DESIGN OF A FOUR-VANE 325 MHZ RFQ COLD MODEL AT TSINGHUA UNIVERSITY*

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Abstract

The design of a Radio Frequency Quadrupole (RFQ) accelerator cold model at Tsinghua University is presented in this paper. The 1-meter-long aluminium cold model is chosen to be the same as the low-energy part of the 3-meter-long RFQ for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University. This cold model will be used mainly for the RFQ field study and education. It will work at the RF frequency of 325 MHz. All the simulations are finished by the SUPERFISH and MAFIA codes.

INTRODUCTION

The RFQ cold model discussed here is a 1-meter-long four-vane aluminum proton accelerator mainly used for RFQ field study. After the cold model is tuned, it will be used for scientific education and training.

Two years ago, we designed a four-vane RFQ for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University, which was not satisfactory in undercuts design because of our unilateral comprehension of matching undercuts. Luckily, we found the problem in time and worked out a new design [2]. However, the cavity wasn't machined based on this proper design because of engineering considerations, so we only amended a little on the basis of the initial design.

At present, though we have succeeded in the construction of the CPHS RFQ [3], we still aspire to finish a complete procedure from design, machining to measurement and tuning. This is why we have the project of constructing a 1-meter-long aluminium four-vane RFQ cold model. Thanks to the experience of the 3-meter-long RFQ of the CPHS project, we are familiar with the design method of RFQ and have finished the design smoothly.

Three sections are included in the design of the RFQ cold model: the cavity, the undercuts and the dipole mode stabilization rods.

DESIGN OF THE CAVITY

As shown in Fig. 1, the cavity of the cold model is chosen to be the same as the first 1-meter-long section of the 3-meter-long CPHS RFQ [1]. Therefore, the cavity shape and vane dimensions are the same. In this case, many of our past design details can also be used for reference in the new design, such as the transverse position and dimension of dipole-mode stabilizer rods [2].

The designed beam energy at the end of the cold model is 0.48MeV with a 50 keV input beam.

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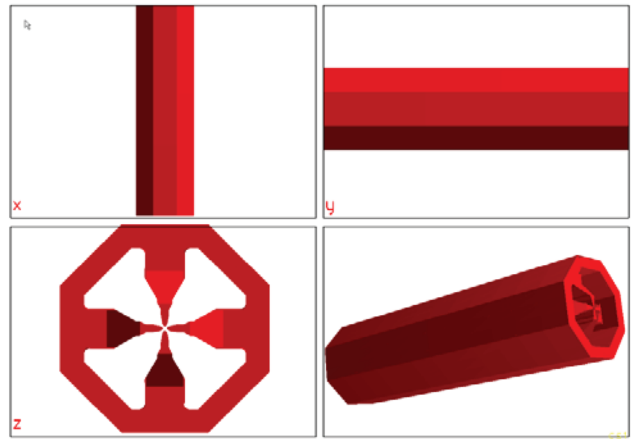

Figure 1: RFQ cold model cavity.

The designed frequency of the cold model with flush tuners is 323.5 MHz which is lower than the working frequency of 325 MHz. The insertion of the slug tuners will raise the cavity frequency.

DESIGN OF THE UNDERCUTS

Undercuts at the end of the four vanes are very important to the RFQ to close the magnetic field lines. In our design, Two goals are achieved by optimizing the parameters of the undercuts: one is to make the frequency of TE_{210} mode to be near the desired frequency of 323.5 MHz and another one is to make the maximum magnetic field distribution along the RFQ just same as the designed result by the SUPERFISH code.

A trapezoid-shape-like undercut is adopted for the RFQ cold model in consideration of its cooling convenience, as shown in Fig. 2.

