DESIGN OF A TRIPLE-SPOKE CAVITY AS A REBUNCHER FOR RIKEN RI-BEAM FACTORY

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Abstract

A 219 MHz, $\beta = 0.303$ superconducting triple-spoke cavity has been designed to be used as a rebuncher for intense uranium beams at RIKEN RI-Beam Factory. Shapes and positions of spokes has been optimized reducing peak surface electric field and a diameter of the cavity. For the purpose to establish a fabrication method, and to check accuracy of calculation, a single-spoke copper model is planned to be constructed.

INTRODUCTION

At RIKEN RI-Beam Factory (RIBF) [1], very heavy ions such as ^{238}U and ^{124}Xe are accelerated up to 345 MeV/u using the injector linac RILAC2 [2] and four booster cyclotrons (RRC, fRC, IRC, and SRC) as shown in Fig. 1. In

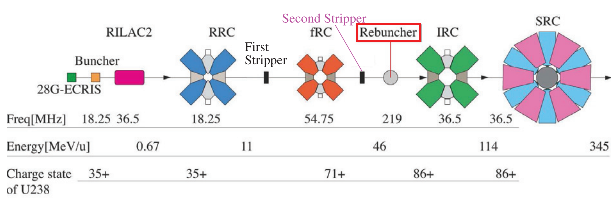

Figure 1: Accelerating mode for very heavy ions (^{238}U beam).

this acceleration mode, there are two charge stripping sections. The first one is located after the RRC ($\beta = 0.16$), and the second one is after the fRC ($\beta = 0.303$). Charge stripping causes an increase in longitudinal emittance of beams, which should be reduced by using a rebuncher so that the transmission efficiencies of the following cyclotrons are improved. Besides of the existing rebuncher located after the first stripper [3], it is crucial to construct a new rebuncher after the second stripper.

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. This frequency gives the cell length of $\beta\lambda/2 = 207$ mm. Although a higher frequency helps to reduce the cavity length, the phase acceptance of the rebuncher might be smaller than the beam phase. The total voltage required is estimated to be 3 MV. The superconducting technology for rf cavity is necessary to achieve low power operation, combined with using a small refrigerator.

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DESIGN OF CAVITY

Triple-Spoke Structure

Among possible structures for the rebuncher, we have chosen a spoke resonator, which is popularly used in the medium β region, with three spokes. There are several ad-

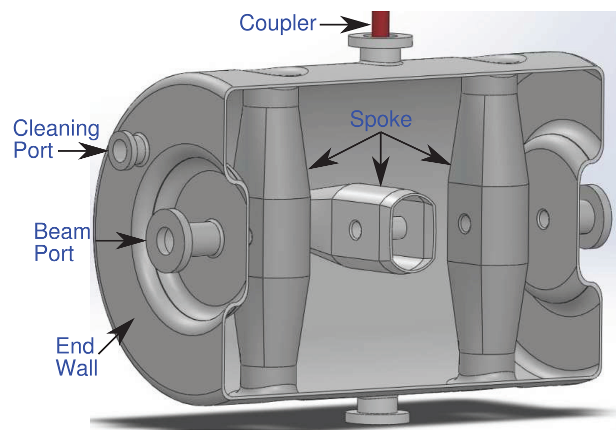

Figure 2: Triple-spoke cavity.

vantages for this structure; (1) A radial size of the cavity is relatively smaller than for other structures. (2) Strong cell-to-cell coupling offers robustness of the resonant frequency against manufacturing error. (3) The frequency for the fundamental mode is well separated from that for higher order mode. The designed model is shown in Fig. 2. As for (1), a diameter of the cavity was further reduced from 600 mm to 580 mm by increasing a volume of the central part of each spoke. A capacitive coupler is inserted from the outer conductor in a vertical direction. A cleaning port is attached on each end-wall.

The disadvantage of this structure is that electric and magnetic fields around the central spoke are higher than that for other spokes, if the gap length is the same for all the gaps (103.6 mm = half of cell length). As a result, the gap voltage (V_{inner}) between the central spoke and the other (side) spoke is more than twice compared with that at outer gaps (V_{outer}). In order to decrease peak surface electric field (E_p/E_{acc}), two side spokes are shifted to the adjacent end wall by 34 mm. The electric field distribution on beam axis is improved as shown in Fig. 3.

The parameters for the designed model are listed in Table 1. The acceleration field E_{acc} is defined as V_{total}/L_{eff}, where V_{total} is a total gap voltage, and L_{eff} is an effective length ($= 2\beta\lambda$).

