PEFP DUMBBELL FREQUENCY AND LENGTH TUNING OF A LOW-BETA SRF CAVITY*

Sun An#, Tang Yazhe, Zhang Liping, Ying-min Li, Gao Changyi and Y. S. Cho
PEFP, Korea Atomic Energy Research Institute, Daejeon 305-353, Republic of Korea

Abstract

Dumbbell fabrication is a mid-process for manufacturing an elliptical superconducting RF cavity. Control of the dumbbell's length and TM010 π mode frequencies is necessary to build up a desired cavity. A new method was used to measure and calculate the frequencies of the individual half-cells of a PEFP low-beta dumbbell exactly, and to tune the frequency and length of the half-cells. A LabView program was used to measure the dumbbell frequencies of the TM010 modes. The tuning method and results of the PEFP low-beta dumbbells are presented in this paper.

INTRODUCTION

Superconducting RF (SRF) accelerator is an important technology for particle accelerators [1]. Superconducting RF linacs have been one of the accelerating structures of choice in both CW and pulsed high intense proton accelerators [2]. SRF cavities are being considered for accelerating a proton beam at 700 MHz in the linac of the Proton Engineering Frontier Project (PEFP) and its post-project [3-6]. The first section of the PEFP SRF Linac is composed of low-beta cryomodules. Every low-beta cryomodule has three superconducting RF cavities of β_g=0.42. The PEFP low-beta cavity has 5 cells. A double stiffening-ring is welded between the cells or between an end cell and an end dish to control the Lorentz force detuning [6, 7].

Based on the present technology, a dumbbell fabrication is a necessary mid-process for a SRF cavity manufacture. Before a dumbbell fabrication of the PEFP low-beta dumbbell, each half-cell equator is 1.0 mm longer than the length determined by a SUPERFISH calculation, and each iris is trimmed to a suitable length by considering a welding shrinkage, then the two half-cells are welded at their irises to become a primary dumbbell. After that, a stiffening-ring (single or double) is welded between two half-cells on their outer wall. Due to a stiffening-ring welding shrinkage, the frequencies and the lengths of the two individual half-cells become different, and also the electric fields become non-uniform in the two half-cells.

A dumbbell with a right length and TM010 π mode frequency is necessary to build up a desired cavity. In order to know how the stiffening-ring welding shrinkage affects the frequencies and how difficult it is to tune the length and frequency of the individual half-cells of a PEFP dumbbell, we have tuned the TM010 π mode frequency and the length of the individual half-cells.

In order to tune the PEFP low-beta dumbbells, we have developed a new method to measure and calculate the frequencies of the individual half-cells of a PEFP low-beta dumbbell, and to tune the frequency and length of a half-cell [8]. In this article, the tuning method and results of the PEFP low-beta dumbbells are presented.

THEOREM AND METHOD OF DUMBBELL TUNING

A dumbbell shorted at its ends with two metal plates is a resonator. According to Slater perturbation theorem, a perturbation of a simple oscillator resulting in a change in the stored energy will generally result in a resonant frequency shift [9]. We installed two small antennas on the metal plates and used a network analyzer to measure the dumbbell frequencies of the TM010 π/2 and π modes: $f_{\pi/2}$ and f_{π}, as shown in Fig. 1. A metal perturbation plate with an antenna and a short metal stick is used to measure the dumbbell perturbed frequencies of the TM010 π/2 and π modes (see Fig. 2). Alternating the positions between the plates with and without a tip, we obtain the frequencies of the TM010 π/2 and π modes of the left and right half-cells due to a perturbation, respectively.

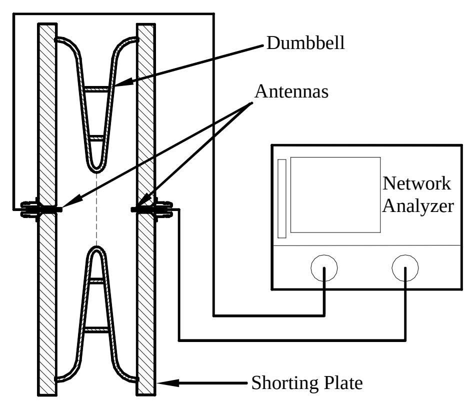


Figure 1: A sketch of the frequency measurement setup for a PEFP low-beta dumbbell.

