R&D OF ICHIRO HIGH GRADIENT 9-CELL CAVITY FOR ILC

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Abstract

We are planning to construct Superconducting RF Test Facility (STF) at KEK for the R&D of ILC accelerator. In STF, four TESLA-like type 9-cell cavities and four Low-Loss (LL) type cavities will be installed into a cryomodule. We are aiming at the gradient of 51 MV/m with this LL-type cavity, and we named this cavity as ICHIRO after the back-number of famous base-ball player ICHIRO; 51. The four ICHIRO cavities were successfully fabricated and delivered to KEK. Two of them were already surface-treated and measured in vertical cryostat. In this article, the results of vertical tests by these two ICHIRO cavities would be reported.

INTRODUCTION

After the first ILC Workshop in KEK in November 2004, the Working-Group 5 (WG5) Asia made a plan to fabricate four 9-cell high-gradient cavities in LL-shape for Super-conductivity Test Facility (STF) at KEK. The details of the STF plan is found elsewhere [1]. The four LL-shape cavities were successfully fabricated and delivered to KEK on 4 July 2005. Two of them were surface-treated with the KEK recipe and measured in the cryostat.

DESIGN OF 9-CELL ICHIRO HIGH-GRADIENT CAVITY

The design of 9-cell high-gradient cavities started in collaboration with J. Sekutowicz from DESY. He originally designed so-called Low-Loss type cavity, where the Hp/Eacc ratio is lower than TESLA type cavity [2]. We modified this LL-type cavity so as to change the wall-angle of cell to zero degree, where each wall of cavity-cell is vertical as shown in Figure 1. Consequently, the Hp/Eacc ratio of 36 Oe/(MV/m) was obtained for our cavity, where the high-gradient of Eacc ~ 51 MV/m is expected in the best case. We named the cavity as ICHIRO after a famous Japanese baseball player, ICHIRO, whose back-number is 51.

As shown in Figure 1, both end-cells have slightly larger diameters at their equators and different shapes than the rest of seven central-cells. It is also shown that a beam-pipe of the cavity in the right-hand side has a Higher Order Mode (HOM) coupler and a port for input-coupler. A beam-pipe in the left-had side has a HOM coupler and a pickup port. The first 9-cell ICHIRO cavity was fabricated without HOM couplers and ports in order to finish fabrication as quickly as possible and to perform vertical test earlier. The rest of three ICHIRO cavities have two HOM couplers, an input-coupler port, and a pickup port as shown in Figure 1.

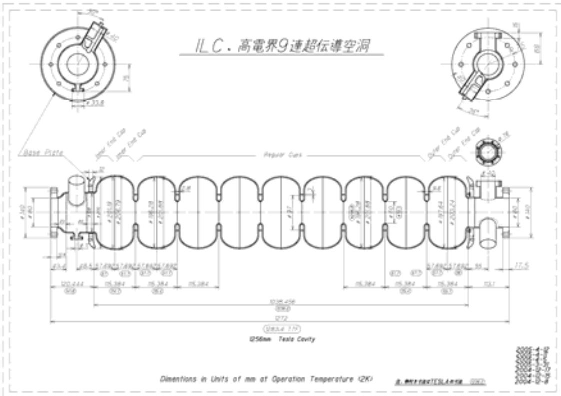

Figure 1: Draft of 9-cell ICHIRO high-gradient cavity.

FABRICATION OF 9-CELL ICHIRO HIGH-GRADIENT CAVITY

The fabrication of four 9-cell ICHIRO cavities started from the end of January 2005, when more than eighty sheets of niobium (Nb) with the RRR of 300 were delivered to KEK. The fifty six sheets were deep-drawn by a press-machine to form half-cell cups on 21st February 2005. The half-cups were trimmed at the iris and equator parts to have the design height with taking into account the EBW shrinkage. Then the iris part of two half-cell cups was welded by an Electron Beam Welding (EBW) machine to form so-called dumbbell-shape. A special jig was made to insert two stiffener half-rings into the iris part of a dumbbell and to align the position. The stiffener-rings were welded to thirty-two dumbbells by an EBW machine on 16th April. The equator parts of eight dumbbells per cavity were welded to make a 9-cell cavity-body. Two beam-pipes per cavity were assembled with main flanges, HOM couplers, input-coupler-port flange, pickup-port flange, end-plates for joint to liquid-helium jacket, and end half-cell cups by an EBW machine.

These assembled beam-pipes with flanges and end-cell were called "end-group". Two end-groups per cavity were finally welded to a 9-cell cavity-body. The first 9-cell ICHIRO cavity was delivered to KEK on 5th May 2005, and the fourth 9-cell ICHIRO cavity was delivered to KEK on 4th July 2005.

