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IN-HOUSE PRODUCTION OF A LARGE-GRAIN SINGLE-CELL CAVITY AT CAVITY FABRICATION FACILITY AND RESULTS OF PERFORMANCE TESTS*

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Abstract

Processes of in-house production of a large grain single-cell cavity and results of performance tests are reported. EBW tests by using test pieces cut out from large grain Nb disks were carried out before the equator welding. The results were consistent with those of fine-grain Nb test pieces. An actual situation of equator welding, however, was different from that expected at EBW tests, because of the large errors of equator thickness due to the difficulty of machining a large grain Nb. As a result, a bead-width distribution contains large errors reflecting those of equator-thickness. The completed cavity was named KEK-R1, and its performance tests were carried out. The accelerating gradient of the cavity exceeded 45 MV/m. The maximum values of Q-factor at the first test achieved 10×10^{10} and 2×10^{10} at very low temperature and 2.0 K, respectively, and those at the second test achieved 6×10^{10}, 5×10^{10}, 4×10^{10}, 3×10^{10} and 2×10^{10} at 1.4 K, 1.6 K, 1.7 K, 1.8 K and 2.0 K, respectively.

INTRODUCTION

Cavity Fabrication Facility (CFF) is a facility of KEK for studying technologies of the mass production of superconducting radio-frequency (SRF) cavities, where a press machine, a vertical lathe, a chemical room with a fume hood and an electron-beam welding (EBW) machine are all equipped in one clean environment. In CFF, fine grain (FG) Nb sheets have been used as a material of SRF cavities rather than large grain (LG) Nb disks [1]. Cavities made from LG-Nb disks, however, have attracted much attention of researchers of this field for the last decade because of their higher Q-factors compared to those made from FG-Nb sheets. A possibility of mass production of LG-Nb cavities is worth studying toward a future accelerator-project. At CFF, the in-house production and studies of fabrication technology of a LG-Nb cavity started last year. The completed cavity was named KEK-R1, and its performance tests were carried out this year. In this paper, processes of the production and results of performance tests are briefly reported.

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Figure 1: (a) LG-Nb disk supplied from Tokyo Denkai. (b) Half-cell with a copper shell. (c) Trimmed half-cell.

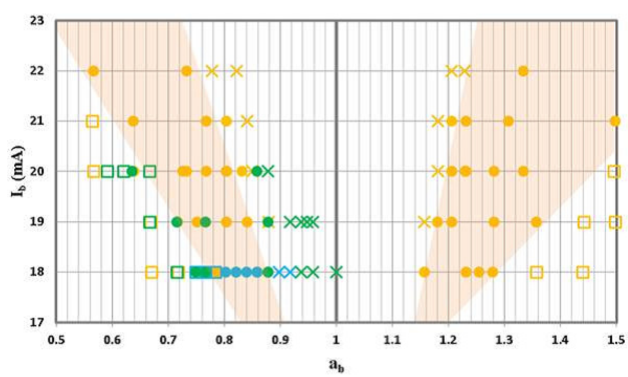

Figure 2: Results of EBW tests. Orange symbols are results of FG-Nb test pieces obtained before. Green and blue symbols are results of LG-Nb test pieces, where the former and latter correspond to bead-on-plate welding and butt welding, respectively. Circles correspond to good welds. Squares correspond to narrow weld beads or non full-penetrating-welds. Crosses correspond to weld beads with holes or spatters.

EBW TEST

LG-Nb disks with diameters 270 mm and thicknesses 3.18 mm were supplied from Tokyo Denkai (Fig. 1(a)). Test pieces with 150 mm × 150 mm and 150 mm × 22 mm were cut out from the disks. The former was for the bead-on-plate welding and the latter was for the butt welding. Both types of test pieces had rectangular areas with thickness 2.0 mm, which imitates the equator thickness. These test pieces were carried to the chemical room of CFF and etched by the buffered chemical polishing (BCP) solutions, where 10-30 μm of materials were removed. Following ultrapure water rinsing and natural drying, the test pieces were car-