For a dumbbell cavity, here we use subscript "l" to indicate the physical parameters of the left half-cell, and subscript "r" to indicate the physical parameters of the right half-cell. The $f_{l,\pi}$ and $f_{r,\pi}$ describe the frequencies of the half-cells with such a boundary: the iris side is magnetic, and the equator is periodic. $f_{p,l,\pi}$ and $f_{p,l,\pi/2}$ are the TM010 passband of the dumbbell with the tip on the left half-cell side; and $f_{p,r,\pi}$ and $f_{p,r,\pi/2}$ are the TM010 passband of the dumbbell with the tip on the right half-cell side. The $f_{l,\pi}$ and $f_{r,\pi}$ can be obtained by substituting the tested data into the following formulae [8]:

* This work was supported by the 21C Frontier R&D program in Ministry of Science and Technology of the Korean Government.
#sunan@kaeri.re.kr

$$\begin{cases} f_{\mathrm{l},\pi} = \sqrt{\dfrac{f_{\pi}^{2} + f_{\pi/2}{}^{2}}{2} + \dfrac{(f_{\pi}^{2} - f_{\pi/2}{}^{2})(2-R)}{2\sqrt{R+4}}} \\ f_{\mathrm{r},\pi} = \sqrt{\dfrac{f_{\pi}^{2} + f_{\pi/2}{}^{2}}{2} + \dfrac{(f_{\pi}^{2} - f_{\pi/2}{}^{2})(2+R)}{2\sqrt{R+4}}} \\ R = \sqrt{\dfrac{f_{\pi}^{2} - f_{\mathrm{p,r},\pi}^{2}}{f_{\pi}^{2} - f_{\mathrm{p,l},\pi}^{2}}} - \sqrt{\dfrac{f_{\pi/2}^{2} - f_{\mathrm{p,r},\pi/2}^{2}}{f_{\pi/2}^{2} - f_{\mathrm{p,l},\pi/2}^{2}}} \end{cases} \tag{1}$$

This formula has been confirmed by the simulated data of a dumbbell.

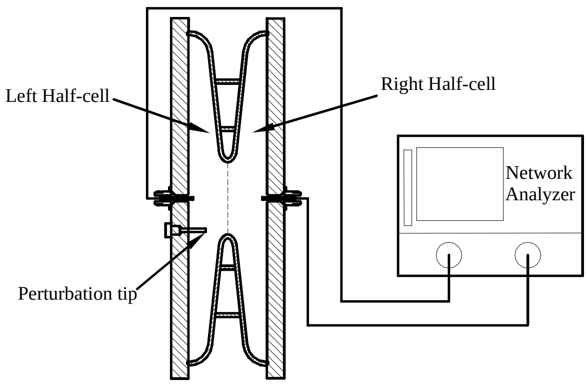


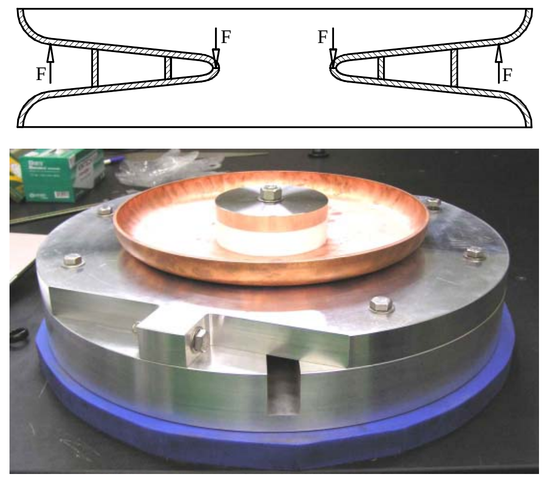
Figure 2: A sketch of the perturbation measurement setup for a PEFP low-beta dumbbell.

According to the tested $f_{\mathrm{l},\pi}$ and $f_{\mathrm{r},\pi}$, we stretched a half-cell to increase its TM010 π mode frequency, or pressed it to decrease its TM010 π mode frequency. In order to measure and tune the PEFP low-beta dumbbells, a frequency tuning set has been designed and fabricated. This set can stretch or press an individual half-cell of a dumbbell. A spacer is used to press a half-cell at its iris. A tuning ring can stretch or press a half-cell at its equator, as shown in Fig. 3. During a tuning, a digital vernier caliper is used to measure a half-cell length change.

