PRODUCTION AND INVESTIGATION OF SUPERCONDUCTING 9-CELL CAVITY MADE OF LARGE GRAIN Nb IN KEK*

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Abstract

Cavity Fabrication Facility (CFF) group in High Energy Accelerator Research Organization (KEK) has succeeded to produce the first in-house superconducting radio frequency (SRF) 9-cell cavity made of large grain (LG) niobium (Nb) in 2016. All process to produce 9-cell cavity from sliced Nb including electron beam welding (EBW) were done in KEK. This accomplished cavity is then first vertical tested in KEK, and resulted accelerating gradient of 20 MV/m.

INTRODUCTION

LG Nb sheets for cavity are sliced from melted Nb ingot which do not undergo the forging process, hence the grain size of LG Nb is bigger than that of fine grain (FG) Nb which undergoes forging process and usually used as SRF cavity material. Figure 1 shows the sliced LG Nb disk used for cavity fabrication. Several large grain can be seen in this sliced Nb. Using LG Nb for SRF cavity has possibility to lower the surface resistance and reach higher Q_0 than using FG Nb. This especially advantages for continuous wave operation, since generated heat load is much higher than that of pulse wave. And, there are some more advantages such as reducing costs for the materials using LG Nb [1].

Figure 1: Sliced LG Nb disk.

KEK CFF group had successfully produced the first in-house SRF Tesla-like 1.3 GHz 1-cell cavity made of LG Nb in 2013, and reached high Q_0 at the vertical test [2]. Then, KEK CFF group started producing the first in-house SRF Tesla-like 1.3 GHz 9-cell cavity made of LG Nb.

This 9-cell cavity was accomplished in February of 2016, then vertical tested via several processed.

CAVITY PRODUCTION

For the LG Nb 9-cell cavity production, CFF group follows several processes as described in the followings.

1. Press forming of Nb sheets and form half-cell shape
2. Trimming of half-cell edges (iris and equator)
3. Chemical Polishing (CP) of half-cells
4. EBW of iris part (assembling dumbbells)
5. Inserting and EBW of stiffener ring to iris
6. Mechanical local grinding of inside the cell
7. Producing end-groups
8. CP of dumbbells
9. EBW of equator
10. Leak check

Nb sheets are first press formed into half-cell shape. Un-level cell edges including lateral side of equator are grinded with the lathe after press forming. To make assembly easier, edges of equator are machined into spigot shape [2].

Two half-cells are jointed at iris by EBW. This two sets of half-cells are called “dumbbell” from that shape. EBW is done in three steps, pre-welding, seam welding and final welding. In pre-welding, only surface of iris for the range of 15 degrees around iris is welded. This welding is done for four spots around an iris (every 90 degrees). In seam welding, welding beam reaches close to the back side of cell. Seam welding is done for whole round of an iris. Final welding uses stronger beam current than seam welding, and beam reaches to back side.

Any tiny scratches or defects which can be found with naked eye are mechanical grinded locally with spinning files. To remain natural surface of LG Nb as possible, not whole of the cell but only defect spots are grinded. The file of #800~#1000 are used as final grinding whose remaining scars will be removed with 100 μm electrolytic polishing which will be done after cavity accomplishment.

After welding each dumbbell and end groups which consists of flanges, input and pickup ports, end-plates and beam pipes, the cavity is finally accomplished. Figure 2 shows the accomplished LG 9-cell cavity.

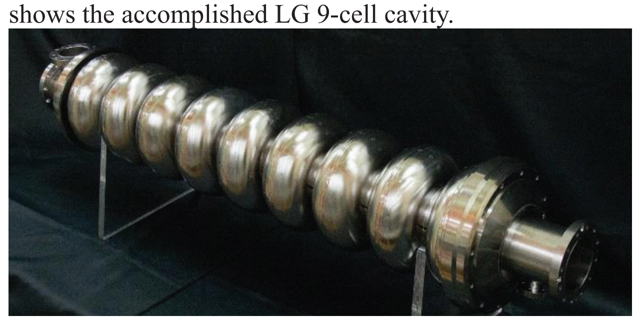

Figure 2: Accomplished LG 9-cell cavity.

Some more details about production are described in following sessions.

Deformation of the Cell

Roundness at inside of the equator is measured by three-dimensional measuring device after trimming. Fig-

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ure 3 shows the measured roundness. It can be seen that the roundness of LG cell is much worse than the average value of FG. This deformation is characteristic of LG Nb, and the extra supporting jig is necessary for equator EBW described in the following session. Since centre cells with younger lot numbers have smaller grain than others, roundness of them are better than others.

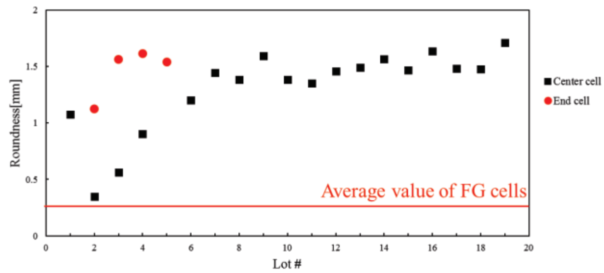

Figure 3: Roundness at equator of LG cell and average value of roundness from FG cells (red line).

