HYDROFORMING SRF THREE-CELL CAVITY FROM SEAMLESS NIOBIUM TUBE

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Abstract

The authors are developing the manufacturing method for superconducting radio frequency (SRF) cavities by using a hydroforming instead of using conventional electron beam welding (EBW). We expect higher reliability and reduced cost with hydroforming. For successful hydroforming, high-purity seamless niobium tubes with good formability as well as advancing the hydroforming technique are necessary. Using a seamless niobium tube from ATI Wah Chang, we were able to successfully hydroform a 1.3 GHz three-cell TESLA-like cavity and obtained an accelerating gradient of 32 MV/m. A barrel polishing process after the hydroforming was omitted. The vertical test was carried out with very rough inside surface. We got amazing and interesting result.

INTRODUCTION

The major manufacture method for SRF cavities which have elliptical cell shape are the press forming of rolled niobium sheet to the cell shape and the assemble of them by a EBW. Although the inner surface of cavity should be smooth, the penetration welding is provided from outside of cavity because the electron gun of EBW is big, and a smooth rear-welding bead with small bump is required.

A hydroforming is one of a plastic working and applied to cavity fabrication instead of the EBW. This manufacture method is well known for a long time, and widely used for manufacture of automobile and hydraulic parts. The hydroforming involves expanding a tube with internal hydraulic pressure while simultaneously swaging it axially. The die is placed around the tube, which is formed along it. Singer has provided the study of applying the hydroforming to the cavity fabrication energetically at DESY. 1.3 GHz TESLA cavities were fabricated using a 150 mm inner diameter (ID) and 2.7 mm thickness seamless niobium tube, and the 9-cell cavities were manufactured by joining three 3-cell cavities by the EBW. The maximum accelerating gradient attained to 30 to 35 MV/m [1]. The series of research in DESY and activities at other laboratories are introduced in detail in Ref. [1], and please refer to it.

KEK started the research of hydroforming since 1994. Fujino, et al. developed the seamless tube using a clad material, which joined thin niobium and fat copper sheets for the cost reduction, and manufactured 1-cell cavity by the hydroforming. The maximum accelerating gradient attained to 40 MV/m [2-4]. Afterwards, Ueno, et al. developed the necking and the hydroforming machines [5-6], and KEK can provide series of process from the seamless tube to finish the cavity in the laboratory. In 2014, we were able to successfully hydroform a 1.3 GHz single-cell TESLA-like cavity and obtained the accelerating gradient of 36 MV/m using a seamless niobium tube from ATI Wah Chang for the first time [7]. Another single-cell cavity was hydroformed using a seamless tube from ULVAC and the maximum accelerating gradient attained to 37 MV/m [8].

The purpose of this study is the hydroforming 1.3 GHz 9-cell cavity and showing the performance of hydroformed cavity is equivalent to the cavity manufactured by the conventional method [9], then take a measure that the hydroforming is effective in the cost reduction. In this report, the result of manufacture of 3-cell cavity and the evaluation of performance.

SEAMLESS NIOBIUM TUBE

For successful hydroforming, high-purity seamless niobium tubes with good formability as well as advancing the hydroforming techniques are necessary. Although KEK could not obtain a good niobium tube until now, has got it manufactured by ATI Wah Chang in U.S. by cooperation of FNAL this time.

The equator ID of 1.3 GHz TESLA-like cavity is approximately 205 mm. Since the iris part is 70 mm. If we only use hydroforming from 70 mm ID tube, required elongation is 200%. Since the maximum elongation with niobium tube is 50 to 60% with suitable heat treatment and grain size. Therefore, we use a combination of necking (iris) and hydroforming (equator) from 123 mm ID tube [5]. A 2.6 mm thickness niobium sheet is used in ordinary press forming for cells; however, that of seamless tube is set to 3.5 mm, a little largely. Because the thickness at the equator part is expected to become thin by hydroforming, the thickness of the tube is increased to secure 2.6 mm there. The tube length required for 3-cell cavity is 800 mm. It contains the length of the portion chucked by the processing machine. The beam pipes joined to both ends of cavity by EBW is separate part, and not included in above length. The tube length for 9-cell cavities is 1700 mm in the same manner. The RRR of niobium ingot, which is the start material of this tube, is 387. The hardness of the tube as received from the builder is 46 HV.