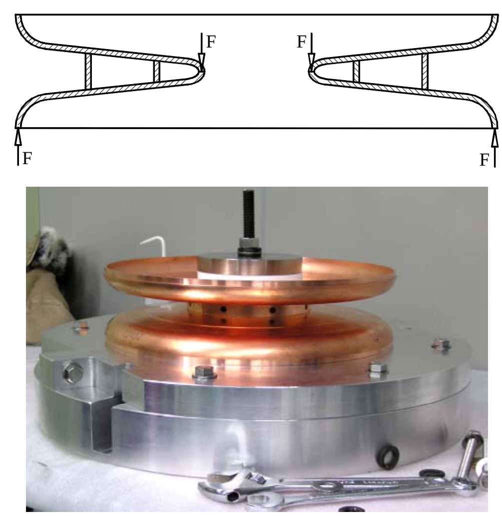
DUMBBELL FREQUENCY MEASUREMENTS AND TUNING RESULTS OF PEFP LOW-BETA DUMBBELLS

According to the frequency measurement principle described in Section II, the frequency measurement sets have been designed and fabricated for the PEFP low-beta dumbbells. Figure 4 shows the frequency measurement setup of a PEFP copper dumbbell.

During the tuning of a dumbbell, following procedure is used: 1. Measure a dumbbell's TM010 passband f_{π} and $f_{\pi/2}$ by using a frequency testing set and a network analyzer (see Fig. 4); 2. Measure a dumbbell's length by a vernier caliper; 3. Test its perturbation frequencies $f_{\mathrm{p,l},\pi}$, $f_{\mathrm{p,l},\pi/2}$, $f_{\mathrm{p,r},\pi}$ and $f_{\mathrm{p,r},\pi/2}$ by using a asymmetrical frequency testing set and a network analyzer; 4. According to Eq. (1) obtain its individual half-cells' frequencies; compare the target frequency and length with the measured frequency and length, and obtain the tuning frequencies or the trimming length: Δf_{l} and Δf_{r}. The trimming frequency sensitivity S_{trim} at an equator in the dumbbell axial direction is obtained by a testing or by a simulation. The trimming lengths $\Delta L_{\mathrm{l}}=\Delta f_{\mathrm{l}}/S_{\mathrm{trim}}$ and $\Delta L_{\mathrm{r}}=\Delta f_{\mathrm{r}}/S_{\mathrm{trim}}$, respectively; 5. If the trimming length is too large or minus, use tuning set with a digital vernier caliper to tune the half-cell frequencies, as shown in Fig. 3; 6. Re-measure the individual half-cell's frequencies of the tuned dumbbell, if their TM010 π frequencies and lengths meet the requirements, the final trimming lengths are decided, if not, re-do the above steps.



(a). Stretch a half-cell and increase its TM010 π mode frequency.



(b). Press a half-cell and decrease its TM010 π mode frequency.

Figure 3: The sketches to tune the individual half-cells and the PEFP tuning set.

In order to ensure the accuracy of the frequency measurements, maintaining a good electric contact between a dumbbell and the plates is very important, for this, a loaded quality factor Q_{L} for the PEFP low-beta dumbbell measurements, should be more than 200 during the frequency measurements. In order to increase the frequency measurement and calculation speed, a LabView program was used to measure the TM010 passband, as shown in Fig. 5.

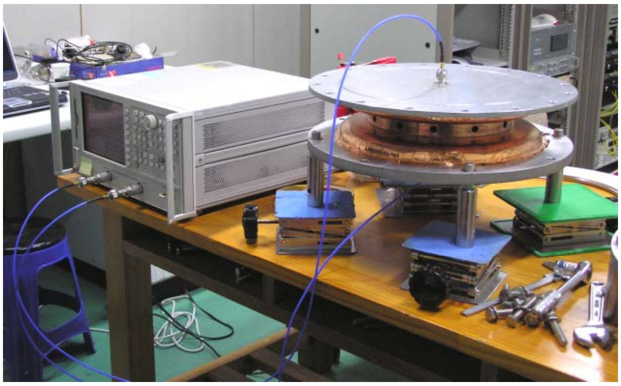


Figure 4: The setup to measure a PEFP dumbbell's frequencies.

