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RF MEASUREMENTS OF THE 3RD HARMONIC SUPERCONDUCTING CAVITY FOR A BUNCH LENGTHENING

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Abstract

The brightness can be increased by minimizing the emittance in the light source, but the reduced emittance also increases the number of collisions of electrons in the beam bunch. Therefore, the bunch lengthening by using the 3rd harmonic cavity reduces the collisions of electrons and increases the Touschek lifetime. Since the resonant frequency of the main RF cavity is 500 MHz, the resonant frequency of 3rd harmonic cavity is selected as 1500 MHz. The prototype cavity is a passive type in which a power coupler is not used, and power is supplied from the beam. The operating temperature is 4.5 K, which is a superconducting cavity. The elliptical double-cell geometry was selected to increase the accelerating voltage of the cavity and reduce power losses. Based on this design, three niobium cavities are fabricated and tested. In this paper, we present the RF measurement results of the 3rd harmonic cavity at room temperature.

INTRODUCTION

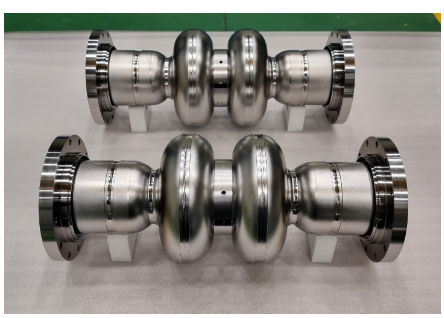

Figure 1: Fabricated niobium double-cell cavities.

The 3rd harmonic superconducting cavity is designed to improve the performance of the 4th generation storage ring. The fabricated niobium cavities are shown in Fig. 1. An elliptical double-cell geometry and a passive type were chosen for the basic geometry of the cavity. The double cell geometry can reach the required accelerating voltage(V_{acc} = 800 kV) at a lower accelerating gradient(E_{acc} = 8 MV/m → 4 MV/m) [1]. The passive type cavity has a simple shape compared to the active type due to the absence of power couplers. We fabricate two niobium cavities by following the typical process of the elliptical cavity except for CBP and EP process [2–4]. For the improvement of the quality of the cavity, we measure every part of the niobium cavities.

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RF MEASUREMENTS

Half-Cell

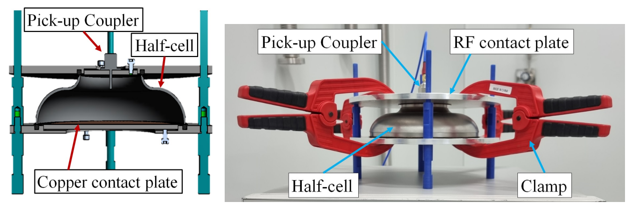

Figure 2: The set-up status of the RF measurement for the half-cell.

Figure 2 shows the RF measurement set-up for a niobium half-cell. A half-cell is a basic part of the cell of cavities. Copper contact plate and clamp are used to increase the RF contact surface [5]. Eighteen half-cells are fabricated by the deep drawing method. The resonant frequency is measured after trimming and fine machining. If we do not perform the trimming at the edge of a half-cell, we can not measure the resonant frequency due to poor RF contact at the copper plate. Before fine machining, we measure the average frequency sensitivity of niobium half-cells and the result is -6.39 MHz/mm.

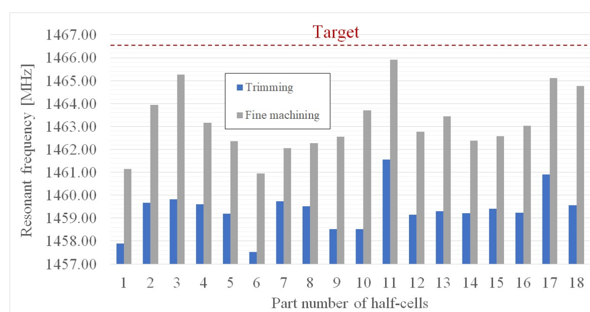

Figure 3: Resonant frequency distribution of niobium half-cells.

The distribution of the resonant frequency of each half-cell is shown in Fig. 3. The target frequency of a half-cell is 1466.42 MHz, but most half-cells are lower than the target frequency. After trimming the edge of half-cells, the maximum error is 7.89 MHz, but reduced to 4.5 MHz by fine machining. The error of half-cell numbers 1 and 6 is bigger than other half-cells due to trimming and chemical etching tests. We select four half-cells, which have the lowest error, to fabricate the dumbbell.

