PROTOTYPING AND VERTICAL TEST FOR PEFP LOW-BETA ELLIPTICAL CAVITY*

Han-Sung Kim#, Hyeok-Jung Kwon, Yong-Sub Cho, KAERI, Daejeon, Korea
Sun An, PAL, Pohang, Korea

Abstract

A superconducting RF cavity with a geometrical beta of 0.42 and a resonant frequency of 700 MHz has been designed to accelerate a proton beam above 100 MeV for an extended program of Proton Engineering Frontier Project (PEFP). The designed cavity is an elliptical shape with 5 cells stiffened by double-ring structure. A design accelerating gradient is 8.0 MV/m at the operating temperature of 4.2 K and a maximum duty factor is 9 %. In order to confirm the fabrication procedure and check the RF and mechanical properties of the designed cavity, two niobium prototypes are under development. One is two-cell cavity mainly for a quick prototyping with the surface treatment study and the other is five-cell cavity. For a vertical test of the niobium cavities, test equipment such as a cryostat, RF amplifier and LLRF control system is under preparation. The status of the niobium prototype development and preliminary results for the vertical test will be presented in this paper.

CAVITY DESIGN

The major parameters of the PEFP SRF cavity are like followings [1].

- Frequency: 700 MHz
- Operating mode: TM010 PI mode
- Cavity shape: Elliptical
- Geometrical beta: 0.42
- Number of cells: 5 per each cavity
- Accelerating gradient: 8 MV/m
- Epeak/Eacc: 3.71
- Bpeak/Eacc: 7.47 mT/(MV/m)
- R/Q: 102.3 ohm
- Epeak: 29.68 MV/m
- Field flatness: better than 8.0 %
- Cell to cell coupling: 1.41 %
- Geometrical factor: 121.68 ohm
- Cavity wall thickness: 4.3 mm
- Lorentz force detuning: 0.4 Hz/(MV/m)^2
- Stiffening structure: Double ring structure
- Effective length: 0.45 m
- External Q of FPC: 8.0E05 ±20%
- HOM load: less than 2 W
- HOM Qext requirement: less than 3.0E05

For quick prototyping, we have designed a two-cell cavity which can be considered to be composed of three parts; the center cells, the fundamental power coupler (FPC) beam tube and the field probe beam tube. We chosed to attach double-ring stiffening ring around dumbbell in center cells to reduce Lorentz force detuning. The ANSYS simulation showed that the Lorentz detuning factor can be as high as 19.2 Hz/(MV/m)^2 with a single-ring stiffening structure, which is unacceptable. The diameter of the cavity is about 380 mm and total length including the NbTi flange is about 530 mm. The two-cell prototype is designed as simple as possible and there is no fundamental power coupler port or HOM coupler port to shorten the prototyping period. The main purpose of the two-cell prototype is to gain experience with niobium cavity fabrication and surface treatment. The drawing for the two-cell cavity is shown in Fig. 1.

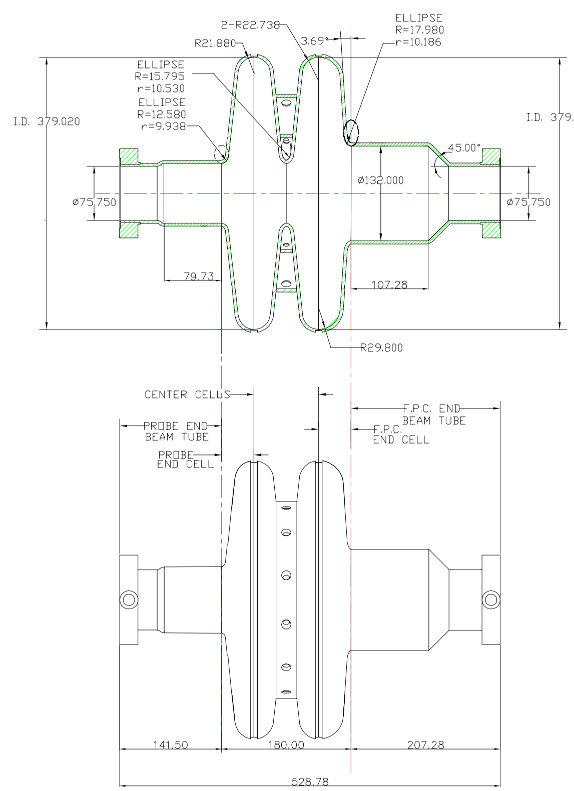

Figure 1: Drawing of the two-cell cavity.