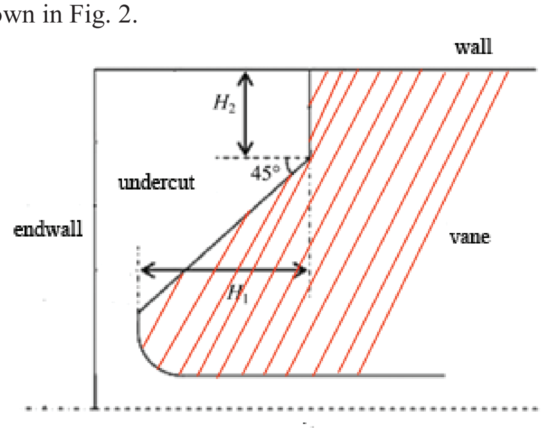

Figure 2: Undercuts parameters.

Fig. 2 shows the undercut dimensions for both the low-energy end and high-energy end. The undercuts at the same end share the same parameters. For convenience, the set of parameters is listed as (31, 31, 50, 30), which corresponds to H_1 at the low-energy end, H_2 at the low-energy end, H_1 at the high-energy end, H_2 at the high-energy end respectively in mm.

For each set of parameters, simulations have been carried out by the Mafia code to obtain the field distribution and resonance frequency of the TE_{210} mode. However, it's not necessary to simulate with too many sets of parameters.

Actually an important formula has been acquired during our past design:

$$\frac{1}{2}\left(\frac{c}{2\pi f_0}\right)^2 \frac{\partial V_g}{\partial n}(L) = \frac{L}{f_0}(f(L) - f_0)V_g(L). \quad (1)$$

where f_0 is the resonant frequency, V_g is the inter-vane voltage and $f(L)$ is the local frequency of an undercut segment with length L. [2]

There exists a regular relationship between the maximum magnetic field and the inter-vane voltage in our structure according to the SUPERFISH simulation, as shown in Fig. 3. The law about maximum magnetic field and the law about inter-vane voltage are almost the same. Therefore an important law about the maximum magnetic field can be derived from the Slater perturbation theory and the formula (1): enlarging the dimension of the undercuts at the low-energy end will decrease the slope of the maximum magnetic field and reduce the resonance frequency; enlarging the dimension of the undercuts at the high-energy end will increase the slope of the maximum magnetic field and reduce the resonance frequency.

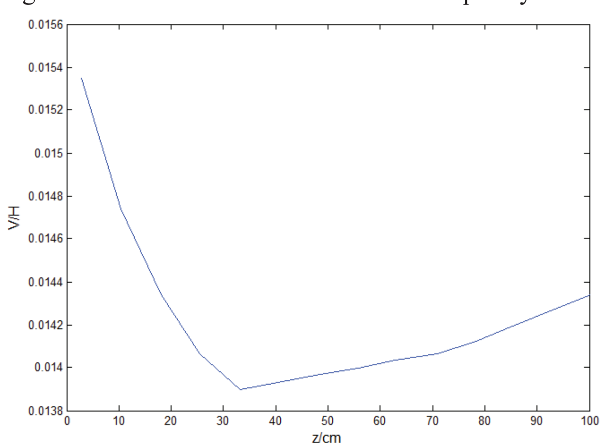

Figure 3: Relationship between the maximum magnetic field and inter vane voltage along the cold model.

Fig. 4 shows the relative maximum magnetic field distribution of three sets of parameters compared to the designed maximum magnetic field. The resonance frequencies of the three sets are listed in Table 1. The three sets of data will be taken as examples to explain how the law works.

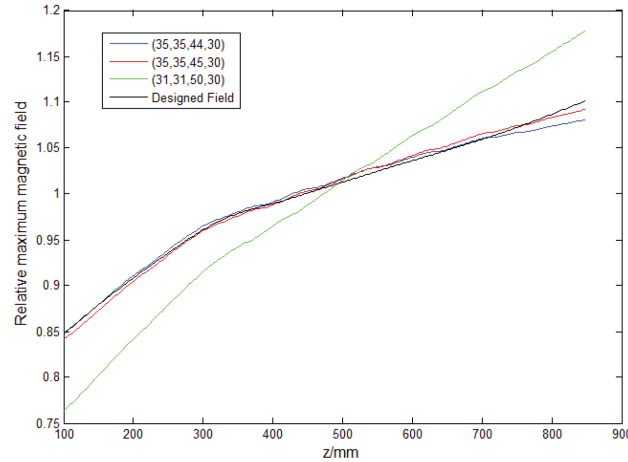

Figure 4: Relative maximum magnetic field distribution of three sets of parameters of the undercuts compared to the designed maximum magnetic field .

