DESIGN OF CW SUPERCONDUCTING BUNCHER FOR RIKEN RI-BEAM FACTORY *

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Abstract

Design of rebuncher cavity for uranium beams withβ = 0.303 has been studied. The estimated peak voltage is rather high as 3 mega-voltages (MV). Superconducting radio frequency (SRF) technology is necessary for the effective operation of a rebuncher resonator. Therefore, we studied the design of an SRF resonator that would operate at a velocity of β = 0.3027. Several structures were simulated and discussed using the Microwave Studio code (MWS) in this initial design study, and the performances and field patterns of these structures were compared.

INTRODUCTION

At the RIKEN RI-beam factory (RIBF) [1], very heavy ions such as uranium can be accelerated up to very high energy. There are two charge-stripping sections in this accelerator chain which consists of a new linac named RILAC2 and four booster cyclotrons (RRC: K = 540 MeV, fRC: K = 570 MeV, IRC: K = 980 MeV, and SRC: K = 2600 MeV), as shown in Fig. 1 [2, 3]. This RILAC2 is equipped with a powerful superconducting ECR ion source [4]. As shown in Fig. 1, there are two charge-stripping sections in this acceleration mode. One is located after RRC (β = 0.16), and the other is after fRC (β = 0.3027). Stripping causes an increase in the phase width of the beam in the subsequent cyclotrons, which should be reduced by using a rebuncher with a longitudinal focusing function. Therefore, we studied the design of a new rebuncher to be placed between fRC and IRC.

The rf frequency of the rebuncher was chosen to be 219 MHz, which is the 12th harmonic of the fundamental frequency of 18.25 MHz, as shown in Fig. 1. This frequency gives the cell length of $\beta\lambda/2$ = 207 mm at β = 0.303. Although a higher frequency helps to reduce the cavity length, the beam phase at the rebuncher becomes too large to be well bunched. The total voltage required for the rebuncher is estimated to be 3 MV at this frequency and use of superconducting rf technology is necessary for the effective operation of the rebuncher resonator.

There are few designs and researches for the SRF cavities at this frequency and velocity region. Therefore, we compared several structures by computer simulations to look for the best candidate for the initial research of cavity: the quarter-wavelength resonator (QWR), triple-spoke structure, coupled-TE structure, and ladder structure, as shown below. We paid attention to the value of Ep/Eacc, where Ep and Eacc are the peak of the electric field and the total voltage of the gaps, respectively, in an effort to increase the voltage gain with minimum risk of rf-breakdown. We also considered the possibility of cleaning the cavity after assembly.

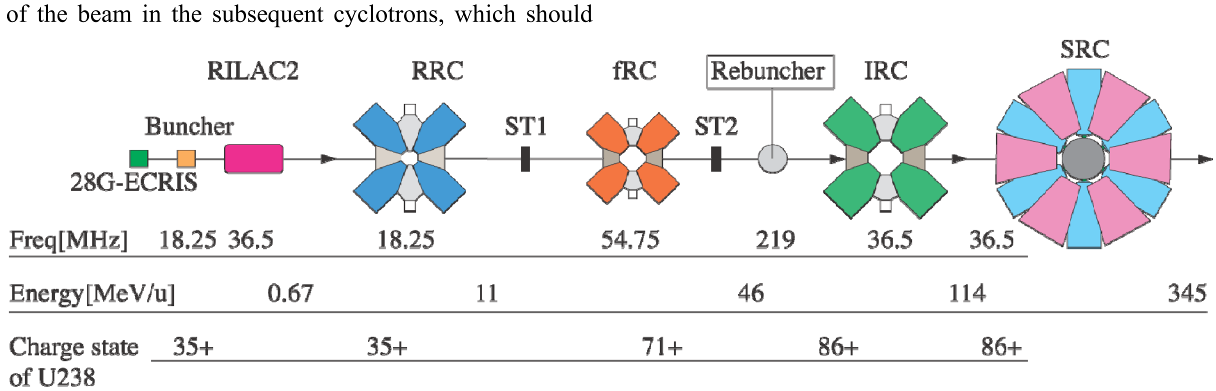

Figure 1: Accelerator chain of RIKEN RIBF for ^{238}U ions.