FABRICATION OF THE CAVITY

The cavity fabrication mainly consists of the deep drawing process to make each components and the electron beam welding process to join them in one piece.

Deep Drawing of the Niobium Sheet

We made the half cells with the deep drawing process as shown in Fig. 2. When we stamped the first half-cell,

*Work supported by MEST of the Korean Government.
#kimhs@kaeri.re.kr

the raw half-cell was broken at iris region. This phenomenon was not observed during copper test and this means that the mechanical properties of the niobium are not similar to those of copper. A possible cause of this breaking is small size of the central hole size and relatively large thickness of the niobium sheet compared with other SRF cavity like ILC nine-cell cavity or high-beta cavity. We increased the central hole size and tried several times to obtain the ideal half-cell shape as shown in Fig. 3.

Figure 2: Deep drawing process to make a half-cell.

Figure 3: Half-cell after deep drawing.

After deep drawing, we trimmed the equator edge and iris edge to suitable length. Each half-cell equator is 1.0 mm longer than the length determined by a SuperFish calculation and each iris region is trimmed to a suitable length by considering a welding shrinkage. In addition the grooves on the outside wall of the half-cell are machined for welding the stiffening rings. The beam pipe transition parts were also fabricated by using similar deep drawing process.

Electron Beam Welding

Two half cells are joined together to make a dumbbell by the electron beam welding as shown in Fig. 4. Following the iris parts welding, we attached the double-ring stiffener to the dumbbell. Before each electron beam welding, we tested the condition of the electron beam current, the voltage of the welder and the rotational speed of the welder with the samples. The FPC beam tube and the field probe beam tube are also assembled with an end cell by the electron beam welding. The fabricated FPC beam tube sub-assembly and the field probe beam tube sub-assembly are shown in Fig. 5.

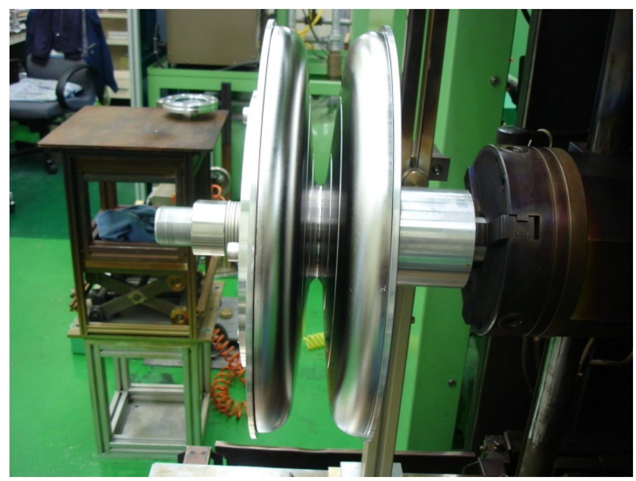

Figure 4: Dumbbell fabrication by joining two half cells by using the electron beam welding.

Figure 5: End cell sub-assembly.
Left: FPC beam tube, Right: Field probe beam tube.

The final stage of the electron beam joining process is to make a cavity by joining three sub-assemblies. Before the equator welding, we etched the surface of each part by using an acidic solution as shown in Fig. 6. The solution consists of HF, HNO_3 and H_3PO_4 with a volume ratio of 1:1:2. The etching time was 4 minutes and 30 seconds, which is equivalent to removing the surface of 10 um. After etching, each part was cleaned with DI water.

Figure 6: Etching before the electron beam welding.

The electron beam conditions used for the final equator welding are like followings, which were fixed by testing the half cell with the same size, shape and material as the real one.

- Electron beam current: 85 mA
- Electron beam voltage: 60 kV
- Beam power: 5.1 kW
- Focusing: Defocused beam

With above setting, we can obtain 100% penetration with a good welding surface. The cavity mounted on the electron beam welding machine with a fixing jig is shown in Fig. 7.