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MANUFACTURE OF CAVITY

Necking and Hydroforming

The processes of the necking and the hydroforming are shown in Fig. 1. The figure shows the case of 3-cell cavity. First, the iris parts are formed by the necking. The state of necking is shown in Fig. 2. The neck is formed by plunging the two counter rollers into rotating niobium tube. The roller rotates due to contact rounding. A lubricant is not used between the roller and the tube. The necking process is provided by each neck. In the case 3-cell cavity, four necks are formed. After the necking process, the tube is annealed using a vacuum furnace. The heat treatment condition is 800 degree for 3 hours.

Next, the equator part is hydroformed. It is provided in two stages as shown in Fig. 1. In the 1st stage, 123 mm ID is expanded to 153 mm. The die is placed outside and the internal hydraulic pressure is applied to the tube while simultaneously swaging it axially. The outer shape of the die is a cylindrical. The dies placed in a long cylinder and can move in longitudinal direction. This dies are swaged until they stick together. The internal pressure is rise to 25 MPa and held for a while to make the tube fits to the die. Then, the dies are removed and the tube is annealed again. The longitudinal length of the tube becomes short as shown in the figure. A hydraulic piston generates the longitudinal loading force. The hydraulic pressure for this piston and the inner tube are supplied from independent hydraulic pump, and the amount of pressure is controlled, respectively. In addition, a fluid is oil. In the 2nd stage, the die is changed for the final shape, and the hydroforming is provided again. The niobium tube which forming is completed is shown in Fig. 3. The photograph of inside cavity is shown in Fig. 4. The equator part is the most expanded part in 67%. Both inside and outside surfaces looked rough. The cell shape is the TESLA-like, which KEK developed.

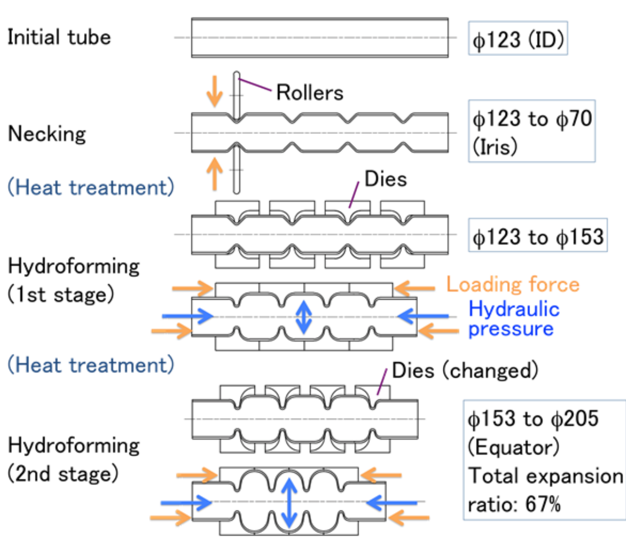

Figure 1: Process of necking and hydroforming.

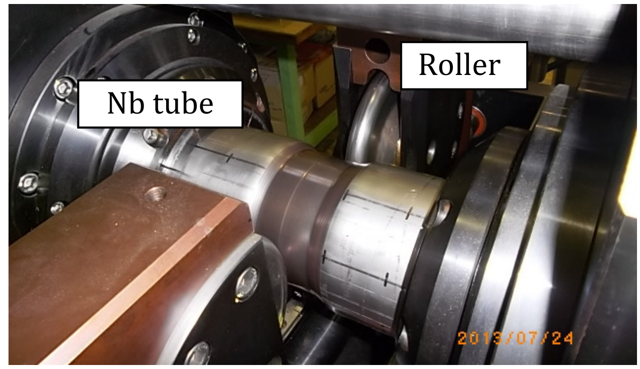

Figure 2: Necking machine.

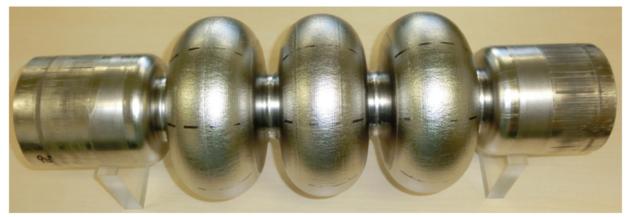

Figure 3: Niobium tube just after hydroforming.