EBW of Equator

For the previous production of 9-cell cavity in CFF, welding of each equator was done one by one to confirm finishing of welding bead as shown in Fig. 4.

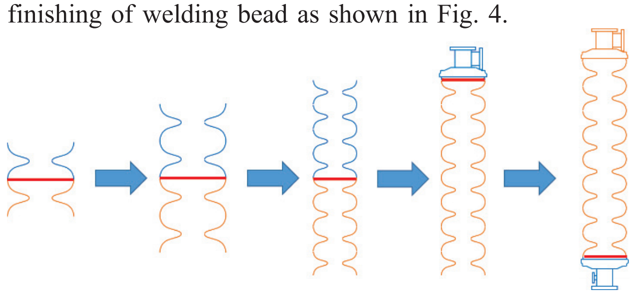

Figure 4: Explanation of previous equator welding process. Red lines represent welding position.

In this time, four dumbbells are set on the jig, three equators are welded; four jointed dumbbells are made at once. Then two end-groups and two sets of four jointed dumbbells are set on the jig and welded. Latter process is shown in Fig. 5. In this way, processing time is much more shortened since open-close time for vacuum chamber is reduced.

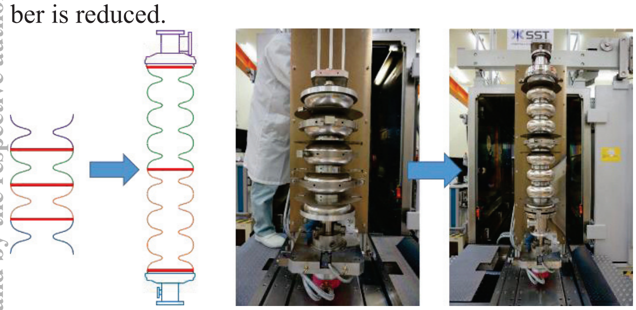

Figure 5: Explanation of current equator welding process (left) and actual photo (right). Red lines in the left picture represent welding position.

Spot welding is done before pre-welding for equator using supporting jigs. Supporting jigs which force equator to be exact circle are put on an equator position of coupled cells. Electron beam is shot into eight penetrated holes around supporting jigs. This process is necessary only for LG Nb cavity production. Figure 6 shows the equator with supporting jigs and the equator after spot welding. The supporting jig is unclasped after spot welding, an entire circle of equator is then welded after pre-welding.

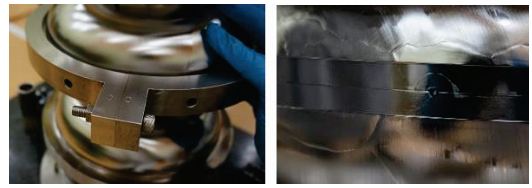

Figure 6: Equator with supporting jig (left) and equator after spot welding (right).

Trouble During Equator EBW

During a seam welding of equator, a penetrated hole has been made with big Nb spattering at 5th cell (centre cell). This hole is made on the welding bead, and its diameter is about 2 mm at the narrowest point and 4 mm at the widest. Repairing of this hole is done in following steps as shown in Fig. 7.

1. The hole shape is trimmed to circular truncated cone shape with a centre drill. To avoid contamination of Nb chips into inside the cavity, pressured air is blown into cavity during trimming which comes out from the hole. 2. CP is then done only around the hole after trimming. 3. A repairing piece which fits trimmed hole shape is made by same material, and CP is also done to this piece. 4. A repairing piece is set into holes, then spot welding is done to four points around the piece. 5. Two lines of seam welding are done for just around the hole (for welding distance of ~30 mm) at the position of ±5 mm far from the hole centre. 6. Final welding is done whole around the equator.

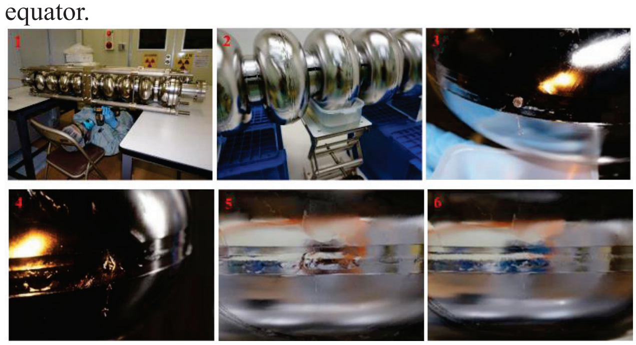

Figure 7: Repairing steps of the hole. Each number corresponds to one in the text.

Figure 8 (left) shows the welding bead at repaired position observed from inside of the cell. The welding bead looks even, however the welding bead width is narrower after passing hole than the other place.