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Dumbbell

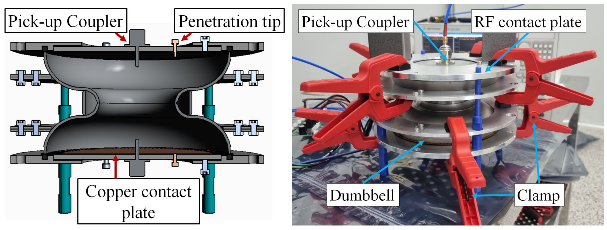

Figure 4: The set-up status of the RF measurement for the dumbbell.

We use the perturbation tip to check the resonant frequency of the individual half-cells, which is welded as dumbbell [6]. Figure 4 shows the RF measurements set-up for a niobium dumbbell and the results of the RF measurement are listed in Table 1. The copper contact plates are the same as the half-cell RF measurement case, but the number and location of clamps are different due to the improvement of the RF contact at the edge of the dumbbells. Each half-cell of the dumbbell is held by four clamps to increase the RF contact. The perturbation tip is made of copper and the dimension is selected by CST simulation to enough perturbation and minimized frequency changes at half-cells of the dumbbell.

Table 1: Unperturbed (f_{π}) and Perturbed ($f_{p,l,\pi}$ and $f_{p,r,\pi}$) Frequencies of Each Niobium Dumbbell

Parts	f_{π}	$f_{p,l,\pi}$ [MHz]	$f_{p,r,\pi}$	Δf ($f_{p,l,\pi}$-$f_{p,r,\pi}$)
A	1504.500	1504.167	1503.904	0.263
B	1505.658	1505.275	1505.125	0.150

The unperturbed frequency(f_{π}) is the resonant frequency of the accelerating mode(TM010,π) of the dumbbells and the perturbation tip is disassembled with copper plates. If we assemble the perturbation tip with the one of copper contact plates, then we can measure the perturbed frequencies($f_{p,l,\pi}$ and $f_{p,r,\pi}$) of the dumbbell. From this measurement, we can check the resonant frequency of dumbbells and unbalance of each half-cell.

The target frequency of the dumbbell is calculated as 1508.892 MHz by the CST simulation. The errors between the measured values and target frequency are within 0.3%. The difference in perturbed frequencies of each half-cell is lower than 300 kHz. From this measurement, we judged that dumbbells can be used for cavity fabrication. Dumbbells A and B are fabricated to the niobium cavity A and B, respectively. We do not perform the tuning process on the parts of the cavity, which are half-cell and dumbbell due to reducing the possibility of any defect and scratch at the inner surface of the cell. Therefore, the bead pull test after the annealing is only a tuning process for the fabricated niobium cavity.

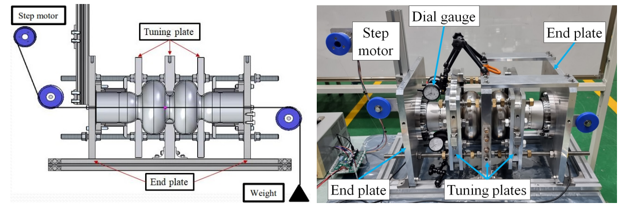

Figure 5: The set-up status of the bead pull test-bench for double-cell cavities.

Bead-Pull Test

After the electron beam welding of every part of the cavity, we performed the bead pull test to measure the resonant frequency and field distribution of the fabricated niobium cavity. Figure 5 shows the bead pull test-bench, which has tuning plate to adjust the resonant frequency of each cell of double cell cavities. The dial gauge used to measure the exact movement of each position of the tuning plate. A cylindrical bead is moved through the niobium cavity by a step motor.

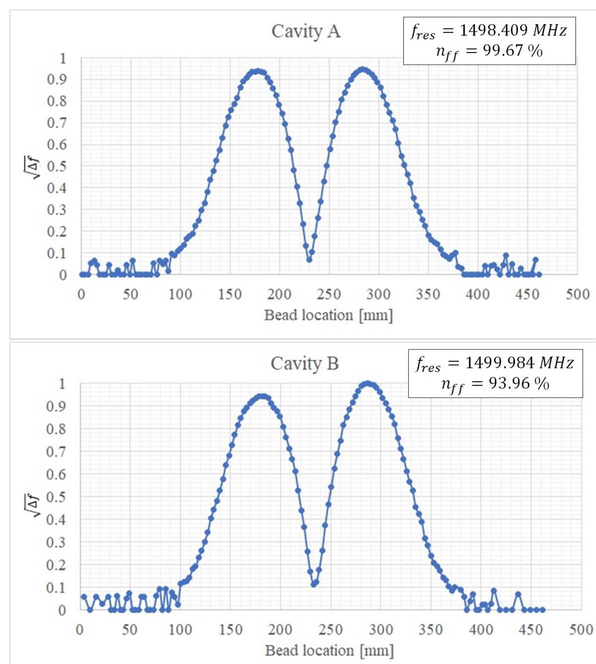

Figure 6: The results of the bead pull test : (Up) Cavity A and (Bottom) Cavity B.