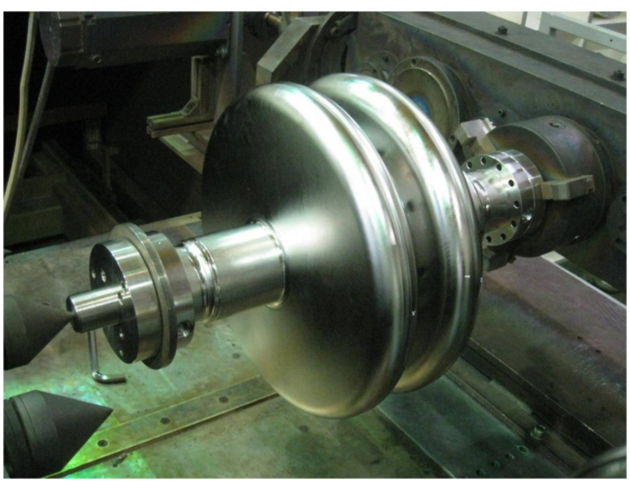

Figure 7: Cavity mounted on the electron beam welder.

CAVITY FREQUENCY SPECTRUM AND FIELD FLATNESS MEASUREMENT

Frequency Spectrum Measurement

We measured the cavity frequency spectrum before and after the final equator welding as shown in Fig. 8. To make a good electrical contact, we used many clamps for measuring the resonant frequency before welding.

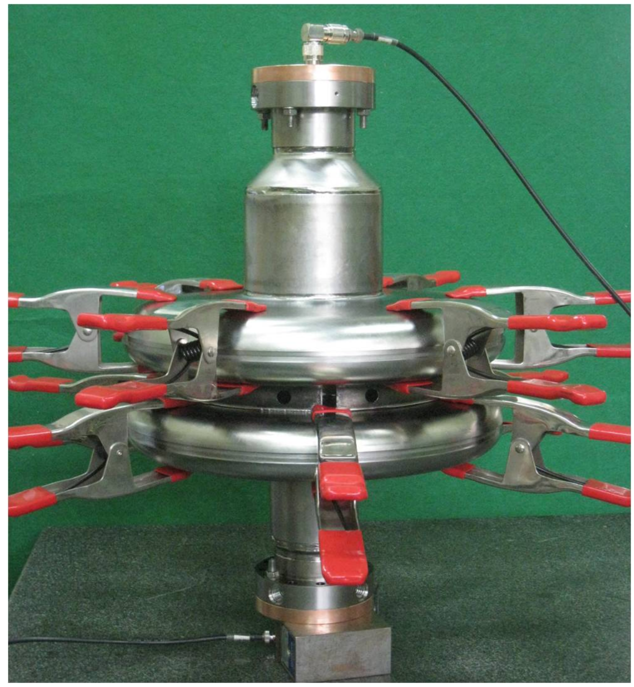

Figure 8: Frequency measurement set-up.

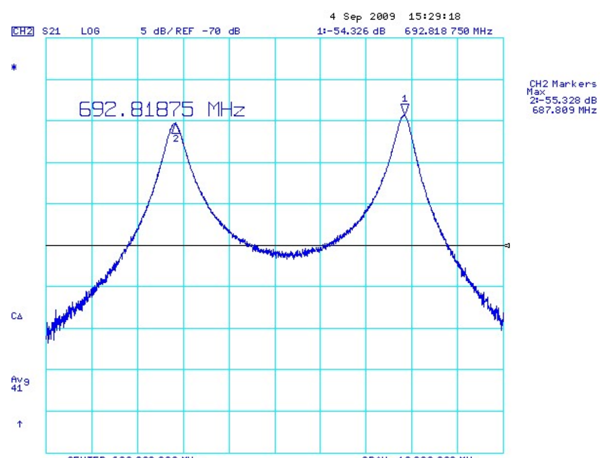

Figure 9: Frequency spectrum before equator welding.

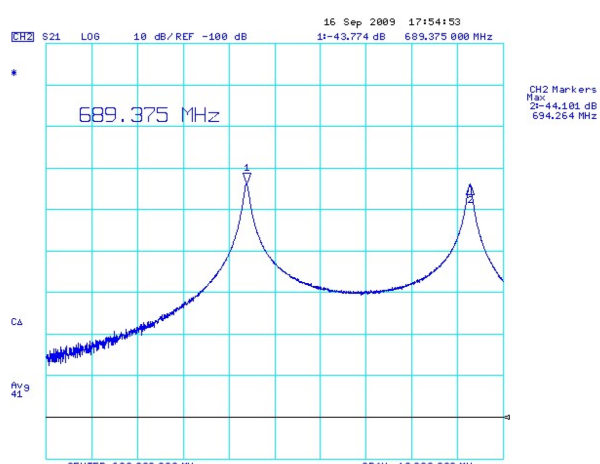

Figure 10: Frequency spectrum after equator welding.

