FIELD TUNING AND HOMS MEASUREMENT OF THE 9-CELL ICHIRO COPPER CAVITY MODEL*

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Abstract

Field tuning and HOMs measurement of a 9-cell superconducting ICHIRO copper cavity model is presented. The field flatness 97.2% of the TM010_PI mode is obtained after a few iterations by inserting perturbation objects into the cells. The frequencies and shunt impendence of the higher order modes (HOMs) are measured and compared with the numerical simulation of the cavity using Mafia 2D code.

INTRODUCTION

One 9-cell superconducting ICHIRO copper cavity model made by KEK was sent to the Accelerator lab, Dep. Engineering Physics, Tsinghua Univ. in 2006, as shown in Figure 1. The ICHIRO cavity has been designed based on the Low-Loss type cavity [1] for high-gradient purpose, which is aiming at the gradient of 51 MV/m [2]. The two beam pipes are designed and equipped at both the Inner End and Outer End in Tsinghua Univ., but HOM couplers and input coupler are not considered at present. The diameters of the inner and outer pipes are 108 mm and 80 mm respectively. The total length of the cavity including the beam pipes is 1.238 m. Primary research work has been carried out for the field flatness tuning and microwave measurement based on this 9-cell ICHIRO copper cavity.

Figure 1: 9-cell superconducting ICHIRO copper cavity model provided by KEK.

FIELD-TUNING EXPERIMENTAL SET-UP

The flat field profile can be achieved by tuning the cells properly relative to each other, which provides two advantages: the net accelerating voltage is maximized, and the peak surface EM fields are minimized for a certain stored energy in the cavity [3]. The cavity is tuned by inserting perturbation objects into the cells respectively in our experiment instead of squeezing or stretching the cells. The field profile can be obtained by the bead-pull method [4].

The experimental set-up is based on the standard bead-pull technique, as shown in Figure 2. The thread carrying the bead through the cavity for the field perturbation is driven by the stepping motor (35BGY250B) made by Stone Electric. The hardware for controlling the motors and measuring the field distribution consists of the Network Analyzer (HP8720B) with one PC controller and one motor controller. A small metal needle with the diameter of 1 mm and length of 10 mm is used as the perturbation object. The maximum frequency perturbation of the cavity is about 70 kHz. The measurement software is developed in the Accelerator lab of Tsinghua Univ. Data of the bead position and resonant frequency per motor step are written into an Excel file. Then the post-processing program is adopted to plot the field profile and compute the field flatness and the *R*/*Q* values.

Figure 2: Field flatness measurement system of the ICHIRO cavity.

FIELD FLATNESS MEASUREMENT AND TUNING OF THE CAVITY MODEL

Tuning of the field flatness is generally one iterative process. The flatness of the cavity field can be described as [5]:

$$field\ \ flatness = \bar{A}_p / A_{p\max} \tag{1}$$

where $\bar{A}_p$ and $A_{p\max}$ are the mean and peak value of the field amplitude in the 9 cells respectively. The field flatness calculated by Superfish is 98.1%, with the PI mode frequency of 1300.2 MHz. But the field flatness obtained from the bead-pull measurement is only 53.2% before tuning. After tuning the field flatness of 97.2% has been achieved with the PI mode frequency of 1298.2 MHz, as shown in Figure 3.

The cavity is tuned by inserting perturbation beads into the cells instead of squeezing or stretching the cells. The tuning process is based on the analysis of the equivalent circuit model [3], which is simulated mathematically to study the correlation between the position of the perturbation and the change of the field profile. Figure 4 gives the change of the field and the frequency spectrum

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corresponding to the perturbation of individual cells in a uniform multi-cell cavity, which has been proved in the tuning experiment.

The measurement of the field profile or the spectrum can give the instruction which cell should be deformed or perturbed at the next tuning step. In our experiment the field profile is measured at each step. Figure 4 only gives the result when the cell of No. 1 (left cell in Figure 1) to 5 is perturbed individually, because the deformation of the symmetrical cells No. 1 and 9, No. 2 and 8, No. 3 and 7, No. 4 and 6 causes an identical change of the spectrum but the opposite influence on the field [6].

