Tuning for the first 9-cell TESLA cavity of PKU *

YANG Liu(杨柳) HE Fei-Si(贺斐思) XU Wen-Can(徐文灿) ZHU Feng(朱凤)
LU Xiang-Yang(鲁向阳)[1)] ZHAO Kui(赵夔)

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China

Abstract A method based on circuit model is used to tune the first home-made 9-cell TESLA type superconducting niobium cavity at Peking University. After tuning, a flat field profile with a final π-mode frequency within 3 kHz of target frequency is achieved. The field flatness is measured by a bead-pull method, and the relative electric field is calculated from the frequency shift perturbed by the bead stepping along the axis of the cavity.

Key words 9-cell cavity, circuit model, field flatness, tuning

PACS 29.20.Ej

1 Introduction

The first 9-cell TESLA type superconducting niobium cavity is made at Peking University. The cavity operates at TM_{010} mode, and a 'flat' π-mode is desired to guarantee that the phase advance between neighboring cells can take on only the value π. To maximize the accelerating voltage and minimize the peak surface EM fields, the axis-electric-field of each cell should be equal. A flat field profile can be achieved only after all the cells are properly tuned relative to each other. Due to the apparent adjustment difficulties caused by the coupling of neighboring cells, a cell-to-cell tuning method is proposed.

2 Mathematic solution using the circuit model

According to the circuit model, for a tuned 9-cell cavity, it is equivalent to 9 capacitive-coupled LC oscillators with the characteristic capacitance C of each cell. As for a detuned cavity, a perturbation e_j for the characteristic capacitance C of cell-j is introduced. It is an absolute capacitance error, while the relative difference between the errors of each cell determines the field flatness. In another word, if e_j is equal, the field profile will be perfectly flat. The sum of e_j contributes the perturbation of π-mode frequency. So that eliminating e_j of each cell would exactly take all of them in tune.

To obtain the cavity's flatness, the bead-pull method is used to measure the frequency shift $\delta f_j'^{\pi}$ when the bead is in the center of cell j. With the measured $\delta f'^{\pi}$ and the π-mode frequency, applying the first-order perturbation technique, it is possible to deduce a corrected parameter e^c to homogenize the field cross all cells without effecting π-mode frequency. Since the sum of the components of e^c is zero, thus it produces no net change in π-mode frequency. Note the components of e^c describe the errors in capacitances, they can be converted to π-mode frequency corrections for each cell via

$$\delta f^c = e^c \frac{f^{\pi}_{\text{measured}}}{2N} . \tag{1}$$

In terms of the desired π-mode frequency, each cell has an equal contribution in determining the π-mode frequency. On the whole, cell j needs to be altered. It is changed by [1]

$$(\delta f^c)_j + \frac{f^{\pi}_{\text{desired}} - f^{\pi}_{\text{measured}}}{N} . \tag{2}$$

3 Procedure of set-up of tuning

As aforementioned, the standard bead-pull method is used to measure the frequency shift $-\delta f'^{\pi}$. An HP-8753D Network Analyzer is connected to the

Received 9 June 2009

* Supported by National Basic Research Programme of China (2002CB713600)

1) E-mail: xylu@pku.edu.cn

9-cell cavity, and a metal bead is driven along the axis of the cavity by a stepper motor. In phase mode, the Network Analyzer feeds a signal with π-mode frequency from one port into the cavity, while the other port picks up the signal from the cavity. The phase shift-$\Delta\varphi$ between these two signals is currently recorded when a metal bead is pulled along the axis of the cavity. In perturbation approximation, the expressions

$$\frac{\Delta\varphi}{Q}=\frac{\delta f'^{\pi}}{f^{\pi}_{\text{measured}}} \tag{3}$$

and

$$\delta f'^{\pi}\propto E^2 \tag{4}$$

are valid [2, 3], where $\delta f'^{\pi}$ represents the frequency shift of the cavity perturbed by the bead. Combining the above two equations, it becomes

$$\Delta\varphi\propto E^2\ . \tag{5}$$

Therefore, the phase shift $-\Delta\varphi$ also expresses the relative electric field distribution on axis.

A LabVIEW program was devised to control the stepper motor and read the data from the Network Analyzer, besides, the frequency corrections for each cell were also calculated in the program. With the guide of the frequency corrections, each cell is tuned, respectively. The tuning mechanism consists of two steel plates. The plates are on either side of the cell desired to be tuned. In order to achieve a permanent deformation, stretching or squeezing are extended into the plastic region of the cell. According to the shape perturbation theory, for a positive frequency correction, the cell should be stretched; on the contrary, it should be squeezed when the frequency correction is negative. During the operation, the shift of π-mode frequency was monitored by the Network Analyzer, thus, the tuning process was under control.

4 Results and conclusions

The above process is applied to tune the first 9-cell TESLA type superconducting niobium cavity made at Peking University. The target π-mode frequency is 1.298600 GHz. After tuning, an almost perfect field profile was achieved. Fig. 1 shows the contrast between the final and the ill initial electric field profile. Note that the left exceptional section on the final field plot was caused by the perturbation of the antenna used to coupling power to the cavity. During the final tuning period, to improve Signal to Noise Ratio, the antenna was replaced by a large-size one. The final π-mode frequency is within 3 kHz of the target frequency, and the accuracy is acceptable enough [4]. Certainly, the result demonstrates that the cell-to-cell tuning method is effective and reliable.

