CAVITY FABRICATION STUDY IN CFF AT KEK

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Abstract

The construction of new facility for the fabrication of superconducting RF cavity at KEK was completed in 2011. It is equipped with the following machines; an electron-beam welding (EBW) machine, a servo press machine and a CNC vertical lathe. A chemical etching apparatus is also equipped. The study on the fabrication of 9-cell cavity for International Linear Collier (ILC) has been started from 2009 using this facility. The study is focusing on the cost reduction with keeping high performance of cavity, and the goal is the establishment of mass-production procedure for ILC.

INTRODUCTION

The International Linear Collider (ILC) is a future project that has been proposed by the world's high-energy physics community to realize high-energy electron-positron collisions at center-of-mass energies above 500 GeV. It consists of a pair of ~11-km-long electron and positron linacs, and contains approximately 16,000 L-band superconducting RF (SCRF) cavities made of niobium. Each 1-m-long cavity contains nine cells, which operate at a mean beam-accelerating gradient of 31.5 MV/m [1]. The Cavity Fabrication Facility (CFF) was established in KEK to develop manufacturing technology for SCRF cavities. The construction of CFF was started in 2009 and completed in July 2011. The first cavity named KEK-0 was fabricated in CFF, and its acceleration gradient attained 29 MV/m.

CONSTRUCTION OF CFF

The R&D works on the SCRF cavities for the ILC was started at the Superconducting RF Test Facility (STF) in KEK. More than 20 cavities have been already produced in Japan and 90% of the recently-made 10 cavities met the ILC specifications. These cavities were fabricated by Mitsubishi Heavy Industries Co., Ltd and their surface treatment after the fabrication was carried out at STF. The careful R&D works on the electro-polishing, the sequence of rinsing, the high-resolution optical inspection device called Kyoto camera and the local grinding machine were very effective in improving the performance and production yield of those cavities. STF is located on the KEK site so that the scientists can test various new ideas immediately. However, at that time, KEK did not have enough facilities to fabricate 9-cell cavities so their fabrication depended on companies outside of KEK.

In order to fabricate more than 16000 cavities within 3 to 5 years, a mass production technology must be developed. Moreover, the cost of the cavities is one of the major issues of the project, and it must be reduced drastically. To solve these problems, it seems effective to establish a R&D center for production of cavities on the KEK site similar to STF. The R&D team is aiming to gain enough experiences in the production of SCRF cavities at reasonable cost and to instruct companies in concrete mass production technologies in the near future. Now, all processes of producing niobium SCRF cavities, from fabrication to evaluation, can be conducted on the KEK site.

Figure 1 shows the exterior of CFF. It is a class 10000 clean room located in KAIHATSU KYOYOTO building aiming to maintain a clean working environment. The clean room is equipped with the following machines; an electron-beam welding (EBW) machine (Fig. 2), a servo press machine (Fig. 3 (a-1), (a-2)) and a CNC vertical lathe (Fig. 3 (b)). The electron beam quality is the most important specification in the EBW procedure. The output power and accelerating voltage of electrons of the EBW machine are 15 kW and 60～150 kV, respectively. This EBW machine is called as a high-voltage type with a long working distance. The optimum EBW conditions are explored through basic tests using niobium plates and calculations. The temperature distribution on the cavity during the EBW process can be obtained by finite element analysis (FEA). In the case of welding between different kinds of materials, FEA is very effective in determining the EBW parameters. The press machine has a maximum applying force of 1500 kN and nine different press patterns for various workpieces. The vertical lathe is used for trimming of half cells after the press process. The clean room is also equipped with a chemical polishing apparatus for cleaning the materials' surface, and all parts are chemically polished before the EBW process.

Figure 1: Exterior of the clean room (Class 10000) Size :19 m×14 m×H5 m (partially H3.5 m).

