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EXPERIMENTAL STUDY OF TUNING METHOD ON A MODEL ALVAREZ DTL CAVITY FOR CPHS PROJECT

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Abstract

This article is devoted to the experimental study of tuning method for an Alvarez-type drift tube linac (DTL) of the Compact Pulse Hadron Source (CPHS) project at Tsinghua University. The biperiodic structure based on the post couplers are introduced to overcome the instability of the Alvarez DTL tank which is used to operate in 0 (or 2π) mode. The experimental method and results are presented, and the tuning scheme for the formal CPHS DTL is summarized from the tuning experiment.

INTRODUCTION

The effective shunt impedance of the Alvarez-type DTL is typically high when it operates in a typical 0 (or 2π) mode with the group velocity of 0. But the structure is very susceptible to perturbation such as the beam loading, mechanical and installation error, because of the narrow space near the adjacent modes on the TM dispersion curve. The post couplers, which are the resonant-coupling elements constitutionally, are mounted on the wall of the DTL cavity oppositely and alternatively to introduce a new PCs (post couplers) dispersion curve. When the stopband between the two passbands of the dispersion curves disappears by adjusting the slugging length of the post couplers, the lowest frequency of the TM passband will be moved to the π/2 mode point of the new dispersion curve. Therefore the new stable biperiodic structure of the DTL will be achieved [1].

To verify the tuning method, one model cavity has been machined and the turning experiment is carried out based on the cavity. The cavity is designed and manufactured for verifying the mechanical design and undertaking some low-power experiment. The model cavity consists of ten full drift tubes, two half drift tubes mounted on the end flanges, three post couplers and two tuners [2]. The end of the post couplers is designed to be eccentric to facilitate the tuning of the local field distribution by rotating the post.

TUNING EXPERIMENTAL CONFIGURATION

On the experimental stand as shown in Fig. 1, the measurement based on the bead-pull method is executed. According to the perturbation theory, when the bead is pulled into the field between the two adjacent drift tubes, the resonant frequency changes. Then the corresponding phase shift can be detected by a vector network analyzer (VNA) and the electric field along the beam-axis can be deduced [3].

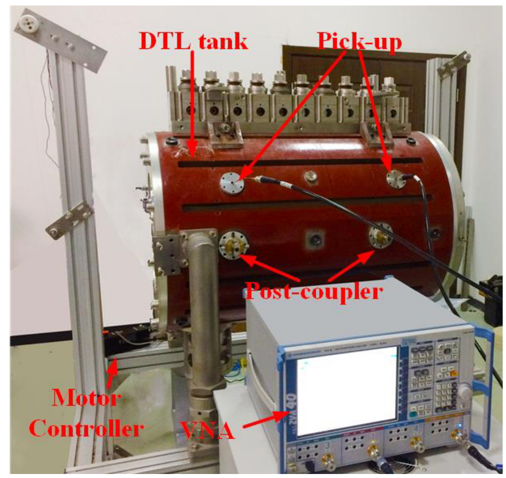

Figure: 1 Tuning experimental stand.

A stepping motor is adopted to pull a fine nylon line on which the small perturbation bead is fixed. The size of the bead shall be rather appropriate, so that the responsive signal caused by the bead is big enough compared with the background noise and at the same time within the linear range of the phase around the resonant frequency. It depends on the Q factor of the cavity. The Q factor of this model cavity is measured as 17796 which is about 44% of the designed value. It is because that the surfaces of the interior copper-plated cavity wall and the aluminous end flanges are oxidic. With the value of the Q factor, the radius of the bead is determined as 0.7 mm by estimation.

To ensure the accuracy of the measurement, the peak field is employed to represent the field distribution instead of the integral one due to its further advantages [4]. Before the measurement, the reproducibility is checked. The reproducibility R_{ij} is defined by Eq. (1).

$$R_{ij} = \frac{E_{ij}}{\left(\sum_{j=1}^{n} E_{ij}\right)/n}. \quad (1)$$

where E_{ij} is the measured electric field strength of the i^{th} cell for the j^{th} time, and n is the number of times of the measurements. Ten sequential measurement is analyzed by this definition, and the reproducibility is better than ±0.15% as shown in Fig. 2.