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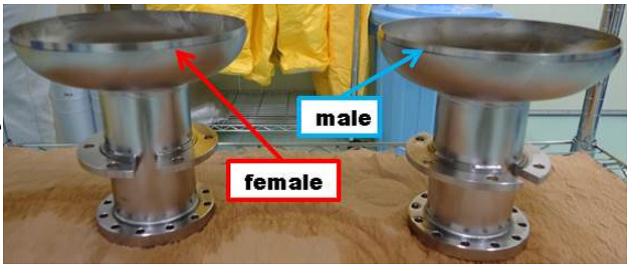

Figure 3: Half cells combined with beam pipes.

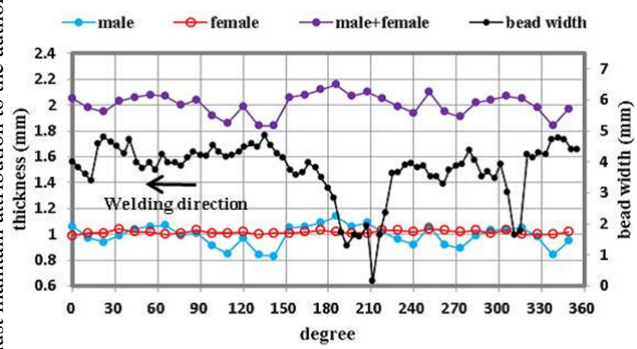

Figure 4: Thicknesses of joint parts of male, female and their summation, which corresponds to the equator thickness to be welded. Bead widths extracted from optical inspections are also shown for comparison with the equator-thickness distribution.

ried to the EBW room and welded with a number of EBW parameters. The free EBW parameters were a beam current I_b and an a_b-factor [1], and the other EBW parameters were fixed: the generator position and the welding direction were both horizontal, the accelerating voltage was $V_a = 120\,\mathrm{kV}$, and the welding speed was $v = 5\,\mathrm{mm/s}$.

Figure 2 shows results of the EBW test for the LG-Nb test pieces and those for FG-Nb test pieces obtained before for comparison. Optimum parameters for FG-Nb test pieces distributes on the shaded region and others induce poor welds: parameter regions with large I_b or small $|a_b - 1|$ result in welds with holes or spatters, on the other hand, those with small I_b or large $|a_b - 1|$ result in non full-penetrating-welds. The results for LG-Nb test pieces were consistent with those of FG-Nb.

FABRICATION

First the LG-Nb disks were machined into concentric disks by wire electrical discharge machining. The concentric disks were carried to CFF and layered with copper disks to fit the existing press-dies, then pressed into half-cells (Fig. 1(b)). The half-cells were machined into male and female by trimming the outside of the equator and both the inside and the outside of the equator, respectively, where design thicknesses of machined tips are both 1.0 mm, and thus that of joint of the male and the female is 2.0 mm. The copper shells were detached at this stage (Fig. 1(c)). Following BCP, ultrapure water rinsing and natural drying in the chemical room, the trimmed half-cells were EB welded [2] with beam pipes made from FG-Nb sheets (Fig. 3).

Before welding the equator, thicknesses of joint parts of the male and the female were measured by a caliper. Figure 4 shows their thicknesses as functions of position in degree. The thickness distribution of the female was close to the target thickness, 1.0 mm. On the other hand, that of the male had large errors $\sim 20\,\%$. As a result, the summations of two thicknesses, which correspond to thicknesses of material to be welded, had 10 % errors from the design value, 2.0 mm. These errors made a choice of EBW parameters difficult: since the EBW test was carried out by using the test pieces with thickness 2 mm, there was possibilities of inducing poor welds at thicker regions and holes at thinner regions due to deficiencies and excesses of the energy deposition, respectively. Taking into account that the cavity has a larger heat capacitance than the test pieces, we chose

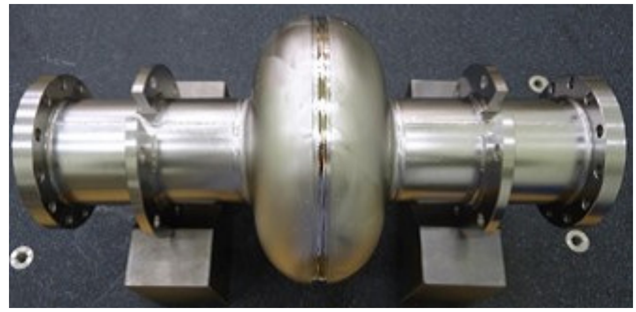

Figure 5: LG-Nb single-cell cavity, KEK-R1.

