PROTOTYPING PEFP LOW-BETA COPPER CAVITY AND HOM COUPLER*

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Abstract

In order to confirm the RF and mechanical properties of the PEFP cavity and HOM coupler, and to produce documentation for a procurement and quality control for an industrial manufacture of the cavities, two prototype copper cavities and HOM couplers have been produced, tuned and tested. The testing results show that the low-beta cavity and its tuning system can work as we designed, and the HOM coupler can meet its specifications.

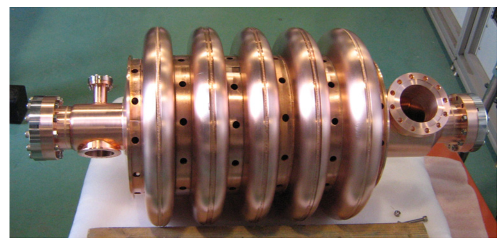
INTRODUCTION

A low-beta superconducting RF cavity (β_g=0.42) is being considered to accelerate a proton beam at 700 MHz in the PEFP linac and its extended project [1, 2]. The PEFP low-beta cavity is regarded as the lowest-beta elliptical cavity operating at a pulse mode so far. Generally, the lower beta cavities have a stronger Lorentz force detuning than the higher beta cavities. For pulse SRF accelerators, a Lorentz force detuning is a more serious problem than that for CW accelerators. In order to control the Lorentz force detuning effects on a low-beta cavity, a double stiffening-ring structure has been designed for a PEFP low-beta cavity [3, 4]. But the field flatness tuning of the low-beta cavity with a double stiffening-ring became a considerable issue.

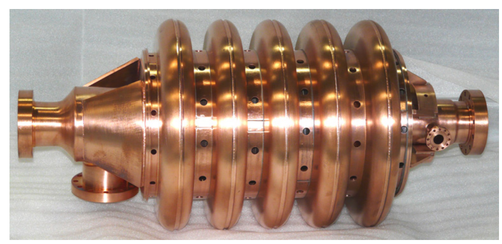
In order to confirm the cavity design for the RF properties and mechanics, and to produce documentation for a procurement and quality control for an industrial manufacturing of the cavities, two prototype copper cavities have been fabricated, as shown in Fig. 1. Cavity A with two HOM ports was used to test the dumbbell tuning system, field flatness tuning system & procedure, and to measure the HOM coupler prototype, prototype FPC by tapers, and field probe prototype. Cavity B was used to confirm the cavity production procedure. During cavity A's production, we tuned the copper dumbbells and developed a new method to measure the frequencies of the individual half-cells of a dumbbell [5, 6]. For confirming the HOM coupler's RF properties, two prototype copper couplers have produced, tuned and tested. In this paper the prototyping results are presented.

CAVITY FIELD FLATNESS TUNING

Due to a manufacturing error and shrinkage during a welding of the stiffening rings by an electron beam during a cavity production, the individual cells' frequencies of a multi-cell cavity become unequal. This indicates that the cavity frequency would not be the required frequency, and the cavity field flatness would become bad. In order to correct the frequency and field flatness variation, a raw cavity needs to be tuned on a warm tuner before an RF testing.



(a) Cavity A.



(b) Cavity B.

Figure 1: Prototype copper cavities.

The field flatness of a PEFP low-beta cavity is specified to be less than 8.0%. If the field flatness of a cavity cannot meet this specification, we need to tune a cavity's field flatness.

PEFP Cavity Field Flatness Tuning System

According to the multi-cell field flatness tuning theory and bead-puling results [7, 8], we can obtain the individual cell's tuning frequency and field flatness. The tuning method of the field flatness is to change an individual cell's accelerating voltage (or frequency) and to obtain a more uniform field distribution. Normally we use a pair of cell jaws to stretch or squeeze a cell shape in the longitudinal direction to change a cell's accelerating voltage (or frequency) [9].

Based on this tuning theory, a field flatness tuning system for PEFP cavities has been designed and fabricated. This tuning system (see Fig. 2) includes a warm tuner [9], a bead-puling system, a network analyzer and a control system.

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Results of Tuning a Low-Beta Cavity

For the prototype Cavity A, its raw field flatness and frequency of the TM010 π mode were 75.62% and 697.925 MHz. We need to tune its TM010 π mode frequency to 700 MHz and its field flatness to be lower than 8.0%.

