FREQUENCY AND LENGTH ADJUSTMENT OF A DUMBBELL FOR THE PEFP LOW-BETA SRF CAVITY*

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Abstract

This paper describes a method to adjust the frequency and the length of a dumbbell used to fabricate the PEFP low-beta superconducting RF cavity. A tuning program is used to calculate the π mode frequency of each half-cell according to the resonant frequency of a TM010 passband and the perturbation frequency shifts of a dumbbell. According to the frequency difference between the two half cells and the frequency sensitivity coefficients, we can determine the tuning length in the axial direction or the trimming length at the equator to make the two half cells have the same frequency and length. In order to measure the frequency and to compensate for the length of a PEFP dumbbell for a stiffening-ring welding shrinkage, a frequency measurement set and length tuning set have been fabricated.

INTRODUCTION

A superconducting RF 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 [1-3]. 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 [4,5]. 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].

Based on present technology, a dumbbell fabrication is a necessary mid-process for a cavity manufacture. Before a dumbbell fabrication, each half-cell equator is 1.5 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. For the PEFP dumbbell, the stiffening rings are welded between two half-cells on their outer wall. Due to a stiffening-ring welding shrinkage, the TM010 π mode frequency and the length of a half-cell are not the same.

A dumbbell with a right length and frequency is necessary to build up a desired cavity. The frequency test and length adjustment of a dumbbell assure that it is fabricated rightly. For a PEFP dumbbell, the adjustment process includes three steps: (1) measure the dumbbell frequency and obtain a tuning length; (2) tune the individual half-cell length and obtain the same length of the half-cells; (3) measure the tuned dumbbell again and obtain the trimming lengths. This paper describes a method to make a primary dumbbell to be the right one by a frequency test and an equator length adjustment.

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PRINCIPLE OF DUMBBELL TUNING

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. A dumbbell shorted ends with two metal plates is a resonator [7]. We install two small antennas on the plates and use a network analyzer to measure the dumbbell frequencies of TM010 π/2 and π modes: $f_{\pi/2}$ and f_π, as shown in Fig. 1.

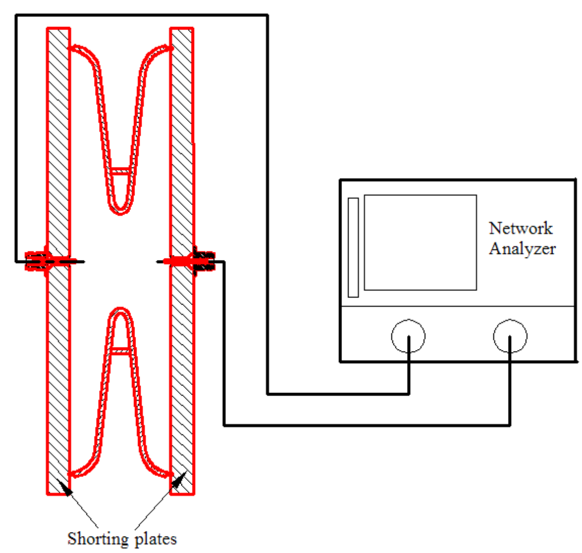

Figure 1: Frequency measurement setup of a dumbbell with a single stiffening ring.

A plate with an antenna and a short metal stick as a perturbation body is used to measure the dumbbell frequency shift of the TM010 π mode (see Fig. 2). Alternating the positions between the plates with and without the tip, we obtain the frequency shifts of TM010 π mode: δf_1 and δf_2.

Using the $f_{\pi/2}$, f_π, δf_1 and δf_2, we obtain the TM010 π mode frequency of an individual half-cell by using the cavity tuning methods [8,9]. Comparing the desired frequency with the measured frequency, we can obtain the tuning frequencies or the trimming frequency: Δf_1 and Δf_2. The tuning frequency sensitivity coefficient S_{tun} has to be measured for at least one dumbbell by stretching it in the axial direction and measuring a length change and corresponding frequency shift. Frequency sensitivity S_{trim} at the equator in the dumbbell axial direction is obtained by a testing or by a simulation. The tuning or trimming lengths ΔL_1 and ΔL_2 are:

$$\Delta L_1 = \Delta f_1 / S_{tun} \quad \text{(for tuning)},$$
$$\Delta L_2 = \Delta f_2 / S_{tun}$$

and

$$\Delta L_1 = \Delta f_1 / S_{trim} \quad \text{(for trimming), respectively.}$$
$$\Delta L_2 = \Delta f_2 / S_{trim}$$

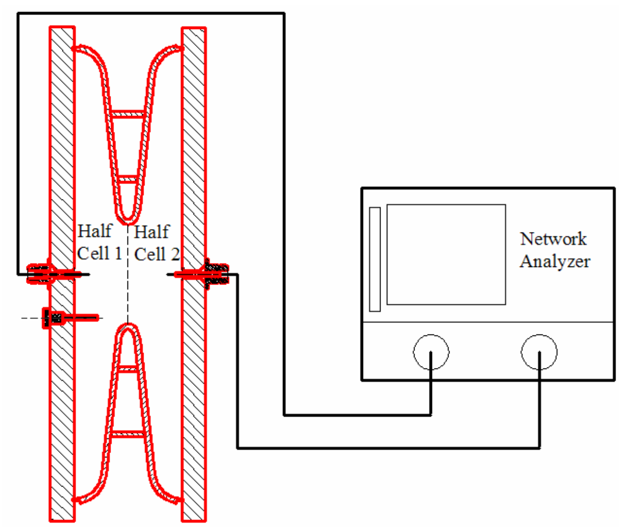

Figure 2: Perturbation measurement setup for a dumbbell with a double stiffening-ring.