SIMULATIONS

QWR Structure

The design for a QWR resonator is shown in Fig. 2. The QWR structure is easy to obtain a flat axial E filed distruibution and also is a re-cleanable structure after assembly. In this design, two cavities would be included in a single cryostat in the real rebuncher, bringing the total voltage to 3 MV. The Ep/Eacc value is very high, mainly caused by the field concentration in the bottom region under the drift tube, as shown in Table 1.

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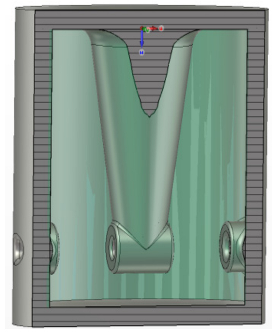

Figure 2: Design of QWR structure.

Triple-spoke Structure

The design of a triple-spoke structure [5] is shown in Fig. 3. This structure is popularly used in the medium β region because the ratio of Ep/Eacc is low. However, there are two disadvantages. One is that the axial E field in the end gaps of the spoke structure is always lower than that in other gaps. Another is that the cleaning of the resonator may be difficult once it is assembled. The simulated results are listed in Table 1.

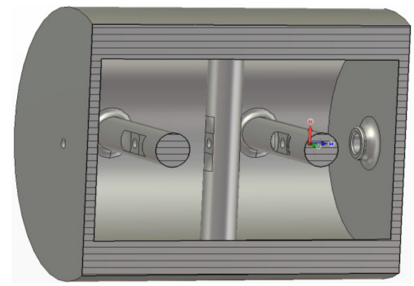

Figure 3: Schematic of triple-spoke structure.

Table 1: Simulated results of proposed structure, ladder structure, QWR, and spoke structure (β = 0.303).

Cavity	QWR	Spoke Structure	Coupled-TE Structure	Ladder Structure
Cavity No.	2 (2 cells/cavity)	1 (4 cells)	1 (4 cells)	1 (4 cells)
Cavity Internal Height (mm)	450	600	460	700
Beam Bore Diameter (mm)	20	20	20	20
Dissipated Power @ V_{acc} = 3MV (W)	1.37	1.03	1.42	0.95
R/Q (Ω)	1.83E+02	3.25E+02	2.25E+02	2.69E+02
E_p/E_{acc}	11.25	4.36	8.22	6.50
B_p (Gauss)	413.53	151.49	387.36	138.74
G (Ω)	9.41E+01	7.88 E+01	6.51E+01	9.40E+01
Q_0 @ 4.2K (R_{res} = 25 nΩ assumed)	3.86E+09	3.15E+09	2.60E+09	3.78E+09

Coupled-TE Structure

The proposed design of the coupled-TE structure [6] is composed of two QWR resonator couples through a terminated bar in the middle, as shown in Fig. 4. It would be possible to make a maintenance port for cleaning in the side wall because the magnetic field is not concentrated there.

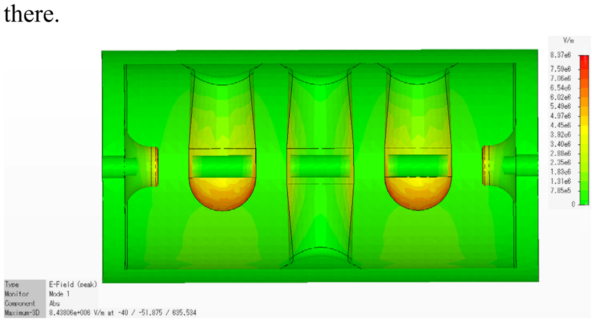

Figure 4: Schematic view of coupled-TE structure with simulated E-field distribution.

An advantage of the coupled-TE structure is that an axial E-field distribution can be made flat. On the other hand, the Ep/Eacc value is high because of the field concentration below the stem, as shown in Fig. 4. Special attention should also be paid to ensure good frequency separation between the fundamental mode and the second mode.