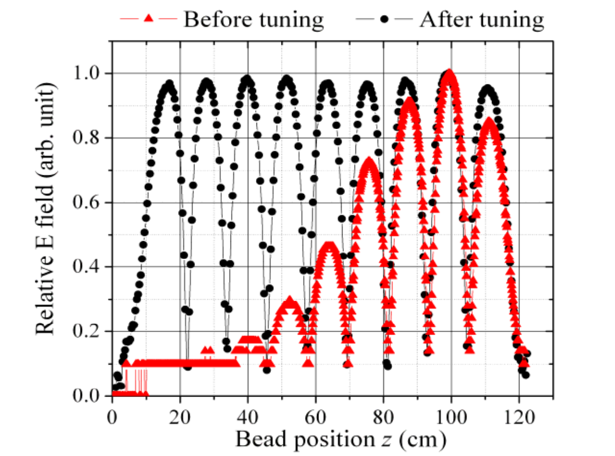
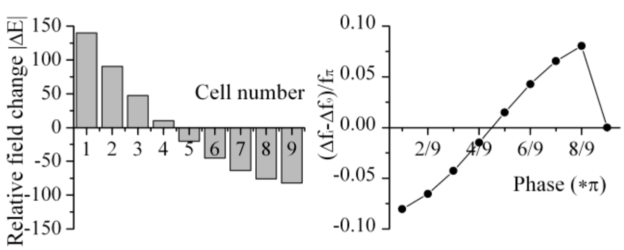
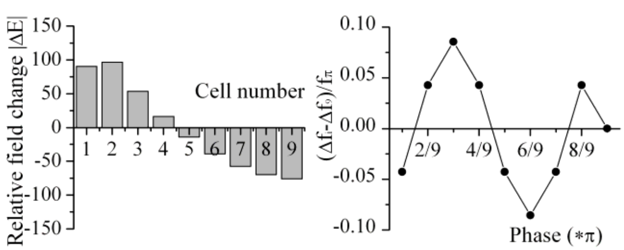


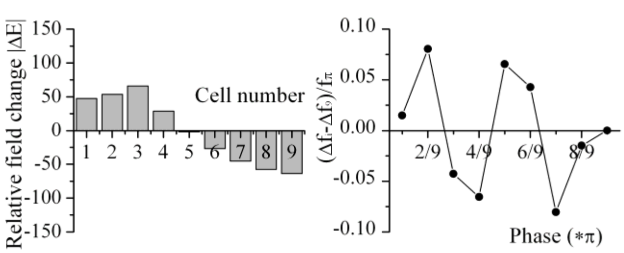
Figure 3: Relative axial electric field of the TM010_PI mode obtained from the bead-pull measurement. The field flatness is 53.2% before tuning, and 97.2% after tuning with the PI mode frequency of 1298.2 MHz.



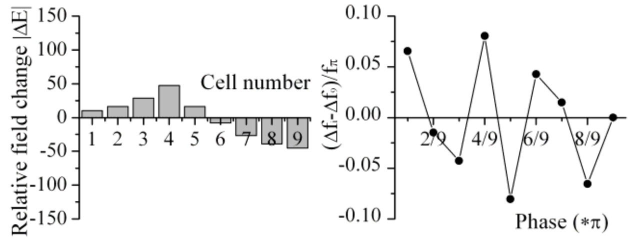
(a) Perturbation of cell No. 1



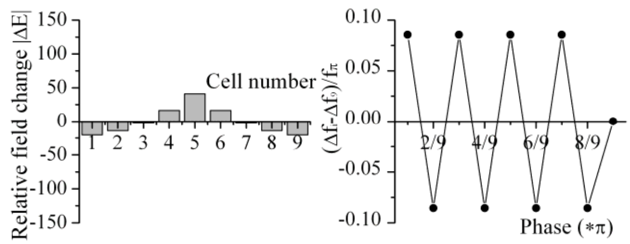
(b) Perturbation of cell No. 2



(c) Perturbation of cell No. 3



(d) Perturbation of cell No. 4



(e) Perturbation of cell No. 5

Figure 4: The change of the field and the spectrum due to the perturbation of individual cells.

HOM CALCULATION AND MEASUREMENT

HOM damping is very crucial for the superconducting linacs and is under study in our experiment. According to the KEK design of HOM damping, several modes with high *R*/*Q* in the 3rd dipole passband (TM111) should be damped [1]. Simulation is carried out firstly with MAFIA 2D to find the HOMs with high *R*/*Q* values. With the designed parameters of the ICHIRO model, Figure 5 gives the dispersion curves of the monopole and dipole modes obtained by MAFIA 2D simulation.

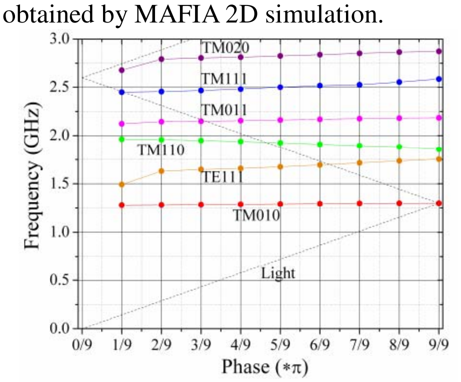


Figure 5: Dispersion curves of the monopole and dipole modes of the ICHIRO cavity.

