STATUS OF THE 9-CELL SUPERCONDUCTING CAVITY R&D FOR ILC AT HITACHI

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Abstract

Hitachi is developing 9-cell superconducting cavities for ILC project in collaboration with KEK. In 2010, Hitachi's first 9-cell cavity without HOM couplers was completed successfully. Surface treatments and performance test of the cavity were carried out at KEK and its accelerating gradient reached 35.2MV/m. We have undertaken our next 9-cell cavity with HOM couplers since January 2011. This paper outlines the fabrication flow and test result of our first cavity, and describes a current status of next cavity briefly.

INTRODUCTION

Hitachi participated in the construction of STF (Superconducting RF Test Facility) cryomodules at KEK, which aims for versatile development oriented toward ILC (International Linear Collider) project [1,2]. The cryostats were subjected to several performance tests and found to be reliable for this study. We also began to develop superconducting cavities for STF, and we completed our first 9-cell cavity without HOM couplers in April 2010, successfully. We have focused on electron beam welding (EBW) and plastic forming techniques, engineering of jigs, so that we have obtained valuable technology and know-how to fabricate a cavity. On the other hand, some technical issues to the next step are cleared, it make us recognize the importance of improving fabrication technology.

FABRICATION OF HITACHI'S FIRST CAVITY

At first this paper describes the structures and specifications of our first cavity briefly. The motivation for developing our first cavity was to establish basic fabrication techniques and to recognize issues for fabricating a cavity.

Structures and Specifications

The main feature and dimension of our first cavity is shown Figure 1. And major specifications of our first cavity are shown in Table 1.

The shape of center cell is based on STF Baseline cavity. Almost all cavity parts are made of niobium (RRR~300), and its flanges are made of Niobium-Titanium (NbTi), which can be directly welded to niobium by electron beam welding. Both the tensile strength and the hardness of NbTi are comparable to those of stainless steel and better than pure niobium. Baseplate which are welded the jacket with bellows are made of titanium (Ti). All of the parts are electron-beam (EB) welded together in a vacuum chamber.

To clear validity of center cell part productivity, we fabricated 9-cell superconducting cavity without HOM couplers, which remove beam induced power from cavity in order to avoid beam instability.

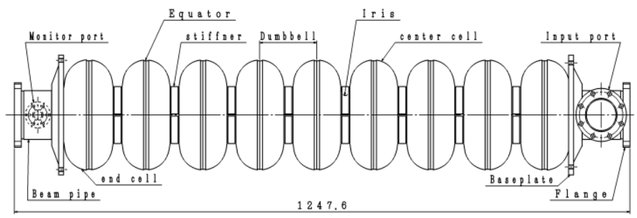

Figure 1: 9-cell superconducting cavity without HOM couplers.

Table 1: Basic Specifications for superconducting cavity

Items	Unit	Spec.
Material	-	Niobium (RRR~300)
Total length	mm	1247.6
Equator diameter	mm	205
Iris diameter	mm	70

Fabrication Flow and Development Items

In order to confirm the basic fabrication techniques of a cavity, we covered the most commonly used fabrication procedures, forming half-cells from sheet niobium. Fabrication flow is as follows.

(1) Deep drawing and trimming, chemical polishing (CP) of center cells
(2) Pressing and machining of stiffener
(3) Dumbbell Electron beam welding (EBW), that is, half-cell iris parts welding.
(4) Multi-dumbbell EBW, that is, dumbbell equator parts welding.
(5) Deep drawing and trimming, CP of end cells
(6) Machining and CP, EBW of baseplates
(7) Machining and CP, EBW of beam pipe.
(8) Assembling (EBW) end cells and baseplates, beam pipe.
(9) Assembling (EBW) center cells and end parts.

In order to achieve the desired high gradients, the superconducting cavity must have clean surfaces especially on the inner surface and therefore have to undergo special treatment and assembly procedures. The important development items are summarized as follows.