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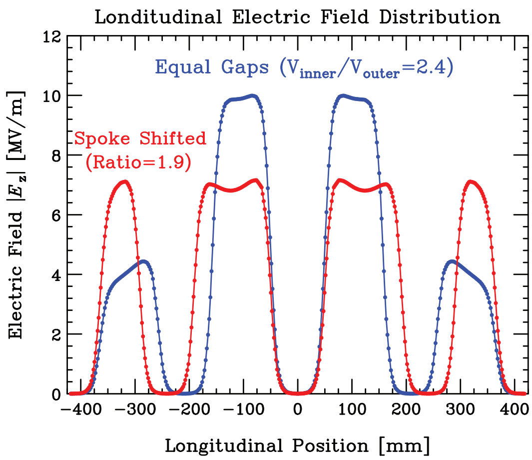

Figure 3: Longitudinal electric field distribution.

Table 1: Parameters of Triple-Spoke Cavity

Frequency	219 MHz
$\beta(=v/c)$	0.303
Voltage (V_{total})	3 MV
Cavity Length	829 mm
Effective Length (L_{eff})	829 mm
Cavity Diameter	580 mm
Beam Bore Diameter	30 mm
R/Q	665 Ω
G (=QR_s)	74.0 Ω
E_{acc}	3.62 MV/m
E_{pk}/E_{acc}	4.42
B_{pk}/E_{acc}	11.01 mT/(MV/m)
R_s @ 4.5 K	48 nΩ
Q	1.54×10^9
Power Dissipation	8.8 W

Frequency Tuning

Two types of frequency tuning method have been considered. One is to use the deformation of end walls (end-wall tuner) [4], the tuning sensitivity of which is estimated to be 270 kHz/mm by the calculation of CST Microwave Studio [5]. The other method is to use a block tuner located on the outer conductor. If the cylinder with a diameter of 100 mm is used, the sensitivity is estimated to be around ∼ 25 kHz/mm (Fig. 4).

Mechanical Stiffness

In order to achieve design frequency, the deformation of the cavity by a helium pressure should be taken into account in the design. The change in frequency of the cavity by a constant pressure was simulated (without a helium vessel). A pressure of 1.2 atm was applied on the surface of the cavity. The cavity material was assumed to be niobium with the thickness of 4 mm. Eight stiffening ribs were attached on each end-walls (Fig. 5). The simulation was performed for two boundary conditions: (i) the flanges of beam ports are unfixed, or (ii) the flanges are fixed to the

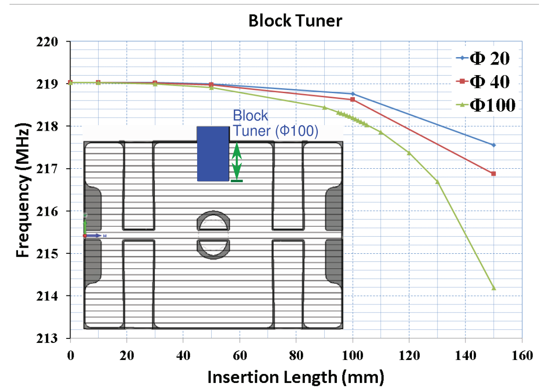

Figure 4: Frequency tuning by a block tuner.

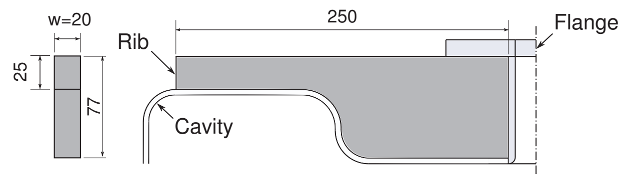

Figure 5: A rib on an end-wall of the cavity.

initial position. The condition (ii) can be assumed to be nearly the same condition as that for the flanges of beam ports are tightly connected to the helium vessel, which is more stiff than the niobium cavity. The simulated results for the unfixed and fixed conditions are shown in Figs. 6 and 7, respectively. Maximum deformations for the unfixed and fixed condition are 0.35 mm and 0.08 mm, respectively, and the corresponding changes in frequency are 94 kHz and 22 kHz.

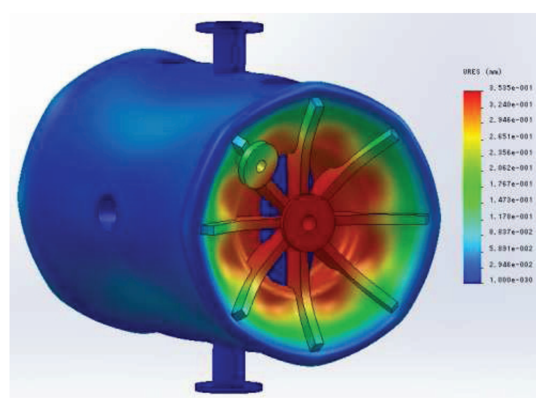

Figure 6: Deformation of Nb cavity with unfixed beam ports.

Further simulation is necessary taking into account a deformation of a cavity connected to a helium vessel.