The measurement results are shown in Fig. 9 and Fig. 10 before and after welding, respectively and summarized in Table 1. The frequency change was about 1.5 MHz for both PI/2 mode and PI mode, which is reasonable considering that the length change is about 0.6 mm and the sensitivity is about 3 MHz/mm.

Table 1: Frequency Measurement Results

Mode	Before Welding	After Welding	Frequency Change
PI/2 mode [MHz]	687.810	689.375	1.565
PI mode [MHz]	692.813	694.264	1.451

Field Flatness Measurement

The field flatness used to express how uniform the field profile is in an N-cell cavity is defined as following [2];

$$\eta_{\mathrm{ff}} = \frac{V_{\mathrm{c\,max}} - V_{\mathrm{c\,min}}}{\frac{1}{N}\sum_{i=1}^{N} V_{\mathrm{c}i}} \times 100\% \cdot \qquad (1)$$

Here, V_{ci} is the accelerating voltage of the ith cell. V_{cmax} and V_{cmin} is the maximum and minimum cell voltage in a cavity, respectively. The accelerating voltage in Eq. (1) can be expressed as a phase shift which can be directly measured by using bead-pull test.

We measured the field flatness by using a warm tuner as shown in Fig. 11. The measurement result without any tuning is shown in Fig. 12, from which we calculated the field flatness to be 1.8%. Considering the field flatness requirement of the PEFP low-beta cavity is 8.0%, the cavity needs no further field flatness tuning.

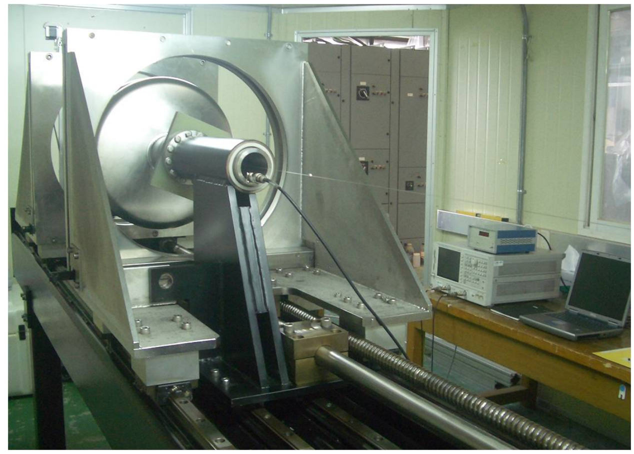

Figure 11: Bead-pull test to measure the field flatness.

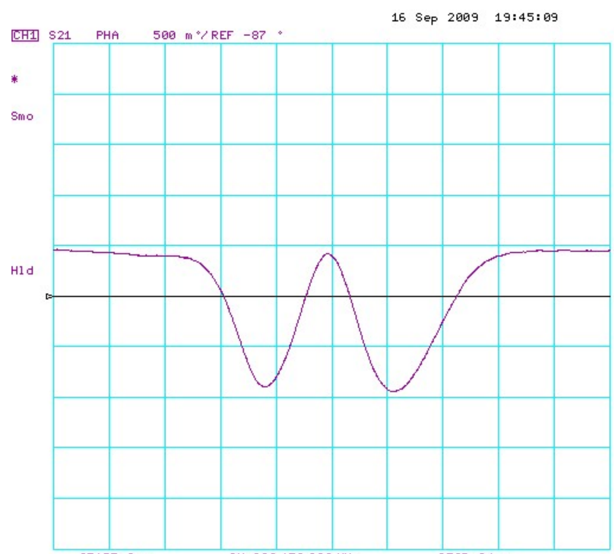

Figure 12: Phase shift during bead-pull test.

VERTICAL TEST PREPARATION

RF System

The RF system required for the vertical test is under preparation. For the basic test, we carried out the PLL (phase locked loop) experiment [3]. The block diagram for the experiment is shown in Fig. 13. The output of the phase comparator we used is ranging from 0 V to 2 V according to the phase difference from -180 degree to 0 degree. We used a signal generator (E4432B, Agilent) as a VCO by using the frequency modulation function. The voltage offset circuit is used between the phase comparator and the signal generator to match the output of the comparator and the input of the signal generator. We confirmed that the setup can track the resonant frequency well and this setup will be used as an RF system for the vertical test.