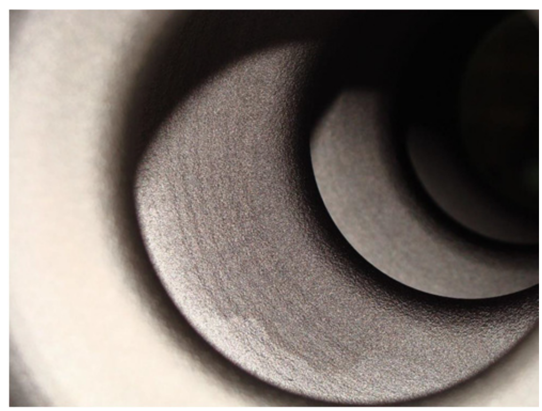

Figure 4: Inside cavity after hydroforming.

Finish to Cavity

The both iris parts of tube shown in Fig. 3 were cut and the 70 mm ID beam tube was joined to both ends by the EBW. The beam tube was manufactured by rolling a niobium sheet and the EBW. The flanges made from niobium titanium alloy were attached to both ends by the EBW. Figure 5 shows the completed 3-cell cavity. Since the inside surface after forming looked too rough for an electrolytic polishing (EP) process, the barrel polishing (BP) was performed last time. However, we tried EP without BP this time to check the effect of roughness on the cavity performance. Inside cavity after EP is shown in Fig. 6. Its surface roughness is 9.1 μmRa.

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Figure 5: Finish to 3-cell cavity.

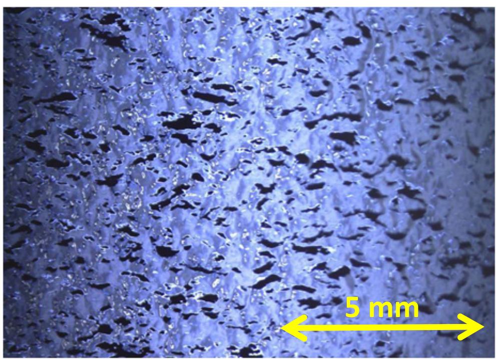

Figure 6: Inside cavity after EP at equator.

PERFORMANCE EVALUATION

This cavity has all center-cell shape due to manufacturing reason. This led to some imbalance on the field flatness, which is expected to be ~70 % in π mode. Since the fields of both end cells of fabricated cavity were not balanced, some mechanical tuning was performed and the flatness improved to 66.6 % at the frequency of 1290.085 MHz. The vertical test was carried out after EP at Superconducting Test Facility (STF) in KEK. The result of the vertical test was shown in Fig. 7. E_{acc} is measured at first (end) cell. A quench occurred at second (center) cell caused by heating. The maximum E_{acc} of 32 MV/m at the second cell was obtained by converting the measured result at the first cell.

SUMMARY

It succeeded in the manufacture of the 1.3 GHz three-cell cavity by the hydroforming. From the result of the vertical test, the maximum accelerating gradient attained to 32 MV/m with too rough inside surface. We will continue the study to successfully hydroform a 9-cell cavity.

ACKNOWLEDGMENT

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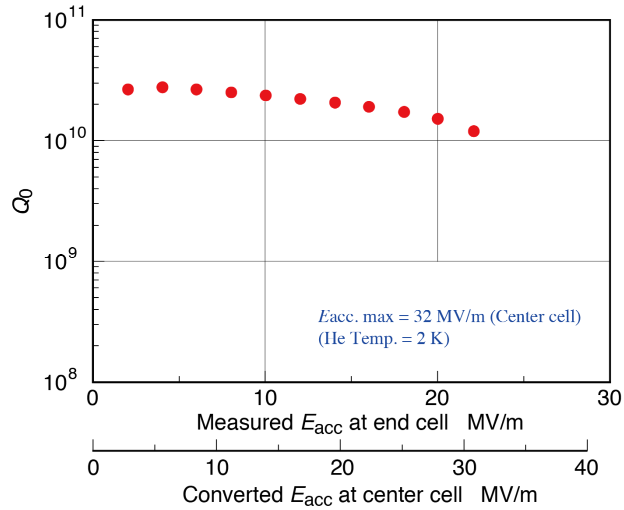

Figure 7: Result of vertical test (Q-E curve).

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