Table 1: Resonance frequencies of the three data sets

Parameters (mm)	Resonance Frequency (MHz)
(31, 31, 50, 30)	322.77
(35, 35, 44, 30)	323.48
(35, 35, 45, 30)	323.36

Firstly, the simulation results of (31, 31, 50, 30) has been obtained. As shown in Fig. 4, both of the slopes at the low-energy and high-energy end of the curve are larger than designed. Therefore, the undercuts at the low-energy end should be larger and the undercuts at the high-energy end should be smaller according to the law. As listed in Table 1, the resonance frequency is smaller than designed. Therefore, both the undercuts at the low-energy and high-energy end should be smaller according to the law. For overall consideration, the undercuts at the low-energy end should be larger and the undercuts at the high-energy end should not change. Thereafter the set of (35, 35, 50, 30) is chosen to be the next set. In this way, the optimum undercuts parameters can be approached in a few simulations.

In the last two simulations, both curves of (35, 35, 44, 30) and (35, 35, 45, 30) are pretty good. Then Table 1 is used to compare their resonance frequency with 323.5 MHz: the first set has a frequency of 323.48 MHz while the other set has a frequency of 323.36 MHz. At last the set of (35, 35, 44, 30) is chosen with the frequency closer to 323.5 MHz.

DESIGN OF THE DIPOLE-MODE STABILIZER RODS

The dipole-mode stabilizer rods are used to enlarge the frequency gap between the TE_{210} mode and the nearby dipole modes. Thereafter the dipole modes will have less influence on the TE_{210} mode.

The design parameters of the dipole-mode stabilizer include the diameter "*D*", the centre position "*r*" between the centre of the column and the beam axis, and the length of the rods "*l*". As mentioned above, we adopt *D*=15 mm

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and *r*=5.535 cm based on our past design. So only the "*l*" is undetermined.

Accidentally, we found some different modes besides the dipole modes and quadrupole modes. Their magnetic field and electric field are shown separately in Fig. 5 and Fig. 6. As they have a direct relationship with the dipole-mode stabilizer rods, we just call them the "Stabilizer rod modes". Their frequencies are very large when the rods are short. The frequency reduces as the rods become longer, as shown in Row 5 in Table 2.

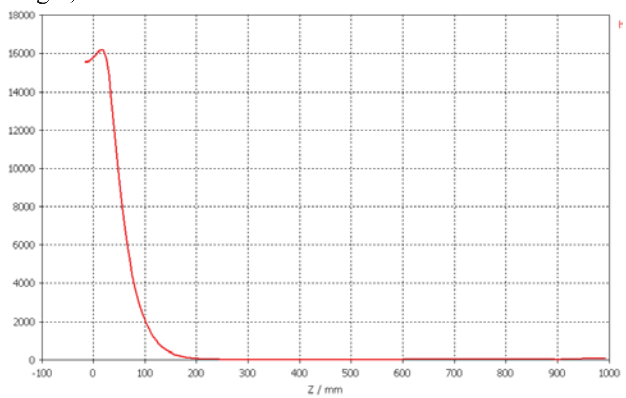

Figure 5: Maximum magnetic field of the "Stabilizer rod mode" along the z-axis of the cold model.