For the monopoles and dipoles of an accelerating cavity, *R*/*Q* is defined as [1]:

$$R/Q = \frac{1}{b^n}\cdot\frac{1}{2\pi f_0 W}[(\int_0^L E_z \cos\frac{2\pi z}{\lambda_0}dz)^2 + (\int_0^L E_z \sin\frac{2\pi z}{\lambda_0}dz)^2] \quad (2)$$

where f_0 is the resonant frequency of the mode, W is the stored energy of the mode, L is the length of the cavity. For the monopoles, $n = 0$ and E_z is the axial electric field on the z-axis. For the dipoles, $n = 2$ and E_z is the axial electric field on the axis $r = b$.

With Mafia 2D programme, *R*/*Q* is computed for the monopole and dipole modes of the cavity up to 3 GHz.

The Accelerating mode and HOMs with significant calculated *R*/*Q* values are listed in Table 1. For the monopole modes, *R*/*Q* is computed along the axis of the cavity. For the dipole modes the path is 1.5 cm off the z-axis.

To determine the *R*/*Q* measurement values, E_z field profile should be measured. This is commonly accomplished by the bead-pull technique. The resonant frequency shift (Δf) produced by perturbation is given as follows [4, 7]:

$$\frac{\Delta f}{f_0} = \frac{1}{W}(K_1\varepsilon_0 E_{//}^2 + K_2\varepsilon_0 E_{\perp}^2 - K_3\mu_0 H_{//}^2 - K_4\mu_0 H_{\perp}^2) \quad (3)$$

where $E_{//}$ ($H_{//}$) and $E_{\perp}$ ($H_{\perp}$) are the electric (magnetic) fields parallel and perpendicular to the symmetrical axis of the bead respectively. K_i (i = 1, 2, 3, 4) is the perturbation form factor which depends upon the material, size and shape of the bead. A cylindrical pill-box cavity with $2R$ = 76.55 mm, L = 74.68 mm is used to calibrate the form factor K_i of the perturbation objects.

For the monopoles, E_z is measured along the axis. A metal needle with the diameter of 1.11 mm and length of 11.1 mm (K_i/K_1 < 4%, i = 2, 3, 4) is used. E_z field profiles of nine modes in the TM010 passband and seven modes in the TM020 passband are coordinated with those of calculated. Since the perturbation objects tuning for the TM010-PI mode are detuned for the TM011 modes, only the resonant peaks of some cells are observed in the TM011 passband.

For the dipoles, E_z is measured 1.5 cm off the axis where the longitudinal electric field and other field components coexist. According to the perturbation theory, the wave length of the field being measured should be larger than the size of the perturbation object ($\lambda_0 >> l$). And a thin metallic needle ($d << l$, d and l are the diameter and length of the needle) is needed to separate the axial electric field from other components. But for such a thin and short needle ($d << l << \lambda_0$), the frequency shift would be too small to produce the relevant data [4,7]. The amplitude of E_z is as large as the other field components in the TM110 and TM111 passbands according to the result of the Mafia 2D programme. A metal needle with diameter of 0.99 mm and length of 10 mm (K_i/K_1 < 4.1%, i = 2, 3, 4) is used. For the TE111 passband, the amplitude of E_z is one sixth of the other field components. A thin metal needle with the diameter of 0.31 mm and length of 20 mm (λ_0 / l > 8.5; K_i/K_1 < 0.40%, i = 2, 3, 4) is used. Only several E_z profiles are clearly measured in each dipole passband and modes of different polarizations are found. Accelerating mode and HOMs with significant measured *R*/*Q* values are listed in Table 1.

Due to the fabrication errors and perturbation objects used in the field-flatness tuning, the resonant frequency and field profile of each mode should be different from the originally designed values. It is assumed for the cavity a classifiable set of excitation modes exist [8]. The reason for the difference between the calculated and the measured *R*/*Q* of the fundamental mode is under study. Since other field components exist, the results for the transverse modes are less reliable. Further efforts will be made for more reliable results.

Table 1: FM and HOM data calculated and measured

Mode	*f* (GHz) Calculated	*f* (GHz) Measured	*R*/*Q*(1) (Ohm/cm^n) Calculated	*R*/*Q*(1) (Ohm/cm^n) Measured
TM010-9	1.299249	1.298271	1125.75	974.02
TE111-7a	1.715894	1.728774	6.91	2.63
TE111-8a	1.737056	1.752081	3.76	3.49
TM110-5a	1.926031	1.924716	14.20	7.91
TM110-4b	1.939577	1.939012	13.11	1.01
TM011-6	2.169293		134.42	
TM011-7	2.175969		184.35	
TM111-1	2.448334		30.49	
TM111-2a	2.454574	2.456481	20.01	7.55

(1): n=0 for monopoles, n=2 for dipoles; a, b indicate polarizations.

CONCLUSION

Field tuning and HOMs measurement of a 9-cell superconducting ICHIRO copper cavity model is presented. By inserting perturbation objects into the cells, field flatness of 97.2% for the TM010_PI mode has been obtained after a few iterations. Frequencies and shunt impendence of the higher order modes are measured and compared with the numerical simulation of the cavity using the Mafia 2D code.

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