DUMBBEL FREQUENCY MESUREMENTS

In order to measure the TM010 π mode frequency of an individual half-cell of the PEFP dumbbell, the dumbbell frequency measurement sets have been designed and fabricated. There is a circle groove on the plate to assure a dumbbell axis matching with a plates' centre. Two small antennas respectively sited at the centre of each disk are connected to a network analyzer. These sets can be used to measure the $f_{\pi/2}$, f_π, δf_1 and δf_2, and also the frequency sensitivity S_{trim}. Figure 3 shows the measurement setup to measure a PEFP copper dumbbell frequency.

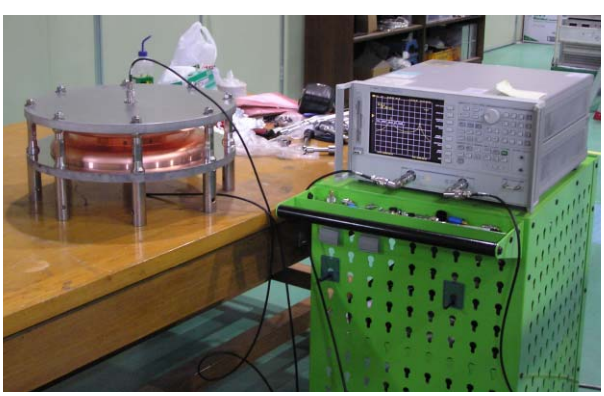

Figure 3: Measurement setup to measure a PEFP copper dumbbell frequency.

During the measurement, the pressure on the dumbbell should not deform it but just keep it in contact with the two plates. The pressure is adjusted by a torque wrench. The frequency changes (with and without the symmetry measurement tip) for both the π/2 mode and π mode are tested with the network analyzer. The other half-cell is tested in the same way.

The tested frequency data are edited to an input file to be put into a tuning program. The output file of the tuning program provides the frequency of the π mode for each half cell, from which we can establish how symmetric they are.

There are two aims of the dumbbell frequency measurements: one is for correcting the dumbbell length after a stiffening-ring welding; another is for trimming the dumbbell equator edges after a dumbbell tuning. Therefore, there are two desired dumbbell frequencies, respectively. For the PEFP low-beta dumbbell, the desired frequency for tuning the dumbbell length is 696.721 MHz; and for trimming the dumbbell equator edges it is 697.907 MHz. Table 1 lists a group of the measurement data and output data for trimming a PEFP low-beta dumbbell length.

Table 1: Frequency measurement data and output data for trimming a PEFP low-beta dumbbell length.

Desired frequency f_0 (MHz)	697.907
$F_{\pi/2}$ (MHz)	688.805
f_π (MHz)	698.871
S_{tun} (MHz/mm)	1.687
δf_1 (MHz)	-2.325
δf_2 (MHz)	-1.68
Δf_1 (MHz)	-1.36647
Δf_2 (MHz)	-0.77602
ΔL_1 (mm)	0.81
ΔL_2 (mm)	0.46

LENGTH ADJUSTMENT

In order to compensate for the dumbbell length due to a stiffening-ring welding shrinkage, each half cell should be stretched by the same length. This increases the frequency of a half-cell. A PEFP dumbbell length tuning set has been designed and produced for a low-beta cavity, as shown in Fig. 4. This set can be used to tune a low-beta dumbbell with a single stiffening-ring and with a double stiffening-ring, and also to measure the frequency sensitivity coefficient S_{tun}.

According to the frequency measurement results, the individual half-cells are stretched to the same length. There is a groove on the set bottom, which is used to measure the dumbbell length during a tuning. During the tuning, we use a vernier calliper through the groove to measure the dumbbell length change, but do not need to take the tuning set apart.

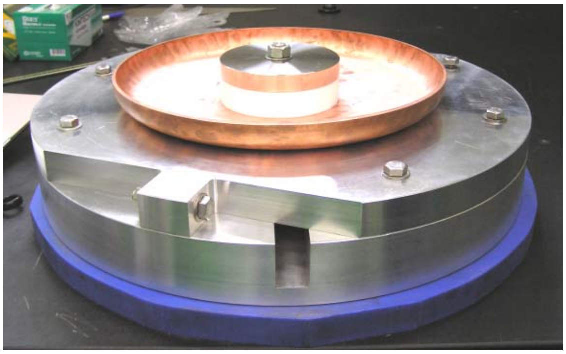

Figure 4: A PEFP dumbbell length tuning set

EQUATOR EDGE TRIMMING

To fabricate a dumbbell with a right length and frequency, after a length tuning, we need to trim the extra length at the equator of the dumbbell. Re-measuring the dumbbell frequency by using the measurement methods described in section III, we obtain the trimming length. To decide the trimming length, we need to plus the groove depth of the plates to the ΔL_1 and ΔL_2.

SUMMARY

A frequency and length control of a dumbbell is a necessary mid-process to fabricate the PEFP low-beta cavity. Our method of a frequency measurement and a length adjustment of a dumbbell is used to make it exactly right.

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