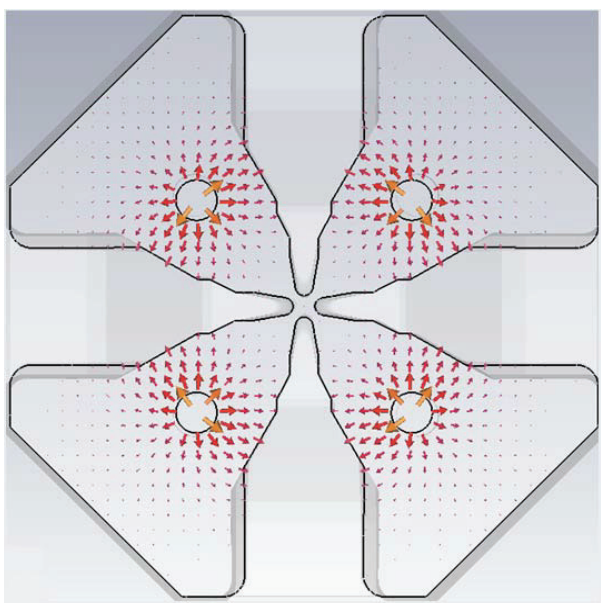

Figure 6: Transverse electric field of the "Stabilizer rod mode" in the position z=65 mm.

Table 2 shows the frequencies of the TE_{210} mode and some modes near it which shall be as far as possible. The data with red font in Table 2 shows that without rods, the frequency gap is 2.01 MHz. Finally rod length is chosen to be 135 mm. With this length, the frequency gap is quite large (6.63 MHz).

It is not necessary to be very accurate for the length of the rods because of the errors in the computer simulation and machining. Moreover, the length of the rods can be adjusted in the experiment.

Table 2: Frequencies of modes when the length of the rods changes

Rod length (mm)	TE_{110} (MHz)	TE_{210} (MHz)	TE_{111} (MHz)	Stabilizer rods modes (MHz)
0	321.45	323.46	362.37	Very large
40	321.17	323.57	361.26	514.48
50	320.97	323. 57	360.65	494.63, 527.14
60	320.68	323. 57	359.82	469.59, 500.68
70	320.38	323. 55	358.94	448.29, 475.65
110	318.74	323. 57	353.88	>357.64
120	318.13	323.57	351.93	358.63, >357.63
125	317.78	323.57	350.80	351.16, >357.58
130	317.38	323.57	349.53	343.97, 357.09
135	316.94	323.57	348.08	336.99, 349.39
140	316.44	323.58	346.46	330.25, 341.96

CONCLUSSION

The design of the RFQ cold model is done by simulations with the SUPERFISH and MAFIA codes. The final whole cavity is showed in Fig. 7. Thanks to the experience of the 3-meter-long RFQ of the CPHS project at Tsinghua University, we are familiar with the design method of the RFQ and have finished the design smoothly. Now we are preparing for the machining and it is expected to see whether the theoretical calculation can be a good estimate.

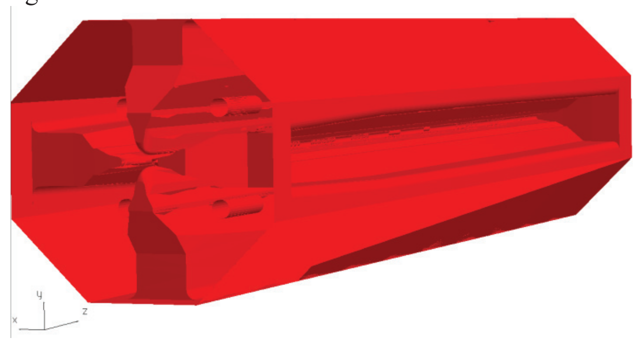

Figure 7: Final whole cavity of the RFQ cold model.

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REFERENCES

[1] Q.Z. Xing, et al. Design of the CPHS RFQ Linac at Tsinghua University. IPAC'2010, MOPD047 (2010).
[2] CAI Jin-Chi, et al. Design of undercuts and dipole stabilizer rods for the CPHS RFQ accelerator. CPC(HEP & NP), 2012, 36(5): 464-468.
[3] Q.Z. Xing, et al. Construction Status of the CPHS RFQ at Tsinghua University. IPAC'2011, MOPC024 (2011).