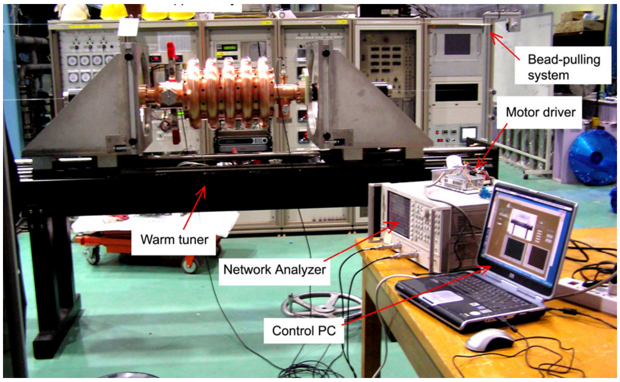

Figure 2: PEFP cavity's field flatness tuning system.

In order to tune the cavity safely and quickly, first we tuned its field flatness at a perfect condition at a frequency, which is very near the target frequency. Then we tuned an individual cell's frequency with the same frequency shift and make its frequency meet the target frequency. The frequency and field flatness of the middle process are 699.650 MHz and 0.69%, respectively.

After this middle process, we tuned the cavity's field flatness and frequency to meet our goal. The final tuning results are: field flatness is 1.43%, frequency is 700.001MHz. Figure 3 shows the field flatness, frequency and axial field profiles of the cavity at an initial state, middle process and final state.

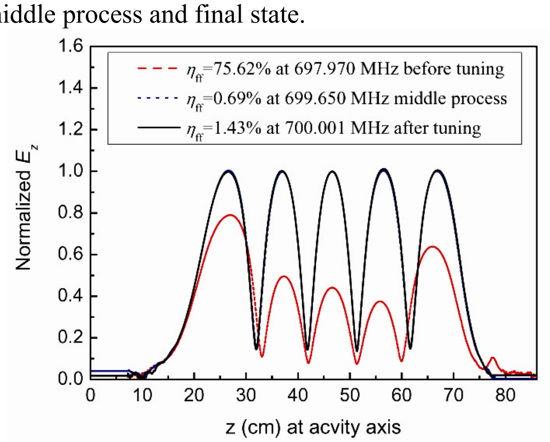

Figure 3: The field flatness, frequency and axial field profiles of the cavity at an initial state, middle process and final state.

After a tuning, due to a field flattening the frequency difference between the TM010 $4\pi/5$ mode and the π mode became bigger. This will make the cavity control system simpler for cavity measurements and operation. The tuning of the cavity field flatness shows that the field flatness also affects the passband, as shown in Fig. 4.

PROTOTYPING PEFP HOM COUPLER

After the HOM analysis for the PEFP low-beta cavities, the specifications of the PEFP HOM couplers were obtained [10]. Table 1 lists the specifications.

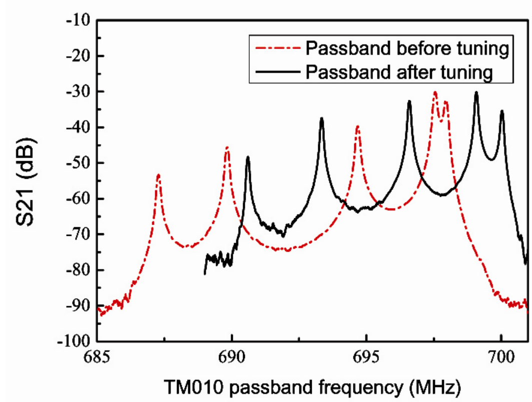

Figure 4: Cavity TM010 passband variety before and after a tuning.

Table 1. HOM coupler specifications of the PEFP low-beta cavity.

Parameter	Value
HOM damping modes	M23, M31, M32, M 33, D11, D32*
Q_{ext} for HOM damping mode	$\leq 3\times10^5$
HOM average RF load	$\leq$ 1.0 W
Q_{ext} for TM010 π mode	$\geq 6.26\times10^{10}$
Fundamental π mode RF load at E_{acc}=8 MV/m (in a macro-pulse)	$\leq$ 10 W

*Here, 'Mm' and 'Dm' mean the m-th mode of the monopole and the dipole of MAFIA calculation, respectively.