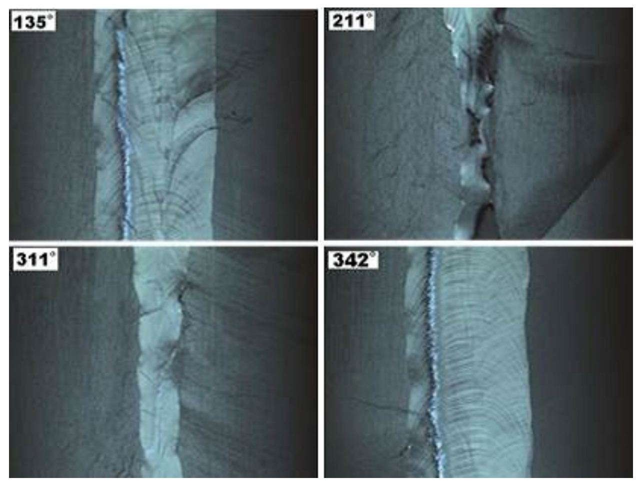

Figure 6: Images of equator weld-beads of KEK-R1 inspected by Kyoto camera [3].

[1] The a_b-factor is defined by $a_b \equiv \ell/f$, where f is a focal length of a magnetic lens and ℓ is a distance between a center of magnetic lens and a test piece. $a_b = 1$ and $a_b \neq 1$ correspond to a focused and defocused beam, respectively. Details of EBW parameters are found in Ref. [2].

[2] Welds of half-cells and beam pipes were carried out by an EBW machine equipped in machine shop in KEK, which is different machine from that of CFF.

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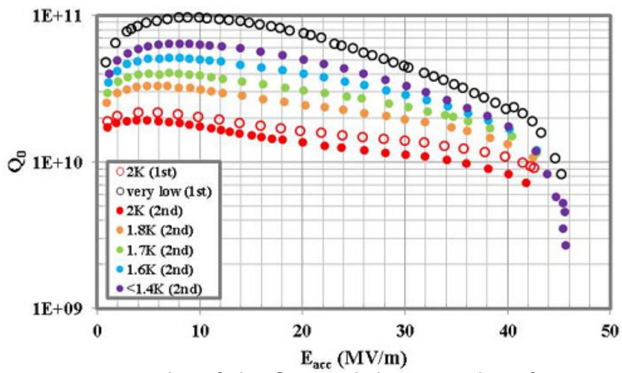

Figure 7: Results of the first and the second performance tests. The horizontal axis and the vertical axis represent the accelerating gradient E_{acc} and the quality-factor of the cavity Q_0, respectively. The black and red circles represent (Q_0, E_{acc}) measured at very low temperature and 2 K, respectively, where temperatures were monitored by the vapor pressure thermometer. Purple, blue, green, orange and red filled-circles represent (Q_0, E_{acc}) measured at 1.4 K, 1.6 K, 1.7 K, 1.8 K and 2 K, respectively, where temperatures were monitored by two silicon thermometers calibrated in a range $T > 1.5$ K put on the beam-pipes. Note that 1.4 K is out of the calibrated range of the silicon thermometers.

$(I_b, a_b) = (18\,\mathrm{mA}, 0.88)$ and completed the equator weld. Figure 5 shows the completed KEK-R1.