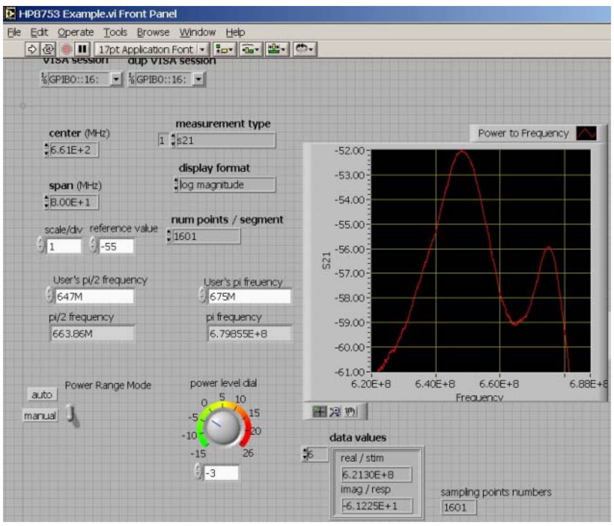


Figure 5: A front panel of the LabView to measure a PEFP dumbbell's TM010 passband.

According to this procedure, four PEFP low-beta dumbbells have been tuned successfully. Table 1 lists the data of the two PEFP low-beta dumbbells before and after a tuning. For the PEFP low-beta dumbbells listed in Table 1, using our tuning calculation and tuning method, one or two tuning processes can complete a dumbbell tuning. In addition, during the tuning, we not only considered the frequency, but also took a dumbbell's length influence upon the cavity length into account. For the PEFP low-beta dumbbells, there was an extra length of 1.0 mm left for trimming and welding, as Table 1 shows, if the length tolerance after a trimming can meet our requirements, the tuning process is complete.

SUMMARY

Based on a two-coupled oscillator model and a cavity perturbation theory, a new formula to calculate the individual half-cell frequencies of a dumbbell and a tuning procedure have been used successfully to tune the frequencies and lengths of the PEFP low-beta dumbbells. Using this tuning method and procedure, we can tune a dumbbell in a short time. The tuned dumbbell met our requirements for fabricating the PEFP low-beta cavities.

Table 1: The individual half-cell frequencies of a PEFP low-beta dumbbell before a tuning and after a tuning, and the trimming length at the equators of the tuned dumbbells.

Dumbbell state trimming length	Frequencies of TM010 mode	Dumbbell
Target frequency	f_π (MHz)	697.907
Before tuning	$f_{l,\pi}$ (MHz)	695.540
	$f_{r,\pi}$ (MHz)	698.171
After tuning	$f_{l,\pi}$ (MHz)	697.075
	$f_{r,\pi}$ (MHz)	697.719
Trimming length (mm)	Left half-cell	0.229
	Right half-cell	0.040

ACKNOWLEDGEMENTS

The authors would to thank P. Kneisel from JLab for the essential assistance in designing the frequency measurement and tuning sets. This work is supported by the 21C Frontier R&D program in Ministry of Science and Technology of the Korean Government.

REFERENCES

[1] H. Padamsee, J. Knobloch and T. Hays, *RF Superconductivity for Accelerators*, John Wiley & Sons, New York, New York (1998).
[2] S. H. Kim, M. Doleans, D. O. Jeon, and R. Sunlelin, Nucl. Inst. & Meth. **A 492**, 1 (2002).
[3] Sun An, Y. S. Cho, B. H. Choi, J. Korean Phys. Soc. **50,** 1421 (2007).
[4] Sun An, H. S. Kim, Y. S. Cho, and B. H. Choi, J. Korean Phys. Soc. **52,** 793 (2008).
[5] Sun An, Y. S. Cho and B. H. Choi, "Design of the PEFP Low Beta Cryomodule", APAC'07, Indore, January 2007, p. 564.
[6] Sun An, C. Gao, Y. S. Cho and B. H. Choi, "PEFP Low-beta SRF Cavity Design", PAC'07, Albuquerque, NM, June 2007, p. 2164.
[7] Sun An, Y. S. Cho and B. H. Choi, "Mechanical Analysis and Design of the PEFP Low Beta Cavity", APAC'07, Indore, January 2007, p. 506.
[8] Sun An, Zhang Liping, Tang Yazhe, Li Yingmin, Gao Changyi, and Yong-Sub Cho, "A method to exactly measure the frequencies of the individual half-cells of a dumbbell cavity", will be published.
[9] E. L. Ginzton, *Microwave Measurements*, McGraw-Hill Book Company, INC., New York (1957), p. 448.