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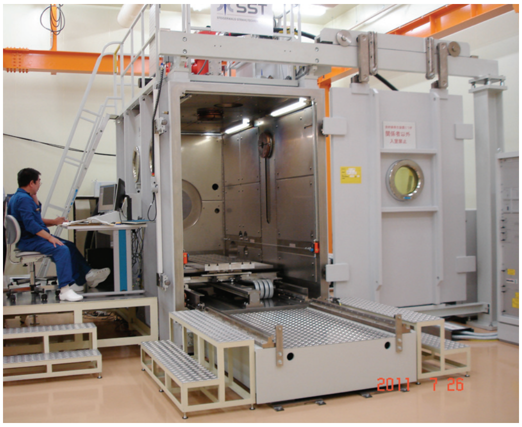
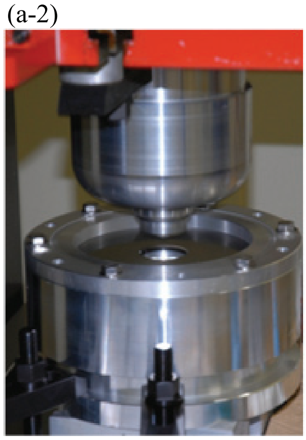


Figure 2: The EBW machine installed in CFF.

(a-1)

(a-2)



(b)

Figure 3: The servo press machine (a-1, a-2) and the CNC vertical lathe (b).

Figure 4 shows the first 9-cell cavity fabricated in the CFF and, which was named KEK-0. The shape of cavity is TESLA-like. It does not have a high order mode (HOM) coupler. Part of the EBW processing of cells was done by KEK technicians at a job shop outside of KEK. The performance test was carried out at a vertical test (VT) stand in the STF. Its acceleration gradient attained 29 MV/m as shown in Fig. 5.

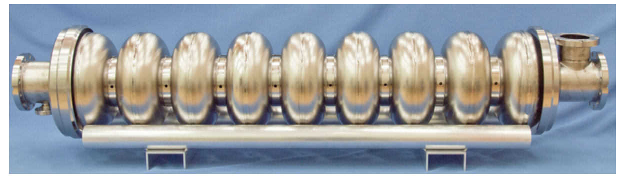


Figure 4: The first superconducting cavity (KEK-0) produced at CFF.

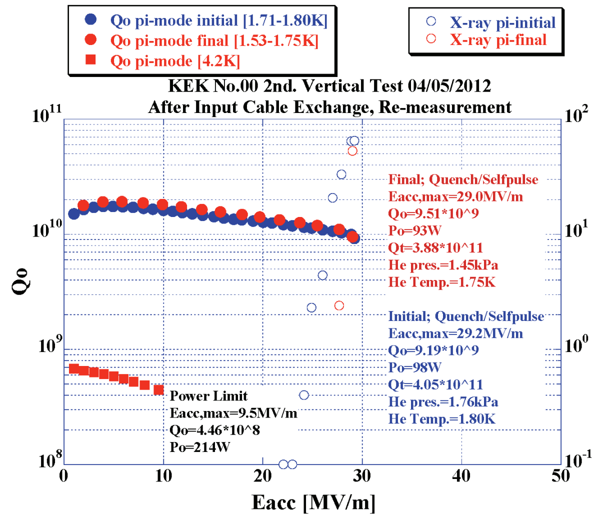


Figure 5: Q-E curve of the vertical test for KEK-0.

FABRICATION OF KEK-1 CABITY

Now, the second 9-cell cavity with HOM coupler named KEK-1 is under fabrication. Some designs in detail were modified from the viewpoint of manufacturing. The EBW is so important process in the cavity fabrication that some improvements are tried aiming a mass-production. In the fabrication of KEK-0 cavity, the electron gun of EBW machine was set on the ceiling of EBW machine and then the direction of electron beam was vertical with the horizontal posture of cavity. On the other hand, in the fabrication of KEK-1 cavity, the electron gun is set on the sidewall of EBW machine with the upright posture of cavity. Stacking dumbbells before EBW process is simpler in the vertical direction as shown in Fig. 6. It might be available for multiple welding during one vacuum.