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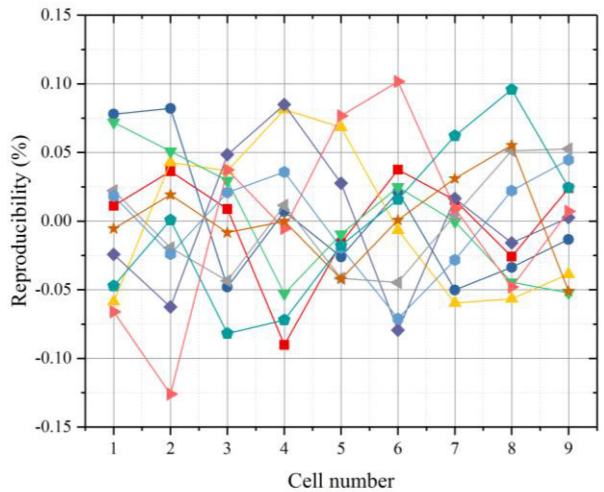

Figure 2: The measured reproducibility of the peak field on the model cavity for CPHS.

For predicting the performance of the tuners, the tuning effect by adjusting the slugging length of tuners is checked. The motioning range of tuners is from 0 mm to 100 mm corresponsive to slugging length of them. The tuning gradient of the tuners is about 0.02 MHz/mm in the condition of slugging the same length of all the tuners at the same time. Satisfactory linearity can help predict the adjusting value of tuners during the tuning process.

Considering the different status of the cavity with or without vacuum condition and under the different temperatures, the tuning resonant frequency shall be set as 324.9 MHz according to the following estimate:

Temperature Effect

Coefficient of the thermal expansion of the carbon steel DTL tank α is 1.2×10^{-5}/ºC. Compared with the operating temperature 25 ºC with the resonant frequency f_0 of 325 MHz, the experimental temperature is 7 ºC (ΔT=-7 ºC). So, the frequency shift Δf_T by the temperature effect can be calculated by Eq. (2):

$$\Delta f_T = \alpha f_0 \Delta T \,. \tag{2}$$

Atmospheric Effect

It is assumed that the scantly differences are the permittivity ε and permeability μ. The relative permittivity in air $\varepsilon_{\lambda\alpha}$ =1.000585, and the relative permeability in air $\mu_{\lambda\alpha}$ =1.00000004. The new resonant frequency in the air f_α can be calculated by Eq. (3):

$$f_\alpha = \frac{1}{2\pi\sqrt{(\varepsilon_0\varepsilon_{\lambda\alpha}A_C)(\mu_0\mu_{\lambda\alpha}A_L)}} \,. \tag{3}$$

where ε_0 the is the permittivity in vacuum, μ_0 is the permeability in vacuum, A_C and A_L are the capacitive calculating factor and inductive calculating factor which are relevant to the geometry of the DTL cavity respectively. Therefore, the frequency shift by the atmospheric effect can be calculated by Eq. (4):

$$\Delta f_A = f_\alpha - f_0 \,. \tag{4}$$

TUNING EXPERIMENT AND RESULTS

At the beginning of the tuning experiment, the error of field distribution is tuned to be better than ±2% as required at about 324.8 MHz with tuners but without post couplers. Because the frequency of the DTL without post couplers will introduce a frequency shift about 0.1 MHz, and the local tuning capacity of the post couplers is finite. The tuning rules are identical with the perturbation theory: when the inserted length of the tuner located at the bottom of the cavity rose, the frequency increase and the electric field decrease, and vice versa.

The tilt sensitivity can be tuned when all the three couplers are inserted into the cavity. The tilt sensitivity is an important criterion of the cavity stability. The tilt sensitivity of the i^{th} cell TS_i is defined by Eq. (5):

$$TS_i = \frac{(E_i^p - E_i)/E_i}{\Delta f}\times 100\% \,. \tag{5}$$

where E_i is the electric field before the perturbation, E_i^p is the electric field after the perturbation, and Δf is the frequency shift caused by a hollow metallic pipe slide into the cavity at the beam aperture of the high energy end flange. E_i shall be measured before the perturbation. E_i^p shall be measured after the Δf being compensated by tuner close to the low energy end. To obtain the lowest *TS* which the slope of the *TS* is closed to 0, the slopes of *TS* parameters are recorded every time the gap between the drift tube and post-coupler changed. The relationship between the *TS* parameters and the gaps is shown in Fig. 3.

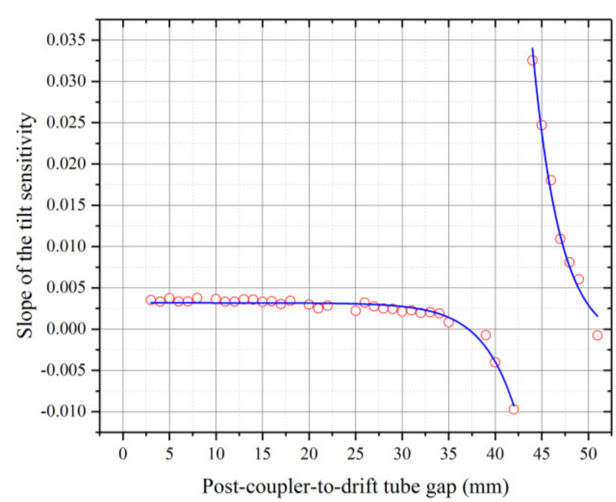

Figure 3: *TS* parameters vs. the gap between the drift tube and post-couplers.

