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Frequency and Length Adjustment of A PEFP Low-Beta Dumbbell

Gao Changyi*, Sun An, Zhang Liping, Tang Yazhe, Li Yingmin, Han-Sung Kim, and Yong-Sub Cho

PEFP, Korea Atomic Energy Research Institute, P. O. Box 105, Yuseong, Daejeon, Republic of Korea

Abstract– **Superconducting RF 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. Dumbbell fabrication is a mid-process for manufacturing an elliptical superconducting RF cavity. During the dumbbell fabrication, control of the dumbbell length and the TM010 π mode frequencies is necessary to build up a desired cavity. A new formula with a perturbation measurement method is used 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 the half-cells. In this article, the tuning method and results of the PEFP low-beta dumbbells have been presented.**

1. INTRODUCTION

Radio frequency (RF) superconductivity is an important technology for particle accelerators [1]. Superconducting RF (SRF) linacs have been one of the accelerating structures of choice in both CW and pulsed high intense proton accelerators [2]. A SRF Linac (SCL) is being considered for accelerating a proton beam at 700 MHz in the linac of the Proton Engineering Frontier Project (PEFP) and its post-project [3-5]. The first section of the SCL 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 present technology, a dumbbell fabrication is a necessary mid-process for a SRF cavity fabrication. 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 (45.0 mm) [3] 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 length 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 the results of the PEFP low-beta dumbbells are presented.

2. PRINCIPLE OF A DUMBBELLL TUNING

A dumbbell shorted at its ends with two metal plates is a resonator [6]. According to the Slater perturbation theorem [9], a perturbation of a simple oscillator resulting in a change in the stored energy will generally result in a resonant frequency shift. 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 perturbation metal 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). By alternating the positions between the plates with and without a tip, we can obtain the frequencies of the TM010 π/2 and π modes of the left and right half-cells due to a perturbation, respectively.

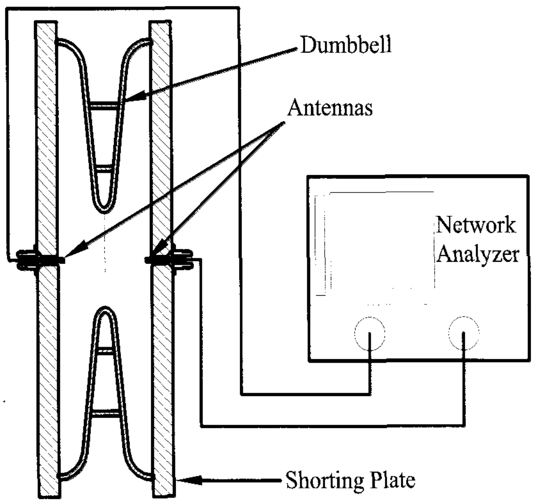


Fig. 1. A sketch of the frequency measurement setup for a PEFP low-beta dumbbell.

* Corresponding author: cygao@kaeri.re.kr

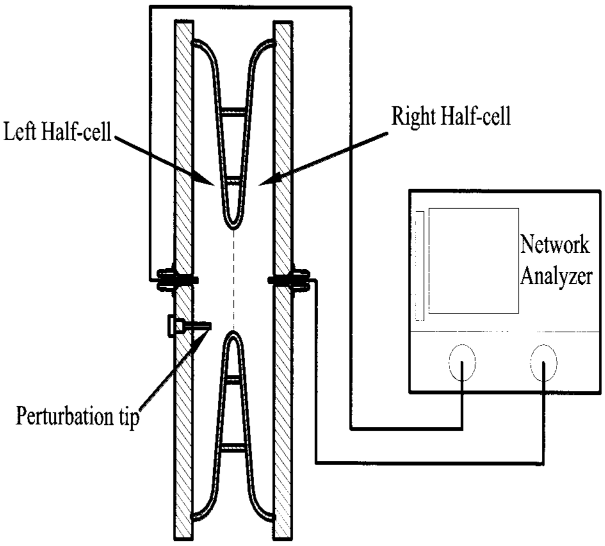


Fig. 2. A sketch of the perturbation measurement setup for a PEFP low-beta dumbbell.

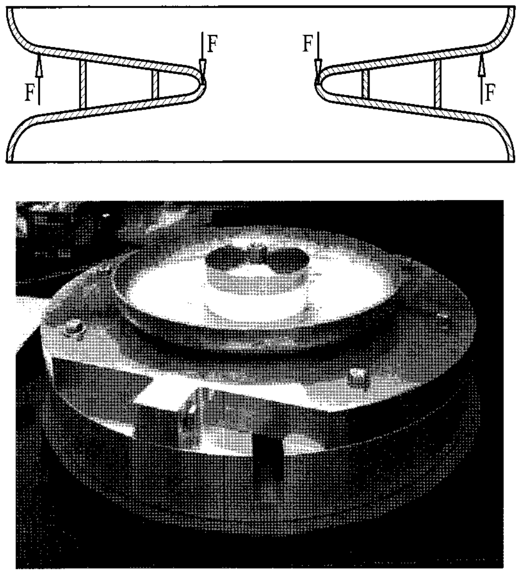
For a dumbbell cavity, here we use subscript "l" to indicate the physical parameters of the left half-cell, and subscript "r" to indicate the physical parameters of the right half-cell. The $f_{l,\pi}$ and $f_{r,\pi}$ describe the frequencies of the half-cells with such a boundary: iris side is magnetic, and the equator is periodic. $f_{p,l,\pi}$ and $f_{p,l,\pi/2}$ are the TM010 passband of the dumbbell with a 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 a 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 formula [8]:

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

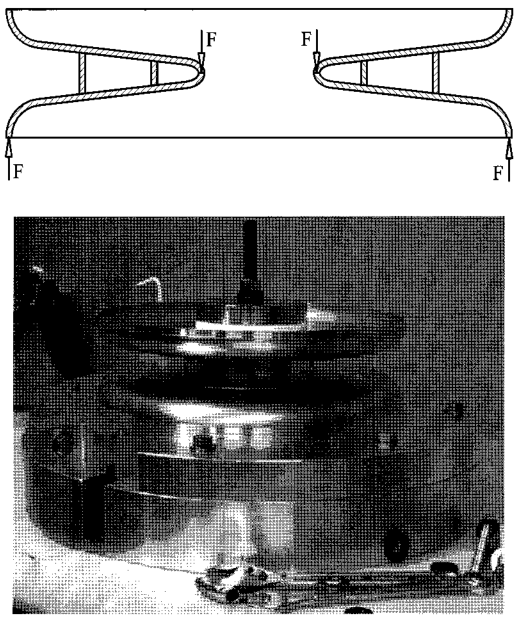
Here, $R = \sqrt{\dfrac{f_{\pi}^2 - f_{p,r,\pi}^2}{f_{\pi}^2 - f_{p,l,\pi}^2}} - \sqrt{\dfrac{f_{\pi/2}^2 - f_{p,r,\pi/2}^2}{f_{\pi/2}^2 - f_{p,l,\pi/2}^2}}$

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

According to the tested $f_{l,\pi}$ and $f_{r,\pi}$, we stretch a half-cell to increase its TM010 π mode frequency, or press 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. The set can stretch or press an individual half-cell of a dumbbell. A spacer is used to press the 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 the half-cell length change.



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



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

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

3. DUMBBELL FREQUENCY MEASUREMENTS AND TUNING

According to the frequency measurement principle described in Section 2, the frequency measurement sets have been designed and fabricated for the PEFP low-beta dumbbells. Figure 4 shows the frequency measurement setup for a PEFP copper dumbbell.

During the tuning of a dumbbell, the 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 $f_{p,l,\pi}$, $f_{p,l,\pi/2}$, $f_{p,r,\pi}$ and $f_{p,r,\pi/2}$ by using a asymmetrical frequency testing set and a network analyzer; 4. According to formula (1), obtain its individual half-cells' frequencies; 5. Compare the target frequency and length with the measured frequency and length and obtain the tuning frequency or the trimming frequency: Δf_l and Δf_r. The trimming frequency sensitivity S_{trim} at the equator in the dumbbell axial direction is obtained by a testing or by a simulation. The trimming lengths $\Delta L_l = \Delta f_l / S_{trim}$ and $\Delta L_r = \Delta f_r / S_{trim}$, respectively. If the trimming length is too large or minus, use a 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 requirements, the final trimming lengths are determined, if not, re-do the above steps. 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, the loaded quality factor Q_L for the PEFP low-beta dumbbell measurements, should be more than 200 during the frequency measurements.

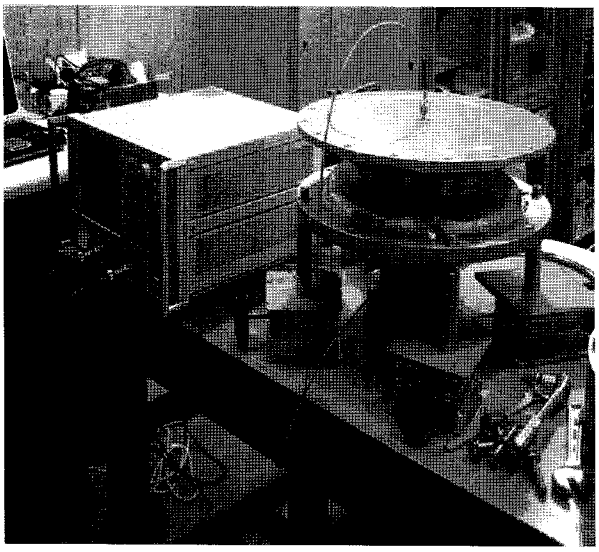


Fig. 4. A setup to measure a PEFP dumbbell's frequencies.

According to this procedure, four PEFP low-beta dumbbells have been successfully tuned. Table 1 lists the data for a PEFP low-beta dumbbell before and after a tuning. During a tuning of the PEFP low-beta cavity listed in Table 1, using our tuning calculation and tuning method, one or two tuning processes can complete a dumbbell tuning.

TABLE I
THE INDIVIDUAL HALF-CELL FREQUENCIES OF A PEFP LOW-BETA DUMBBELL BEFORE AND AFTER TUNING, AND THE TRIMMING LENGTH AT THE EQUATORS OF THE TUNED DUMBBELL

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

4. 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 successfully used 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.

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