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TUNING OF A FOUR-VANE RFQ FOR XI'AN 200 MeV PROTON APPLICATION FACILITY

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Abstract

This paper mainly describes the procedures and results of tuning a four-vane Radio Frequency Quadrupole (RFQ) accelerator for the Xi'an 200 MeV Proton Application Facility (XiPAF) project. The 3-meter-long RFQ will accelerate a 50 keV H^- beam from the ECR source to 3 MeV, and deliver it to the downstream drift tube linac (DTL) with a peak current of 5 mA, pulse length of 10-40 μs and maximum repetition rate of 0.5. The machining, assembly, and RF tuning of the RFQ cavity has been completed successfully. After tuning, the relative error of the operating quadrupole mode field is within ±2.7%, and the dipole mode component is within ±1.9% of the quadrupole mode. The RFQ now is ready for high-power RF conditioning.

INTRODUCTION

The four-vane Radio Frequency Quadrupole (RFQ) accelerator will be used as a component of the linac injector for the Xi'an 200 MeV Proton Application Facility (XiPAF) project, a facility capable of providing single-event effect test of semiconductor devices in spacecraft electronic systems. The main function of this RFQ is to bunch, focus and accelerate low-speed H^- beam and finally match the beam to the DTL. To make this RFQ compact, the inter-vane voltage of XiPAF RFQ rises from the low-energy end to high-energy end.

Tuning plays an important role for the operation of an RFQ. Due to the deviation of undercut design and machining error, the actual field distribution of RFQ is always different from the designed one. The relatively large error of the field distribution can lead to changes in the synchronous energy, twiss parameters, and transmission efficiency of the beam at the RFQ exit. In order to adjust the field distribution, 48 tuners are equipped on this RFQ.

The main objectives of tuning the XiPAF RFQ are as follows: 1) Reduce the field distribution difference between the measured and designed quadrupole field; 2) decrease the dipole mode field component; 3) tune the frequency to the desired value; 4) adjust the coupling coefficient of the power coupler to the desired value; 5) enlarge the frequency separation between the operating quadrupole mode and the nearest dipole modes to enhance the field stability. In order to ensure that the final field distribution can meet the requirements, the RFQ has been tuned twice, including the pre-braze tuning and final tuning.

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XIPAF RFQ

Main parameters of the XiPAF RFQ are shown in Table 1 [1].

Table 1: Main Design Parameters of XiPAF RFQ

Parameters	Value	Unit
Particle	H^-	
Input energy	50	keV
Output energy	3	MeV
Frequency	325	MHz
Peak current intensity	5	mA
Maximum reputation rate	0.5	Hz
Beam pulse length	10-40	μs
Peak wall power	388	kW
Q_0	8600	

Assembled XiPAF RFQ is shown in Fig. 1. This RFQ consists of three segments. A total of 48 tuners are equipped in the four quadrants of the cavity. Each segment is about 1 meter long and contains 16 tuners. Four dipole-mode stabilizer rods [2] are mounted on each of the two flanges in order to adjust the frequency separation between the quadrupole mode and adjacent dipole modes. Undercuts [3] are separately designed for each end of the RFQ in order to help achieve the field distribution close to the designed one. The RFQ is fed by only one power coupler and the coupler is located in the first quadrant in the middle of the RFQ. Power is fed into the cavity by loop coupling [4] and the coupling coefficient can be adjusted by rotating the coaxial coupler.

EXPERIMENTAL SETUP

The magnetic field distribution near the outer wall is obtained by the bead-pull method. Main measuring device is a vector network analyser. One port of the network analyser is connected to power coupler and the other port is connected to a field probe. The probe is inserted into the cavity through a vacuum port to measure the S12 signal. A hollow metal bead with a diameter of 11.5 mm is used for a perturbation. The bead passes through the four quadrants under the drive of a stepper motor.

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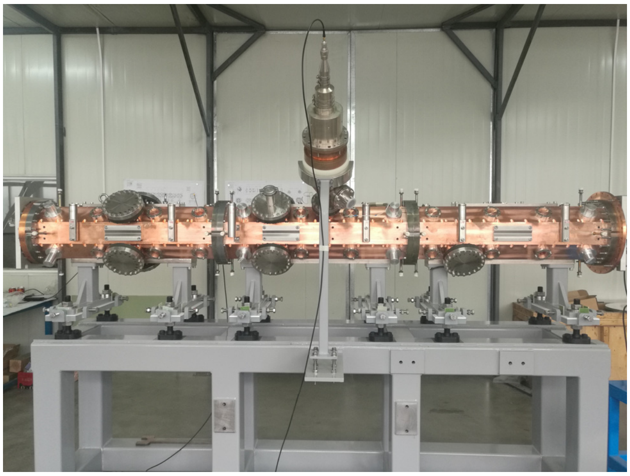

Figure 1: Assembled XiPAF RFQ.

Field distribution is obtained by measuring the phase change of the S12 signal. Figure 2 shows the linear relationship between the S12 phase and frequency. It can be seen that there is a good linearity in the range of ±5 kHz near the centre frequency. The disturbance slightly exceeds +5 kHz near the last tuner in Fig. 2(b). However, the data near tuners are not actually used in the tuning program. Therefore, the method for such measurement is reasonable.

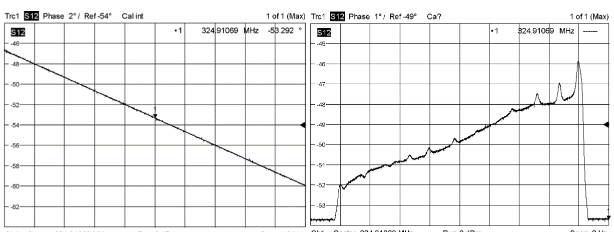

Figure 2: Assessment of the linear relationship between the S12 phase and frequency (a) and phase shift of signal S12 with the bead position (b) in one measurement.