Measurements and tuning of dumbbell-shape

We measured the height and 3-dimentional (3D) shape of dumbbells before the EBW of stiffener-ring. The measured results are shown in Figure 2. The average of dumbbell-height was 114.43 mm with the standard deviation of 0.16 mm. This average is shorter than the design value of 115.86 mm by 1.4 mm because the dumbbells were heat-deformed and shrank when the iris part was welded. A typical example of 3D measurement of dumbbell-cup is shown in the right-hand side of Figure 2. It is seen that deviation from the design curve is small around the equator part. But the deviation becomes larger around the iris part. This deformation is due to the heat of EBW at the iris part, and consequently, the height of dumbbell becomes shorter.

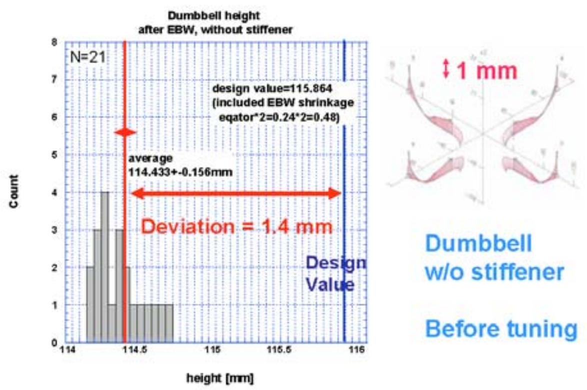

Figure 2: Dimensional measurements of dumbbells without stiffener-ring before tuning. Left-hand side: height measurement. Right-hand side: 3D measurement of dumbbell-cup. Black-curve is design shape and the red-lines denote the deviations from the design curve.

In order to force the dimension of dumbbells into the design shape, the stiffener-ring is very effective. However, the EBW of stiffener-ring changes the cup-shape in another way. We found the serious dimensional deviation after completion of 1st ICHIRO cavity fabrication and considered stiffener-ring is not enough to remove the total shape-deformation.

To remove the total deformation of dumbbell-shape, we pulled and extended the twenty four dumbbells by a special jig as shown in the left-hand side of Figure 3. Using this special jig, we tuned the height and shape of dumbbells for 2nd, 3rd, 4th ICHIRO cavities. After welding stiffener-ring and tuning of dumbbell-shape, we measured the height and 3D shape of twelve dumbbells. The measured results are shown in Figure 3. The average of dumbbell-height was 115.78 mm with the standard deviation of 0.13 mm. This average is shorter than the design value of 115.86 mm by only 0.08 mm.

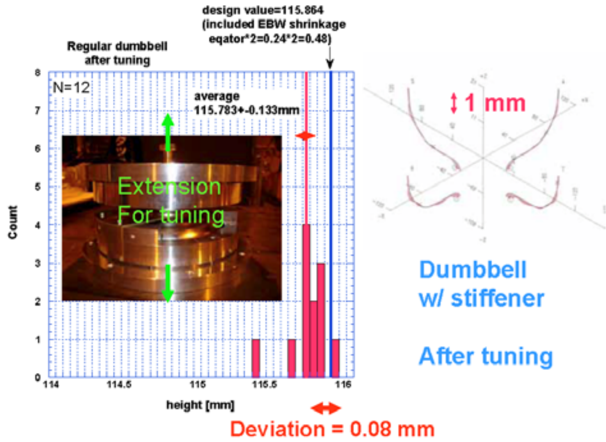

Figure 3: Dimensional measurements of dumbbells with stiffener-ring after tuning. Left-hand side: height measurement and height tuning by a special jig. Right-hand side: 3D measurement of dumbbell-cup. Black-curve is design shape and the red-lines denote the deviations from the design curve.

Dimensional measurements

Length measurement

After four ICHIRO cavities were fabricated and delivered to KEK, we measured the length of four cavities. The purpose of these measurements is to clarify the shrinkage and heat deformation of cells in the EBW process. Therefore, the length of only 9-cell part of cavity without beam-pipes was measured. The deviations from the design value of 1038.5 mm for 1st, 2nd, 3rd, 4th cavities were -10.0 mm, -0.7 mm, -0.1 mm, and -0.1 mm, respectively.

1st ICHIRO cavity has the largest deviation of 10.0 mm. However, after introducing the dumbbell-height tuning from the 2nd cavity as already mentioned, the deviations were significantly reduced.

Measurement of Shrinkage from EBW process

Table 2: Measured shrinkage from EBW process. (mm)

Part	Average	Standard deviation	N samples
Iris	0.148	0.044	32 (dumbbells)
Equator	0.424	0.125	27 (cells)

When half-cell cups were fabricated, a mark-off line was scratched at the constant distance of a few mm from each end of iris and equator edges. After each EBW process of iris and equator of half-cells, the distance between two mark-off lines across the EBW part was measured to estimate the shrinkage from the EBW process. The result of measurements is shown in Table 1. For 4th cavity, mark-off lines at the equator was not made and the data of equator is only from three cavities.