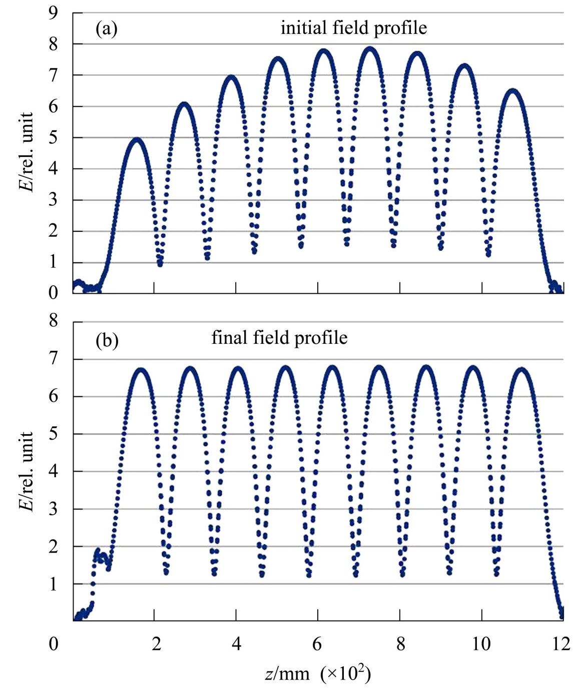

Fig. 1. The relative E distribution along the axis calculated from the bead-pull measurement before tuning ((a), with π-mode 1.299108 GHz), after tuning ((b), with π-mode 1.298603 GHz).

The computed frequency corrections for each cell predict that a flat field profile and right π-mode frequency would be obtained with a single tuning step. But this prediction requires the desired accuracy of 1 kHz for frequency correction. According to the principle of tuning, the frequency correction consists of two parts. The first part determines the flatness of the field profile while the other one fixes π-mode frequency to the target value. In the initial tuning, the first part is generally smaller than the second part. Therefore, a deviation of 10 kHz may badly break the field flatness. To illustrate this, the first tuning consequence is displayed in Fig. 2, with π-mode 1.29876 GHz, and Table 1 lists the computed frequency correction as well as the applied frequency correction. To be explicit, the first part (1) of the frequency correction, determining the field flatness, is also included in Table 1, and the 'Relative error' stands for the relative error between the computed and applied correction of the first part. After the first tuning, the field flatness was not improved as the prediction, but only the π-mode frequency approached to the target. From the 'relative error' section in Table 1, the reason accounting for the result is obvious. Some corrections for the first part were far beyond the acceptable regime, each cell was not homogenized as the program simulated. In fact, even after tuning, each cell was still quite different, so the flatness was not improved.

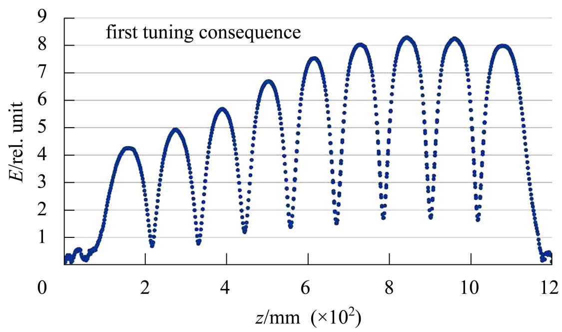

Fig. 2. The result after the first tuning.

Actually, a satisfactory outcome is usually achieved only after an iterative approach. The simple fact is the elastic nature of niobium. Typically, during stretch, the frequency shift must exceed the target value by some 100 kHz to relax back to the exact correction. Therefore, the major error source for the whole tuning process is the human error. Especially by the time of the final tuning, the computed frequency corrections are within 10 kHz, some of them are even merely 1 kHz. As for such a minute frequency shift, it is immerged in the noise floor, so it is rather difficult to satisfy the desired accuracy of 1 kHz. To guarantee the tuning operation is more effective and precise, it calls for a well trained Lab tuner. Besides, the devices and controlled Lab conditions accuracy should be improved, otherwise, even having a perfect mathematical model and resolution greater than 1 kHz does not make any sense.

Table 1. Computed and applied frequency corrections for each cell in MHz.

cell#	computed f correction	applied f correction	computed 1st part	applied 1st part	relative error(%)
1	0.037	0.033	0.093	0.074	−20.43
2	−0.059	−0.064	−0.003	−0.023	666.67
3	−0.067	−0.069	−0.011	−0.028	154.55
4	−0.084	−0.076	−0.028	−0.035	25.00
5	−0.070	−0.061	−0.014	−0.020	42.86
6	−0.072	−0.062	−0.016	−0.021	31.25
7	−0.076	−0.058	−0.020	−0.017	−15.00
8	−0.085	−0.080	−0.029	−0.039	34.48
9	0.027	0.065	0.083	0.106	27.71

References

1 Hasan Padamsee et al. RF superconductivity for Accelerators. John Wiley & Sons, Inc., 1998. 129–143

2 Turner S. CAS CERN Accelerator School RF Engineering for Particle Accelerators, 1992, **1**: 108–110

3 Pozar D M. Microwave Engineering. Third Edition. Publishing House of Electronics Industry, 2006. 259–261

4 Cooper C. Single Iteration Tuning for Multicell RF Cavities for Cornell ERL, Research Report. Cornell University, Ithaca, 2003