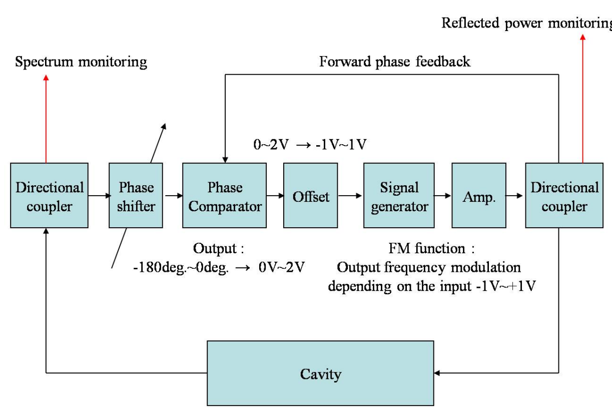

Figure 13: RF System setup for the vertical test.

Cryostat

The drawing and the picture of the cryostat for the vertical test is shown in Fig. 14. The height is about 2550 mm and the outer diameter is about 840 mm.

The cryostat is double-wall structure and the space between the inner chamber and outer chamber is filled with 40 layers of the super-insulation and evacuated down to 3E-07 Torr. The cryostat system is equipped with a liquid helium level monitor (LM-500, Cryomagnetics) and a temperature monitor (218E, Lake Shore).

Total 10 layers of stainless steel plate of 1 mm thickness are adopted as thermal reflectors. The static heat loss is estimated to be about 5.4 W and the dynamic heat loss to be about 3.2 W under the condition of 17 ms RF pulse with 1 Hz repetition rate. With this estimation, the available test time is expected to be about 6 hours.

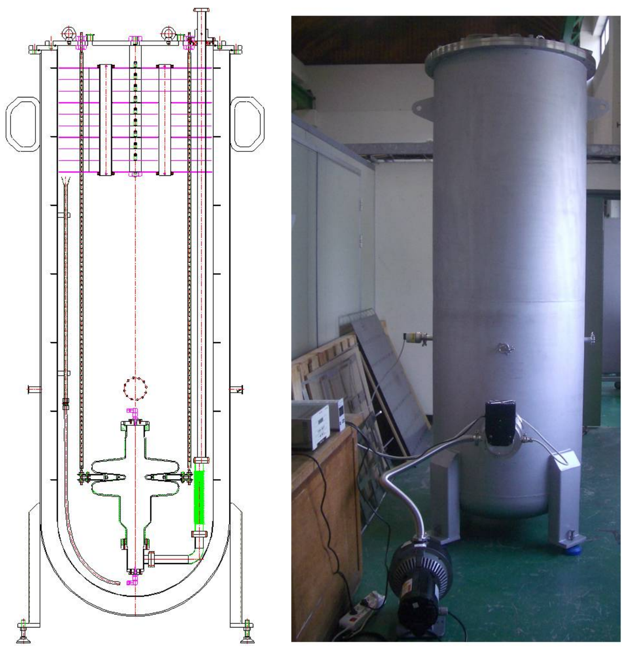

Figure 14: Cryostat for the vertical test.

SUMMARY

Prototype two-cell niobium cavity has been developed for the SRF program in PEFP. The cavity was fabricated through the deep drawing process and the electron beam welding method. We gained some experience on the deep drawing of the thick niobium sheet and the electron beam welding conditions during the fabrication of the cavity. We measured the frequency spectrum and the field flatness. The measured field flatness was 1.8%, which is well below the required field flatness of 8.0%. The vertical test is under preparation. We tested basic PLL test and confirmed that the setup works well. The cryostat is ready to be tested. The vertical test will be performed in near future.

REFERENCES

[1] Sun An, Y. S. Cho and B. H. Choi, “PEFP Low-beta SRF Cavity Design”, PAC’07, Albuquerque, 2007.

[2] Sun An, H. Wang, G. Wu, “Effect of the Tuner on the Field Flatness of SNS Superconducting RF cavities”, LINAC’04, Lubeck, 2004.

[3] Tom Powers, “Theory and Practice of Cavity RF Test Systems”, SRF’05, Ithaca, 2005.