The lowest *TS* slope corresponds to the 39 mm gap, and the gaps are set to be 39 mm uniformly. The TS_i distribution

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is shown as Fig. 4 which corresponds to the electric field distribution shown as Fig. 5.

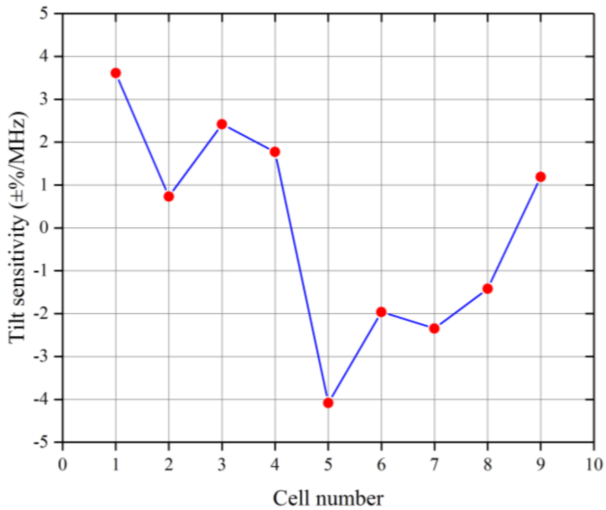

Figure 4: TS_i distribution per 0.15 MHz when the gaps between the drift tubes and the post-couplers are 39 mm.

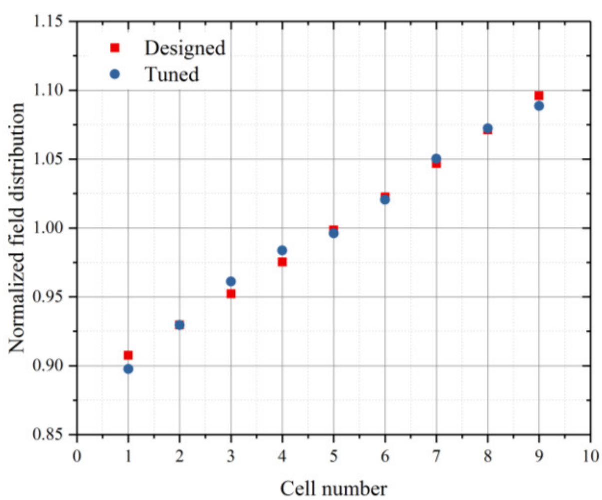

Figure 5: Electric field distribution when the gaps between the drift tubes and the post-couplers are 39 mm.

The local distribution can be tuned to the required range by rotating the post couplers. However, there is coupling relationship between the *TS* and the field distribution because of the eccentric structure of the post coupler. With several iterations, the field flatness is better the ±1.2% and *TS* is less than ±4.2%/MHz.

TUNING SCHEME FOR THE FORMAL DTL CAVITY

There are 39 drift tubes, 13 post-couplers and 9 tuners in the formal DTL cavity for CPHS. The size of each tuning element should be determined and installed permanently. For getting an accurate tuning result finally, the elements cannot be changed in one time, there should be an elements-replacing scheme as following:

1)According the first tuning result, manufacture a half of the elements including post couplers and tuners (except the first and last ones).

For 13 post couplers, No.3, 4, 7, 8, 11 and 12 will be replaced;

For 7 tuners, No.2, 4, 6 and 8 will be replaced.

2)Tuning the field again with the remaining aluminium elements.

3)According the second results, manufacture a half of the remaining elements (except the first and last tuners).

For the 7 post couplers, No.5, 9 and 13 will be replaced;

For the 3 tuners, No.2 and 6 will be replaced.

4)Tuning the field again with the remaining aluminium elements.

5)According the third results, manufacture and replaced the remaining elements.

6)Check the field distribution and tilt sensitivity, tuning the filed with the first and last tuners if necessary.

7)If everything is OK, tuning process is completed.

CONCLUSION

The tuning experiment on the model cavity of the CPHS project is accomplished at Tsinghua University. With the tuning experience, the tuning scheme for the formal DTL cavity is determinated. The gap between the drift tube and the post-couplers will not be coincident because of the different geometries of 40 cells, but the gap can be predicted through the theoretical analyzation and experimental results of this article.

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