In order to improve the field flatness while keeping the E field as low as possible, we changed the dimensions of various cavity parts such as the gap length and shape of the central bar. However, all the simulated results showed that it would be very difficult to obtain a flat field distribution simultaneously with a good frequency separation with this structure. An example of the field distribution is shown in Fig. 5: the field distribution is very good, but the frequency difference between the fundamental frequency and the higher-order mode (HOM) frequency is only 200 kHz.

Ladder Structure

We expected we would be able to separate the frequencies easily and obtain a flat field distribution [7] with the ladder type resonator shown in Fig. 6. And since the magnetic field is not concentrated on the side wall, the ladder structure might be possible to design a hole in the wall for cleaning the cavity after it was assembled [7].

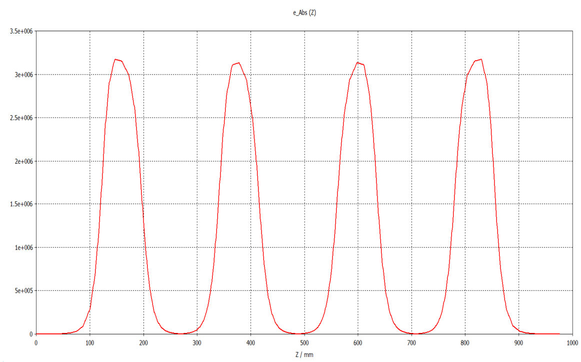

Figure 5: Simulated E-field result of designed model in which it was difficult to separate fundamental frequency from higher mode frequency.

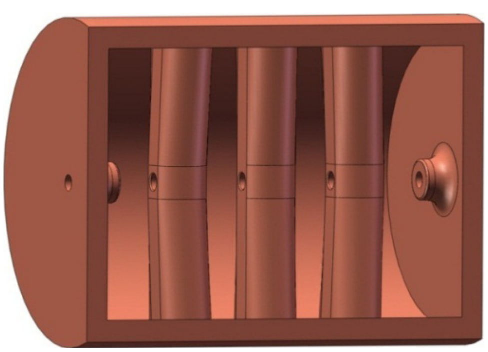

Figure 6: Side view of ladder structure with two bent stems.

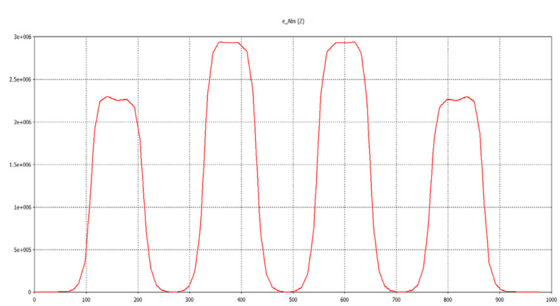

Figure 7: Simulated axial E-field distribution of best ladder structure.

We changed the shapes of the stems as well as their spacing to make the field distribution as flat as possible. The best result obtained so far is shown in Fig. 7, which shows a ratio of the axial E-field distribution of 0.83:1:1:0.83. The separation of the frequency is about 1 MHz, which is higher than that of the coupled-TE structure.

It has also been shown that the resonant mode is very sensitive to the inner shape of the electrode. According the simulations, when the curvature of the two bent stems is increased, the axial E-field distribution flattens. At the same time, the fundamental mode changes into TE112 mode, which not only consumes twice as much power but also influences the beam acceleration.

The Ep/Eacc value of this structure is moderate and comparable to that of the triple-spoke structure, as shown in Table I. The dissipated power is also comparable with that of the spoke structure.

OUTLOOK

From the above-mentioned discussions and the summarized advantages listed in Table 2 below, the ladder structure seems to satisfy the design requirements. In the next step, the ladder type resonator will be further studied by mainly focusing on the detailed structure. A cold model will be fabricated when the simulation study is completed.

Table 2: Summarized advantages of each structure.

Coordinator	QWR	Spoke	Coupled -TE	Ladder
E_p/E_{acc}	higher	lower	higher	lower
Flatness of V_{gap}	good	bad	difficult	fairly good
Re-cleaning	easy	difficult	easy	easy
Separation from HOM	good	good	bad	tolerably

The authors are grateful Dr. P. Ostroumov for giving them guidance of the cavity simulations.

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