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- Plastic forming and machining technique for non-ferrous metal.
- Electron beam welding (EBW)
- Chemical Polishing (CP)
- Barring technique
- Design and manufacture of special jigs
- Cleanness control throughout fabrication process

Electron Beam Welding (EBW)

The outline of EBW, which is the most important technique for cavity fabrication, is described as follows. The primary parameters of EBW are beam voltage, beam current, weld speed, a_b value (focus current), beam oscillation, vacuum level in chamber, then we need parameter adjustment for optimized condition for a cavity. We tried to evaluate quantitatively the seam condition, for example, by focusing on seam height and width.

EBW parameter search is carried out the following flows.

(1) Bead on plate welding
(2) Butt welding between plates
(3) Circumferential welding on pipe
(4) Butt welding between pipes
(5) Real shape model welding

First, the purpose of (1) and (2) steps are the searching and decision of main EBW parameters, that is, beam voltage and beam current and so on. And the purpose of (3) and (4) steps are decision of beam current patterns and welding shrinkage. Finally, (5) is the adjustment step for a reason of the change cell's heat capacity. Figure 2 shows (5) step model.

The quality of the inner surface was visually sufficient for a cavity, and there are not defects and pits at all. The shape of equator seam was measured at KEK, so that we obtained the desired results that our seam is equal to the proven cavity's seam height and width, smoothness.

(a) (b)

Figure 2: (a) Test pieces of equator welding, (b) Typical inner picture of the EBW seam at equator.

Completion of Cavity Fabrication

Figure 3 shows completed our first 9-cell cavity. There are some issues as following under fabrication of first cavity.

- Need hand finishing for surface asperity
- Unstable EBW equator seam on rare occasions

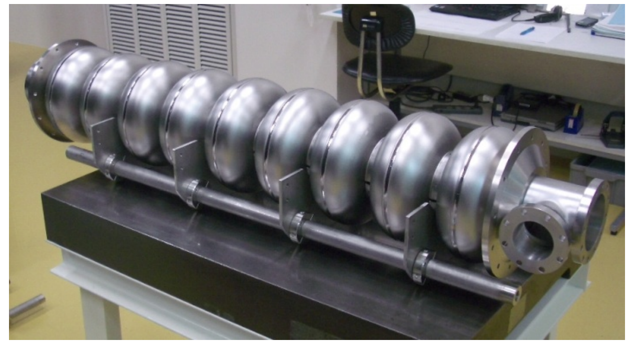


Figure 3: Completed 9-cell cavity.

PERFORMANCE TEST RESULT

To achieve the optimum rf performance, the surface of the cavity must be as close as possible to ideal. Surface treatments and performance test of the cavity were carried out at KEK from May to June 2010.

Performance Test

Once a cavity is completed, it usually experiences many process. Our first cavity also experienced the following main process.

- Electropolishing (EP) of inner surface
- Measurement of cavity frequency and field flatness by bead pulling method
- Annealing (750 degrees, 3 hours)
- Pre-tuning
- Inspection by optical camera
- High Pressure Rinse

The purpose of Electropolishing is the removal of impurities adhered to the cavity inner surface and defects due to poor quality of electron beam welding or material itself. Pre-tuning is also important process, and it ensures electric field flatness among cells. Inspection by optical camera is useful tool for the evaluation of the welding seam. By checking around welding seams, we visually understand the size and location of defects and pits.

Q-E curve

The performance test for our first cavity had been carried out in June 2010. Figure 4 shows the Q-E curve result of the cavity. The accelerating gradient (E_{acc}) reached 35.2 MV/m at unloaded quality factor (Q_0) of 6.5 x10^9 [3].

The main reasons of this good result are summarized as follows.

- Improvement of surface treatment technology at KEK.
- Smooth and uniform welding seam at equator parts compared with some other proven cavity welding seam. We improved the EBW parameters so many times (nearly 300 times) to obtain the optimum and stable welding seam.
- EBW of center cell parts at clean room (Class10000).