Before changing the direction of EBW, rigorous parameter studies were done with niobium plates. One example of result is shown in Fig. 7 in which the good and bad welding conditions are plotted in the 2-dimensional parameter-space of the focus-lens current (focus-intensity of welding electron-beam) and the welding electron-beam current for the welding the niobium plates (2 mm in thickness) in the side-gun configuration. In this plot, the green circles denote the good conditions, and the red and yellow triangles denote bad conditions. Such parameter search was done by changing the welding beam voltage, focus-lens current, beam current, working distance from gun, workpiece moving speed, and thickness of niobium plate [2].

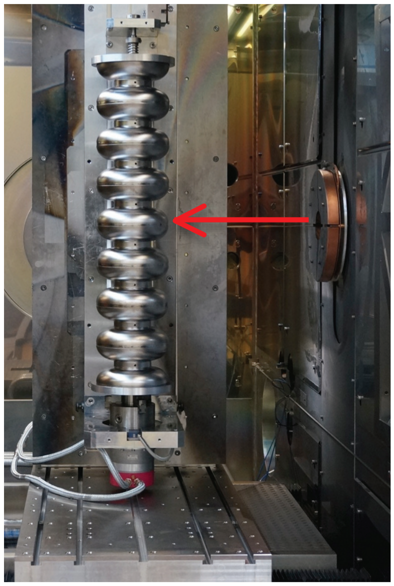


Figure 6: The direction of beam is changed to horizontal in KEK-1.

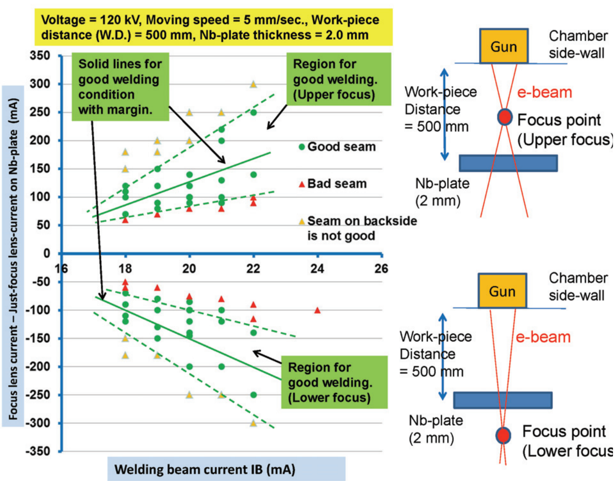


Figure 7: Example of basic welding test.

In addition, one must consider about the 3-dimensional shape of working-pieces because it affects the heat capacity and then the welding results. In order to optimize the welding parameter at the iris of dumbbell, welding parameter search was done using a niobium pipe, which has the same diameter as the iris. The same method was taken for searching the welding parameter at the equator of cell.

The HOM coupler is mounted on the beam pipe at the both ends of cavity. Its main parts are an outer conductor and an antenna. The conventional manufacturing method for the outer conductor is multi-step press firming. The niobium is ductile material and hard to draw deeply in general. To manufacture the outer conductor form a niobium sheet, more than 70 mm drawing is required. Therefore, drawing and annealing were repeated several times to form to the final shape. This time, the new manufacturing method was applied to them. Shinohara Press Service, Japan developed the special deep-drawing technique for a niobium and succeeded to form more than 70 mm in depth with one step as shown in Fig. 8 (a). All fillets of the antenna are rounded. They are machined by milling conventionally. The press forming was also applied to fabricate the fillet shape (Fig. 8 (b)). These processes are very effective for the cost reduction and the mass production. The performance of newly fabricated HOM coupler (Fig. 8 (c)) in a low power test at room temperature is confirmed to be comparable to that of conventionally fabricated one.