Figure 6 shows the results of the bead pull test before heavy BCP(Buffered Chemical Polishing) process. The target frequency of the niobium cavity is 1499.629 MHz at room temperature. The resonant frequency of the cavity A and B is measured as 1498.409 MHz and 1499.984 MHz, respectively. The maximum error is 0.075% even though the tuning process are not applied. The field flatness of each cavity is calculated as 99.67% and 93.96%. We will perform the tuning process to each cavity after the heat treatment for reach the target frequency at room temperature and increase the field flatness over the 96%.

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Surface Treatment

Operation frequency is 1499.631 MHz at cryogenic temperature. The target resonant frequency at room temperature are calculated by frequency changes in the fabrication and operation process from CST and ANSYS simulation. From these calculation, we can write the frequency tuning table as shown in Table 2 [7]. Unfortunately, the resonant frequency of two niobium cavities is different from the target frequency, but we expect that can be corrected by the tuning process after the heat treatment. We already perform the tuning test to copper cavities and niobium cavities and confirmed values of the maximum range of the tuning is ± 2 MHz.

Table 2: Target Scenario of Niobium Cavities

Process	Δf_{π} [kHz]	f_{π} [MHz]
Operation	-	1499.631
Cool down (4.5 K)	-2126.22	1497.505
Vacuum pumping (0.13 MPa)	-35.24	1497.469
Light BCP (50 µm)	524.65	1498.009
Heavy BCP (150 µm)	1573.95	1499.629

We planned four steps of the heavy BCP process and the target etching depth is 150 µm. The BCP(Buffered Chemical Polishing) process affects the resonant frequency of niobium cavities due to the changes in the inner volume of the cavity. Therefore, we measure the resonant frequency of the cavity in each BCP process as shown in Fig. 7. Cavity A is planned to perform the four steps of the BCP process, but the etching depth is different from the calculation and expectation. Therefore, we performed a total of six times of BCP process to niobium cavity A. Cavity B is etched by four steps of the heavy BCP process as per our planned schedule.

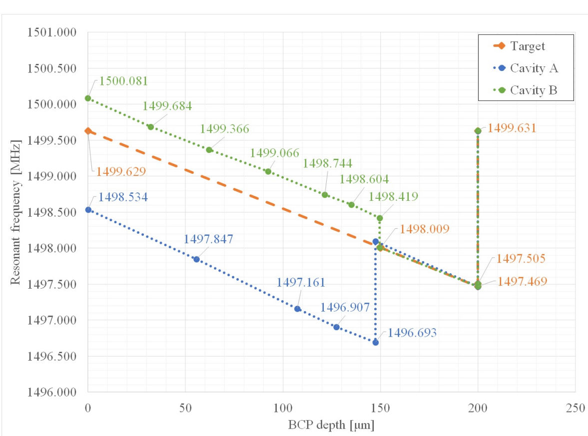

Figure 7: Resonant frequency variation and target scenario of the Nb cavity.

After the heavy BCP process, we need to perform the heat treatment in 800 °C and 3 hours. Over 800 °C of heat treatment will make an annealing effect on the niobium cavity [8]. Therefore, we can be tuning the resonant frequency of cavities to the target frequency more efficiently. The cavities A and B are ready to perform the heat treatment to improve the quality. After the heat treatment and tuning, we will perform a light BCP process (50 µm), low-temperature baking (120 °C and 48 hours), and vertical test as typical fabrication and test procedure of superconducting cavities.

CONCLUSION

We had designed and fabricated the 3rd harmonic superconducting cavity for a bunch lengthening of the 4th generation storage ring. The cavity is based on an elliptical and a passive type. Two copper cavities are fabricated to check the manufacturing processes and test procedures in 2022. After that, we fabricate two niobium cavities and measure the resonant frequency of each part. The field flatness of welded niobium cavity is over 93% without the tuning process. The surface treatment procedure is performed to fabricate niobium cavities for increasing the quality factor such as BCP and HPR. We will perform the heat treatment to increase the quality factor and annealing. A vertical test will be performed to verify the development process of the elliptical cavities.

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