Tolerance of Manufacturing Error

Manufacturing errors cause a deviation of the actual frequency from the design frequency. The deviations were estimated by changing several geometrical parameters of

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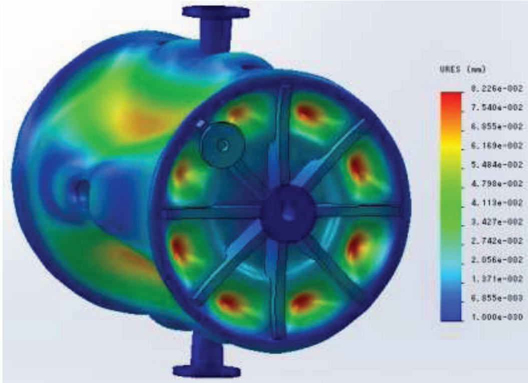

Figure 7: Deformation of Nb cavity with fixed beam ports.

the cavity. As for length, the parameters are L (a length of the cavity), L_{endDT} (a longitudinal length for the central part of the end wall), L_{spoke} 1&3 (a distance from the end-wall and the adjacent spoke), R (a diameter of the cavity), $R_{endspoke}$ (a radius at the end of each spoke), as shown in Fig. 8. Figure 9 shows the calculated results.

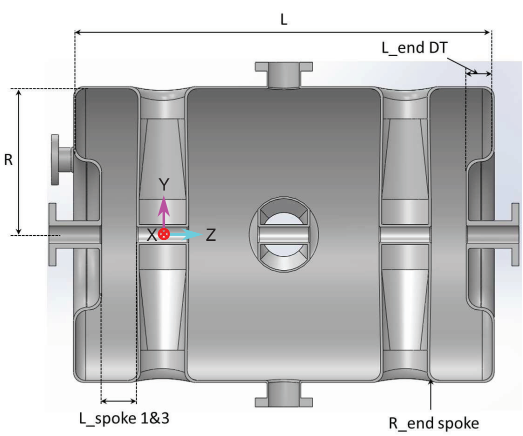

Figure 8: Geometrical parameters considered for manufacturing errors.

The highest sensitivity was obtained for the parameter R

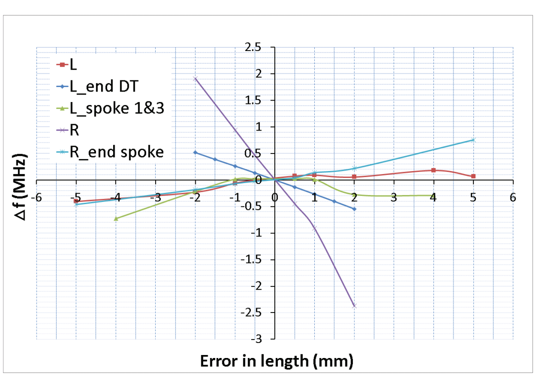

Figure 9: Manufacturing error in length.

(∼ 1MHz/mm). Therefore, a manufacturing error in length must be less than 0.5 mm so as to keep the deviation of the frequency within a tunable range of $\sim \pm 500$ kHz.

As for angles, the central and side spokes were rotated around x-, y-, z-axes (Fig 8). The allowed angles of the central and side spokes for the tunable range are $2.5°$ and $0.5°$, respectively.

DESIGN OF SINGLE-SPOKE COPPER MODEL

To establish fabrication method, a full scale copper cavity is planned to be built as a test model partly using the same fabrication technology that is supposed for manufacturing a Nb cavity. The test model is composed of one spoke and two end walls (Fig. 10). A fabrication method is

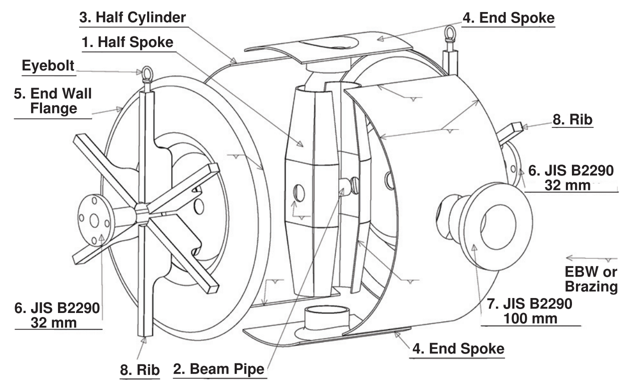

Figure 10: Parts for single-spoke model.

based on the methods of press, welding, and brazing. First, the most parts would be shaped by using press method. Then, they are welded by Electron Beam Welding (EBW) or brazed.

OUTLOOK

Further investigation to optimize or simplify the proposed models is in progress so that the fabrication process is as simple as possible. After the test model is constructed, it's mechanical and RF parameters will be measured to check the accuracy of calculation.

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