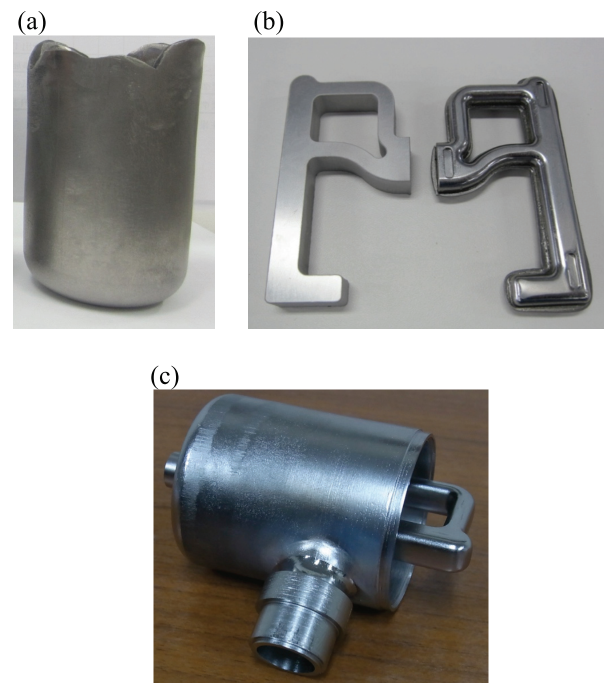


Figure 8: New manufacturing method for HOM coupler, deep drawn niobium cup (ϕ48x64) (a), antenna (left; before press forming, right; after press forming) (b) and assembled HOM coupler (c).

STUDY OF SEAMLESS CABITY

A seamless cavity is fabricated by necking and hydroforming. The advantage of seamless cavity are eliminating the EBW and reducing a cost. Many laboratories have successfully developed seamless cavities [3]. KEK started the R&D of niobium/copper clad seamless cavities in 1994 [4]. A thin niobium material (0.5 to 1 mm) was bonded on a copper material (2 to 5 mm) as the clad material. The necking and the hydroforming machines were developed by the mechanical engineering center of KEK. The excellent potential of clad cavities was confirmed [5].

Recently, we moved to bulk niobium cavities, and started the development of seamless niobium tubes with a collaboration of Japanese company. The improvement of manufacturing technique including heat treatment is continued. Figure 9 shows the 1-cell bulk niobium cavity (just after hydroforming) of the TESLA-like shape, successfully hydroformed at KEK. The niobium tube is 130 mm in outer diameter and thickens is 3.5 mm. It was

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manufactured by ATI Wah Chang, USA and provided by FNAL. The iris area (ID = 70 mm) was necked as shown in Fig. 10 (a) and the equator area (ID = 203 mm) was expanded by hydroforming with the control of internal pressure and axial displacement as shown in Fig. 10 (b). We will evaluate the performance of cavity soon.

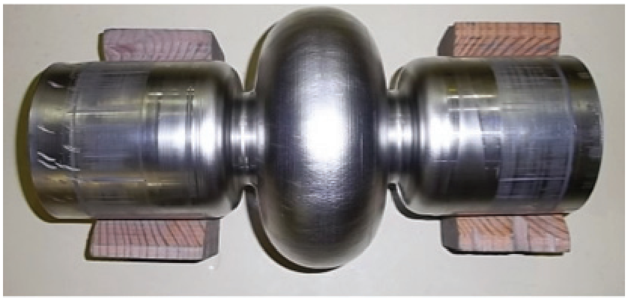

Figure 9: Hydroformed bulk niobium cavity.

(a)

(b)

Figure 10: Necking (a) and hydroforming (b) processes.

SUMMARY

Currently some R&D works are in progress in CFF to improve the EBW techniques, to modify the shape of the cavities for cost reduction and to develop equipment for mass production. They contribute to the R&D effort for the ILC. In near future the CFF, facilities and experiences, will become available for uses by companies and researchers from outside of KEK, who would contribute to the SCRF cavity production. Moreover, R&D of seamless cavity is continued for another option of fabrication method of cavities.

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