The inner surfaces of KEK-R1 were inspected by Kyoto camera [3], where images of equator weld-bead were taken every 4.5 degree (Fig. 6). Width distribution of the weld bead can be extracted from the images, which are shown in Fig. 4 for comparison with the equator-thickness distribution. As expected, thicker and thinner regions tend to induce narrower and wider weld beads, respectively.

PERFORMANCE TESTS

The standard recipe of the surface treatment adopted in KEK was applied to KEK-R1 at Superconducting rf Test Facility (STF). The light electropolishing, which we call pre-EP, was applied for cleaning the inside of the cavity and 5 μm of materials were removed, which is necessary not to contaminate the stored EP solution. Then the bulk EP, which we call EP1, was applied and 100 μm of materials were removed. Following the ultrasonic rinsing and the ultrapure water rinsing, the cavity was baked in a vacuum furnace at 750 °C by three hours. After inspections by Kyoto camera, the final EP, which we call EP2, was applied to the baked cavity and 20 μm of materials were removed. Following the ultrasonic rinsing, the high-pressure rinsing, assemblies in the clean room, and baking at 100 °C by 48 hours, the cavity was inserted into the vertical cryostat.

The performance tests were carried out twice. In the first test, the cavity temperature was monitored by a vapor pressure thermometer. The cavity temperature was decreased from room temperature to 5 K, then increased up to 17 K, and decreased down to a very low temperature, at which the vapor pressure thermometer showed negative values indicating outside of calibrated range. Following the test at a very low temperature, the cavity temperature was increased again, and the test at 2 K was also carried out. In the second test, the cavity temperature was monitored by both the vapor pressure thermometer and two silicon thermometers put on the beam-pipes, which were calibrated in a range $T > 1.5$ K. The cavity temperature was decreased down to 2 K, and tests at 2 K, 1.8 K, 1.7 K, 1.6 K, and 1.4 K were carried out. Note that 1.4 K is out of the calibrated range of the silicon thermometers. The results of first and second tests are shown in Fig. 7. The accelerating gradient of the cavity exceeded 45 MV/m. The maximum values of Q-factor at the first test achieved 10×10^{10} and 2×10^{10} at very low temperature and 2 K, respectively, and those at at the second test achieved 6×10^{10}, 5×10^{10}, 4×10^{10}, 3×10^{10} and 2×10^{10} at 1.4 K, 1.6 K, 1.7 K, 1.8 K and 2.0 K, respectively.

Surface resistances R_s as functions of an inverse of temperature and residual resistances $R_{\rm res} \equiv \lim_{T\to 0} R_s$ for every E_{acc} value can be extracted from the results, and field dependences of BCS and residual resistances can be evaluated [4, 5]. Analyses are in progress and will be presented elsewhere.

SUMMARY

We started the in-house production and studies of fabrication technology of a LG-Nb cavity last year. According to the EBW tests with LG-Nb test-pieces, the optimum EBW parameters for LG- and FG-Nb are consistent. EBW parameters that have been searched so far by using FG-Nb test pieces might be used in equator welding of LG-Nb cavities. Difficulty in equator welding of LG-Nb cavity is caused by the large errors of equator thickness due to the difficulty of machining a large grain Nb, which make choices of EBW parameters difficult. Even if the equator welding is succeeded, a bead-width distribution might contain large errors reflecting those of equator-thickness like that of KEK-R1. Improvements of machining processes are essential.

REFERENCES

[1] T. Saeki et al., in these proceedings, IPAC2014, Dresden, Germany (2014).

[2] T. Kubo, Y. Ajima, H. Inoue, T. Saeki, K. Umemori, Y. Watanabe, S. Yamaguchi, M. Yamanaka, and T. Nagata, in Proceedings of SRF2013, Paris, France (2013), p. 421.

[3] Y. Iwashita, Y. Tajima, and H. Hayano, Phys. Rev. STAB **11**, 093501 (2008).

[4] A. Romanenko and A. Grassellino, Appl. Phys. Lett. **102**, 252603 (2013).

[5] G. Ciovati, P. Dhakal, and A. Gurevich, Appl. Phys. Lett. **104**, 092601 (2014).