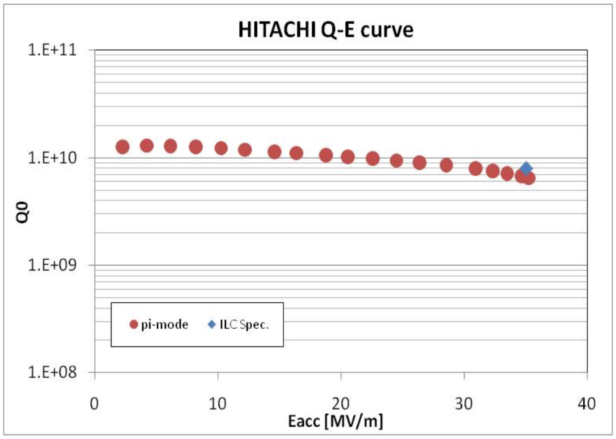


Figure 4: Q-E curve for our first 9-cell cavity.

CURRENT STATUS OF #2 CAVITY

We have undertaken next 9-cell cavity with HOM couplers since January 2011. The motivation for developing the #2 cavity is to confirm the reproducibility of #1 techniques and know-how and improve upon the cavity performance, and recognize the influence of HOM coupler to cavity performance. To improve the cavity performance and stability of fabrication methods, we improve the welding condition at equator parts, which is a region of high surface current and can show strong heating if weld is done poorly.

Now we are focusing on precision improvement of equator welding seam and fabricating HOM coupler. Only the outline of equator welding seam improvement is reported below.

Improvement of Equator Welding Seam

We adjusted a welding condition to improve the smoothness and height of equator welding seam. Moreover, we consider the stability of the conditions against the niobium thickness error and the Work distance (from RF gun to work) error at equator part.

We took a replica of equator seam to measure the seam shape at KEK, and we compared with our first cavity seam (#1). The measurement result is shown in Figure 5. The seam height of #2 was about 0.04mm, so that we obtained lower than #1 seam (about 0.17mm, 76% reduction).

In addition, we carried out the inspection of #2 welding seam utilizing the optical camera at KEK. The inspection result is shown in Figure 6. The seam has no pits and defects, non-uniform area, and we think that this result is positive tendency.

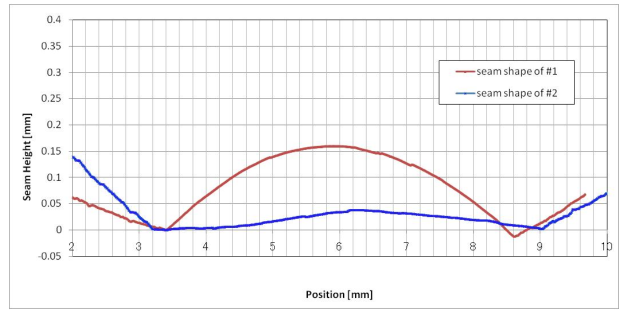
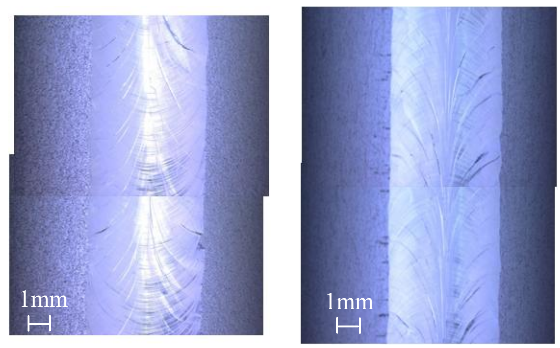


Figure 5: Equator welding seam comparison. The red line shows first cavity's seam form (#1) and the blue line shows improved seam form (#2).



(a) (b)

Figure6: Equator welding seam comparison by optical camera. (a) Improved #2 seam, (b) #1 seam.

CONCLUSIONS

Hitachi completed the first 9-cell superconducting cavity without HOM couplers in April 2010. Surface treatments and performance test of the cavity were carried out at KEK and the accelerating gradient reached 35.2 MV/m at unloaded quality factor of 6.5 $x10^9$. To confirm the reproducibility of #1 techniques and know-how and improve upon the cavity performance, recognize the influence of HOM coupler to cavity performance, we have undertaken our next 9-cell cavity with HOM couplers since January 2011.

ACKNOWLEDGMENTS

We wish to express our thanks to A. Yamamoto at GDE, K. Yokoya and K. Ueno, H. Inoue, Y. Ajima, Y. Watanabe at KEK for their useful advice and cooperation.

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