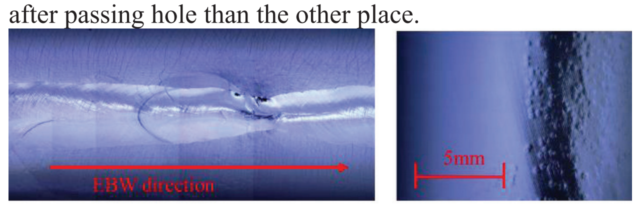

Figure 8: Welding bead at repaired position observed from inside (left) and strange structure (right).

Some strange structures look like a crater were made inside the 5th cell during CP for repairing as shown in Fig. 8 (right). A diameter of each crater is about 500 µm, and distributes around the repaired position parallel to equator at both side of 20 mm far from equator. These structures are remained for vertical testing.

PERFORMANCE MEASUREMENT

Preparation

The accomplished cavity is vertical tested to measure its performance in KEK. Some typical surface treatment such as electrolytic polishing (EP), annealing and high pressure rinse with ultrapure water are done before measurements [3]. Barrel polishing is skipped for this cavity. Thickness of 100 µm is polished in first EP, and 30 µm is polished in the final EP for this cavity. This EP makes insides the cavity mirror like surface.

Tuning is done before vertical testing. The field flatness of 98 % which is the ratio of maximum and minimum peak field at π-mode is performed. Fields at other passbands (π/9 to 8π/9) are also measured.

Vertical Testing

The cavity performance is measured in vertical cryostat.

Figure 9 shows the obtained cavity surface resistance comparing to FG 9-cell cavity in π-mode. Residual resistance value is calculated from fitting with following function,

$$f\left(\frac{1}{T}\right) = A\frac{1}{T}\exp\left(B\frac{1}{T}\right) + C,$$

where A and B are fitting constant, and C represents residual resistance.

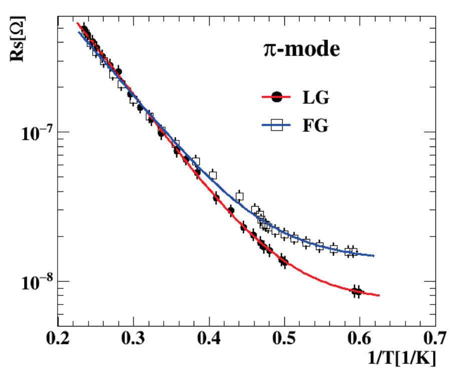

Figure 9: Surface resistance.

The residual resistance of LG and FG cavity is 7.3 ± 0.7 nΩ and 13.7 ± 1.0 nΩ respectively. This lower resistance of LG cavity can perform higher Q_0 value than that of FG cavity.

Figure 10 shows Q_0 curve with respect to accelerating gradients at π-mode. Measurement was done twice; at temperature between 1.8 K to 1.9 K (1st) and 1.5 K to 1.6 K (2nd). In both cases, measurement was stopped at 20 MV/m due to quench at the equator of the 3rd cell.

Cavity performances in other passbands are also measured between 1st and 2nd π-mode measurement. Expected gradients at each cell are calculated from measured gradient at end-cell in the other passband and field distribution which is measured during tuning. Table 1 shows calculated fields of each cell. High gradients over 30 MV/m are expected at each cell except the 3rd cell.

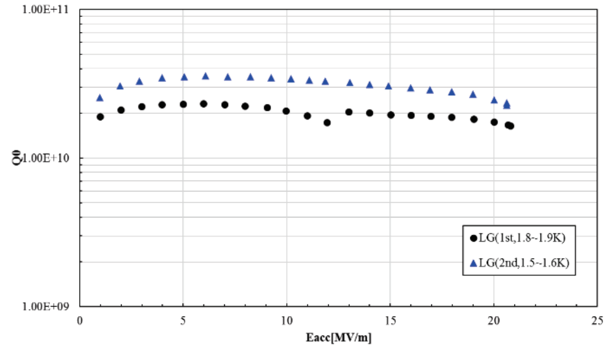

Figure 10: Q_0 curve with respect to accelerating gradients.

Table 1: Expected Maximum Gradient at Each Cavity

Cell	1	2	3	4	5	6	7	8	9
E_{acc} [MV/m]	36	37	23	>32	>39	32	>23	>37	>36

Inspection of the Cavity after Vertical Testing

Around the quench spot is observed after vertical testing from inside of the cavity. In consequence of observation, a suspicious structure was found around the quench spot of the 3rd cell as shown in Fig. 11. This structure looks like grain boundary which can be seen only in LG Nb. This structure will be locally mechanical grinded and second vertical test will be tried.

Figure 11: Found structure around the quench spot.

CONCLUSION AND OUTLOOK

KEK CFF group has successfully produced the first in-house SRF Tesla-like 9-cell cavity made of LG Nb. Performance of this cavity is then measured in first vertical testing. Lower residual resistance than FG Nb cavity which can reach higher Q_0 is obtained as expected. Measured maximum gradient is 20 MV/m at π-mode which was stopped by quench at the 3rd cell. However, over 30 MV/m gradients are expected in other cells. This means that the repairing of the hole and strange structures found around the hole at 5th cell did not critically affect the cavity performance.

The second vertical test is currently planned after local grinding of the quench spot.

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