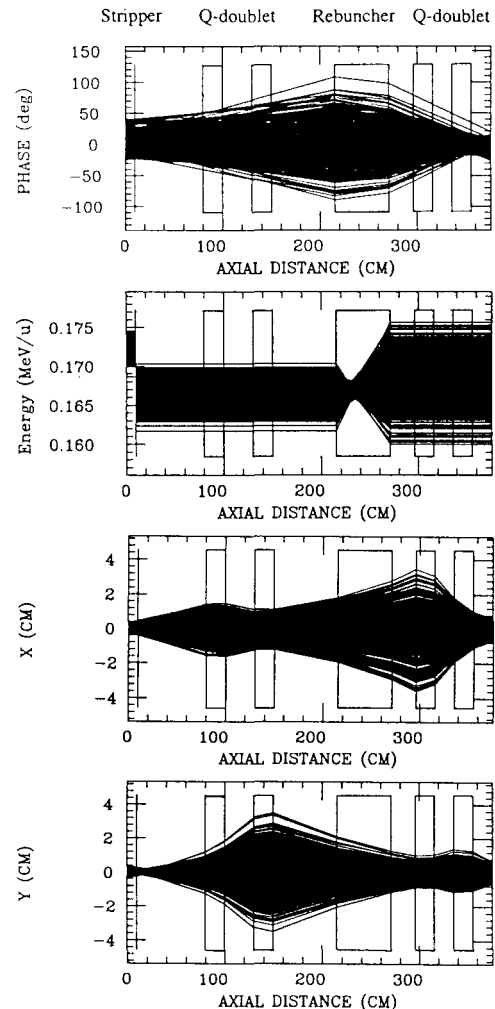
rebuncher design. It also brings more capacitance to the drift tubes and results in reducing transmission line length. The necessary rf power rather becomes low since the necessary potential for the drift tubes decreases in inverse proportion to the number of the acceleration gaps. With these merits, we have employed the six-cell structure.

The detailed configuration of the resonator has been examined by SUPERFISH calculations. For two-dimensional calculation, we have replaced the drift tubes and the stem with a pair of disks which bears the same capacitance as the drift tube structure. The resonator design has been finally confirmed with three-dimensional calculation by MAFIA. It is the aim of the half cold-model scale in Fig. 3 to know the effects of the mechanical structure on the rf characteristics, which can not be took into account in the calculation. The model is made of brass and has an rf coupler and an inductive tuner. Assembling is made by use of a lot of screws instead of using rf contactors. While the inner(central) conductor was a circular column in the calculation, it is a square pillar with rounded edges in the model to reduce multipactors against intermediate circular conductor,

the cross-sectional area being equal to the calculational model. Major parameters of the model rebuncher are shown in Table 1.

Table 1 Parameters of the 1/2 model rebuncher.

Cavity (Outer conductor)		
	Diameter:	345 mm
	Height:	585 mm
Intermediate conductor		
	Inner diameter :	75 mm
	Outer diameter :	80 mm
	Length :	395 mm
Inner conductor		
	Cross section:30 mm x 30 mm	
	Length :	453 mm
Drift tube		
	Cell length :	56.2 mm
	Inner diameter :	30 mm
	Outer diameter :	50 mm
	Gap distance :	10 mm

Measurements on the Cold Model

Resonant Frequency

In order to adjust the resonant frequency to 51.0 MHz , we have prepared three models which have slightly different inner structures. The resonant frequencies for these models are proved to be in agreement with the calculation within 1.3 %. Since the inductive tuner can shift the resonant frequency to higher value, we have selected the natural resonant frequency to be 50.8 MHz.

Unloaded Q

The unloaded Q of the cold model is around 2,200. Scaling to a 25.5 MHz copper cavity, it will be around 7,000, which is close to the calculation by SUPERFISH.

Electric Field Distribution

The electric field distribution, measured by bead perturbation method along the drift tube axis, is shown in Fig. 5. Though the field levels at the gaps far from the center may
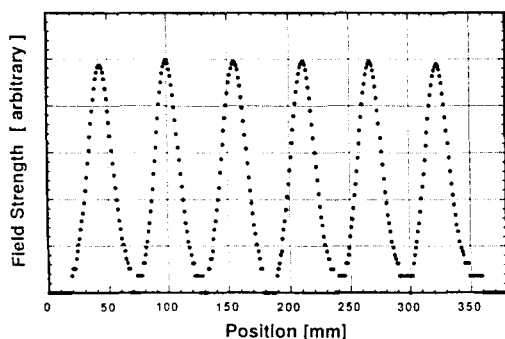

Fig. 5 Electric field distribution along the drift tube axis.

decrease due to the capacitance around the drift tube stem, they remain almost constant as seen in the figure. The bare shunt

impedance is measured to be 14.6 MΩ/m. For the real rebuncher which is made of copper and is operated with a half frequency, it will be 20.8 MΩ/m. The transit time factor estimated from the detailed measurement of the on-axis field distribution in a gap is 0.84. Thus the effective shunt impedance of the real rebuncher will be about 15 MΩ/m, and the rf power loss in the real rebuncher will be about 1.4 kW when it generates integrated voltage of 200 kV.

Tuner

In the model, a cylindrical block tuner of 94 mm in diameter can shift the resonant frequency higher, for example, by 370 kHz for an inner length of 100 mm. This justifies our choice of 50.8 MHz for the natural resonant frequency of the model.

Coupler

An rectangular-shaped loop coupler made of 2.5 mm thick wire and with a size of 50 mm x 70 mm can feed the rf with a power reflection less than 0.01 % when the coupler angle for the magnetic field is optimized.

The Real rebuncher

Since the results of the RF measurements on the half-scale cold model are satisfactory, we will build the real rebuncher by, in principle, scaling double all the dimensions of the model, considering the conditions for the vacuum and the high power rf. The evacuation of the cavity will be made from a port near the drift tube where the electric field is strongest. For the evacuation of inner part, the intermediate conductor has many holes on its entire area. According to SUPERFISF calculation, the heating by rf loss occurs mostly around the middle parts of the inner and the intermediate conductor. Thus we will install two cooling-water channels to both parts, other parts being cooled by conduction.

Acknowledgment

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