In order to satisfy the PEFP HOM damping requirements, a new type of coaxial HOM coupler with one hook and two stubs has been designed for the PEFP SRF cavities [11]. This coupler has a good filter property, low electromagnetic fields at the inner conductor ends, and it is easy to tune and control a notch frequency.

In order to confirm the HOM coupler design and finalize the inner conductor penetration depth and angle between the cavity axis and the hook of the inner conductor, two prototype HOM couplers have fabricated.

Prototype HOM Coupler

Figure 5 shows a prototype HOM coupler. A flange with three 60^o circular slotted holes on the HOM coupler body is designed for adjusting the angle between the coupler hook and the beam axis. Each HOM port on a cavity beam pipe has a flange with 24 screw holes. Two types of washes with three 60^o circular slotted holes and thicknesses of 0.1 mm and 1.0 mm are inserted between a coupler flange and a HOM port flange. By changing the wash number, the penetration of an inner conductor of the HOM coupler is varied. And by changing the HOM coupler flange's relative angle, the angle between the hook and beam axis is varied.

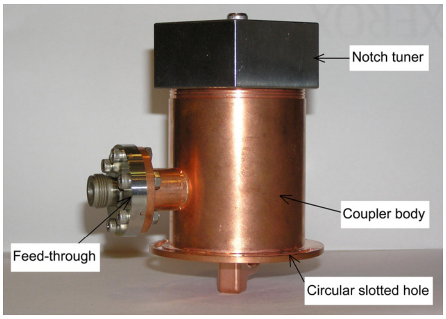

Figure 5: A PEFP prototype HOM coupler.

Measurements of the Filter Characteristics of the PEFP HOM Coupler

The measurements of the HOM coupler's filter characteristics include the filter properties for the HOM spectrum and for the TM010 π mode. Due to fabrication errors, the original notch frequency was not at 700 MHz. For example, the notch frequency of HOM coupler 1 (Field probe side) was 718.723 MHz, and that of HOM coupler 2 (FPC side) was 768.598 MHz. We used a notch tuner and tuned the notch frequency to 700 MHz. The cross-talk method was used to measure the notch shift and filter properties for the HOM spectrum. The test results reveal that the HOM couplers' filter properties are almost the same as that of the simulation design.

We used S21 and S11 to measure the HOM coupler filter properties for the TM010 π mode, namely the Q_{ext} at 700 MHz. The specification for the filter for the TM010 π mode in Table 1 is: $Q_{ext} \geq 6.26\times10^{10}$. Tested results are: for HOM coupler 1, its $Q_{ext} = 9.16\times10^{12}$; for HOM coupler 2, its $Q_{ext} = 1.59\times10^{11}$. This means that our new HOM coupler can meet our filter requirements.

Hook Angle and Penetration Testing

By the measurements of S11 and S21 and changing the hook angle, we obtained a curve of the HOM couplers' Q_{ext} versus the angle between the hook and the beam-axis. According to the test results and theoretical analysis, and considering the final HOM coupler feed-through assembly, 45° was chosen as the final angle.

By changing the wash number, the inner conductor penetration of the PEFP prototype HOM coupler was changed. According to the measured results and considering the fundamental power leak and the effects of the inner conductor on the beam, the final wash thickness was chosen as 5.32 mm for both of the HOM couplers.

HOM Damping Measurements

After fixing the HOM coupler's hook angle and inner conductor penetration depth, we measured the Q_{ext} of the HOM couplers. The HOM damping specification is that the HOM coupler's $Q_{ext} \leq 3\times10^5$ for the HOMs. The measurement results showed that the new HOM couplers can fully meet the PEFP HOM damping requirements.

CONCLUSIONS

The frequency and field flatness of the fundamental π mode for the prototype cavities have been tuned, and meet their specifications. This tuning has demonstrated that a cavity with a double-stiffening-ring can be tuned as a normal cavity. The field flatness tuning system is working as we designed it.

A new-design HOM coupler prototype has been fabricated and tested on a cavity. The testing and measurements of the HOM couplers have shown that the PEFP HOM coupler has good filter properties and can fully meet the damping requirements of the PEFP low-beta superconducting RF linac. Based on the test results, the final dimensions of the HOM couplers have been fixed.

ACKNOWLEDGEMENTS

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