Straightness measurement

The straightness of cavities was measured by a 3D measurement machine when the cavities were delivered to KEK. The central position of equator circle for each cell was estimated by 3D measurements. The straightness measurements were performed for four ICHIRO cavities. The maximum deviations of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} cavities from the ideal strait line are 0.33 mm, 0.24 mm, 0.27 mm, and 0.38 mm, respectively.

Pre-tuning

The pre-tuning was performed for all cavities. Cell-to-cell coupling of ICHIRO cavity is as small as 1.6 %, but there was no problem in pre-tuning process. Field flatness of 1^{st} ICHIRO cavity after pre-tuning is shown in Figure 4, where the final field flatness was 98 %. The pi-mode frequencies of 1^{st} ICHIRO cavity before and after pre-tuning were 1298.774 MHz and 1298.547 MHz, respectively.

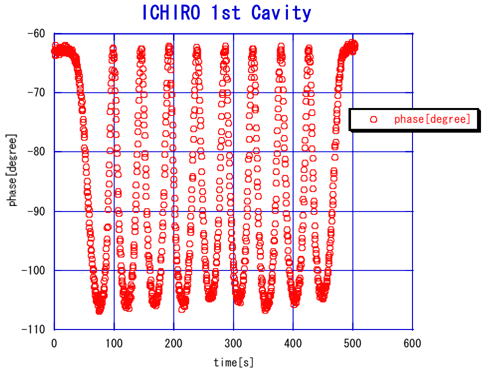

Figure 4: Field flatness of 1^{st} ICHIRO cavity after pre-tuning. Pi-mode frequency is 1298.547 MHz.

PREPARATION WITH KEK RECIPE

Two of four ICHIRO cavities were already surface-treated with the KEK recipe. The KEK recipe consists of Centrifugal Barrel Polishing (CBP), light Chemical Polishing (CP), annealing / degassing, Electro-Polishing (EP), High-Pressure Rinse (HPR), and baking. The details of each process are found in elsewhere [3].

CBP process removes the inner surface of cavity mechanically. Stones and water are put into the cavity and it is tumbled by a special machine. This process aims at removing defects of Nb material and obtaining smooth surface at the EBW-seam. CP process removes the inner surface of the cavity chemically by the thickness of 10 um. The purpose of light CP is to remove contamination in CBP and prepare smooth surface before EP. In order to release the mechanical stress of the cavity and to remove hydrogen gas in the material, annealing / degassing is performed at 750 ^{O}C for 3 hours. EP process removes the inner surface of cavity by the thickness of 80 um, and it prepares very smooth surface. Immediately after EP process, the cavity is rinsed with Pure-water (PW) and then High-Pressure Rinse (HPR) is applied, where Ultra-Pure Water (UPW) comes out from a nozzle inserted in a cavity and cleans up the cavity. After HPR process, the cavity is moved into a class-10 clean-room for assembly with an RF input-coupler and pick-up antenna. After pumping the inside of cavity, the cavity is baked at 120 ^{O}C for 48 hours to diffuse the oxidation layer on the inner surface of cavity.

VERTICAL TESTS OF ICHIRO CAVITIES

The best results of vertical tests for 1^{st} and 2^{nd} ICHIRO cavities are shown in Figure 5. Before 1^{st} ICHIRO cavity reached the best result in the 8^{th} measurement, we additionally EP-processed it by the removal thickness of 30 um. In the measurement, we encountered a hard barrier at Eacc = 29 MV/m. It is also found from multi-pacting (MP) simulation at SLAC that there is a hard barrier at Eacc = 29 MV/m around the papered part of enlarged beam-pipe of ICHIRO 9-cell cavity. 2^{nd} ICHIRI cavity has a problem of low Q factor. We are suspecting that it is from imperfect EBW between HOM coupler antenna and pipe. We have a plan to re-design the beam-pipe shape and to re-EBW the HOM coupler antenna. No Q-disease was found for these two cavities in series vertical tests.

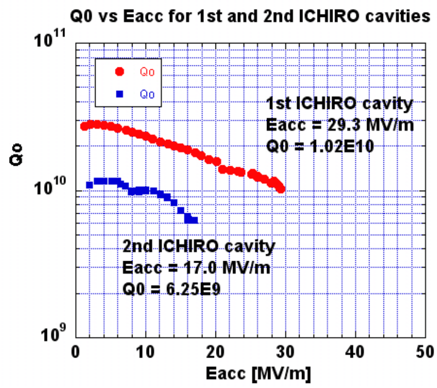

Figure 5: Vertical test results for 1^{st} and 2^{nd} ICHIRO cavities.

SUMMARY AND ACKNOLEDGEMENTS

Four Low-Loss type ICHIRO 9-cell cavities were successfully fabricated and delivered to KEK. Two of these four cavities reached Eacc = 29.3 MV/m at Q = 1.02E10 and Eacc = 17.0 MV/m at Q = 6.25E9 in vertical tests after preparation with the KEK recipe. We would like to acknowledge Nomura Plating Co. and Cryogenic Science Center at KEK.

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