PRE-BRAZE TUNING

Before the pre-braze tuning, the four vanes of the XiPAF RFQ are assembled, but not brazed together. The dipole-mode stabilizer rods are not brazed on the flanges and the lengths can still be adjusted. A dummy coupler is mounted on the cavity to imitate a real coupler. The main objectives for the pre-braze tuning are: 1) verify that both the field distribution and resonance frequency can be tuned to meet requirements; 2) determine the length of dipole-mode stabilizer rods to ensure a large frequency separation between the operating quadrupole mode and the nearest dipole modes.

The pre-braze tuning begins with all the aluminium tuners flush with the inner surface of the cavity wall. Before pre-braze tuning, the relative error of the operating quadrupole mode field is within ±25.0%, and the dipole mode component is within ±12.8% of the quadrupole mode. With the field distribution measured, the tuning program THURT [5] can calculate new insertion depth of tuners.

After several iterations, the relative error of the operating quadrupole mode field drops below ±2.0% while the dipole mode component is about ±16%. The dipole component is rather large, because we finally find that a wrong normalization method for the dipole field has been adopted during the pre-braze tuning. Figure 3 shows the corrected normalized field distribution of the quadrupole and dipole modes after pre-braze tuning.

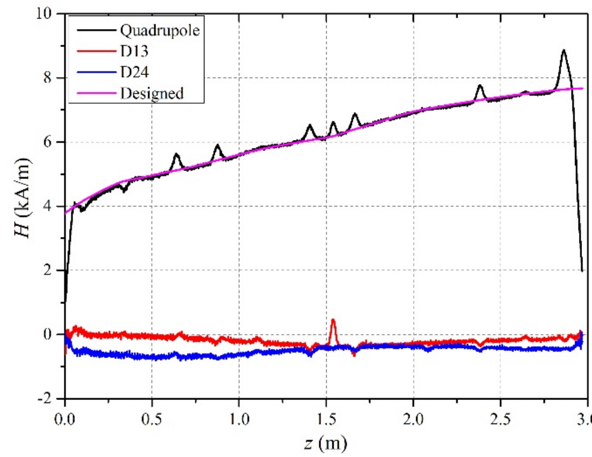

Figure 3: Normalized field distribution of the quadrupole and dipole modes after pre-braze tuning (22 °C, and 42% humidity).

After the field distribution and frequency are tuned, the frequency separation of the operating mode and adjacent dipole modes is adjusted by adjusting the length of the dipole-mode stabilizer rods. Figure 4 shows Measured frequency of operating mode and adjacent modes with the rod length. As the length increases, the frequency separation of the operating mode and adjacent dipole modes first increases and then decreases. The length of the dipole mode stabilizer rod is finally set to 150 mm, and the frequencies of the nearest dipole mode are separated from the operating mode by at least 5.25 MHz.

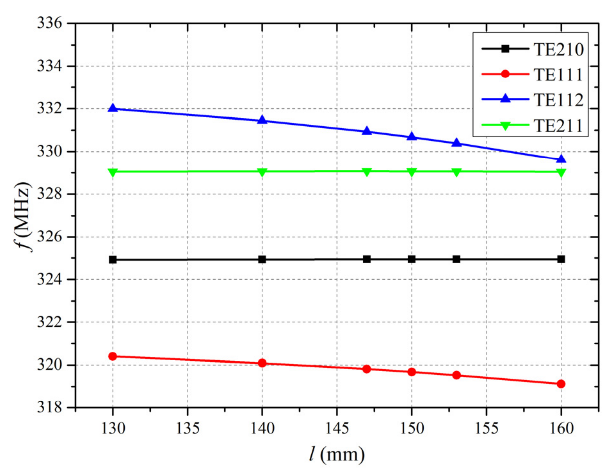

Figure 4: Measured frequency of operating mode and adjacent modes with the rod length.

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FINAL TUNING

The final tuning is carried out after the vanes of the RFQ are brazed together. Main objectives of the final tuning are: 1) determine the length of the copper tuners so that both field distribution and resonance frequency meet requirements; 2) determine the size and angle of the coupling loop in order to adjust the coupling coefficient to the target value.

The final field distribution is shown in Fig. 5. It can be seen that after the final tuning, the relative error of the operating quadrupole mode field is within ±2.7%, and the dipole mode component is within ±1.9% of the quadrupole mode. Quadrupole field error exceeds ±2% only in a small part of the bunching section.

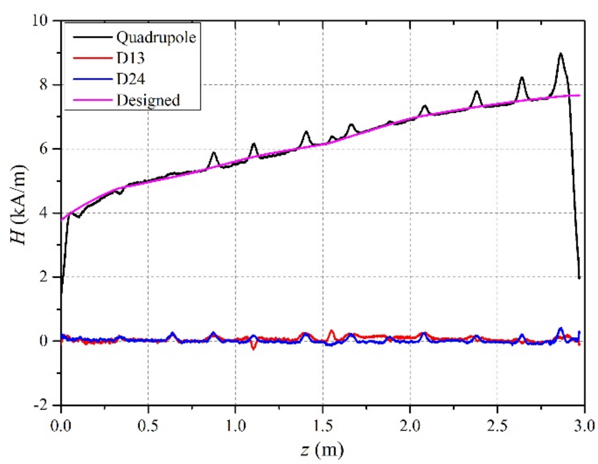

Figure 5: Normalized field distribution of the quadrupole and dipole modes after final tuning (23.7°C, with nitrogen fed into the cavity).

The resonance frequency of the operating mode is 324.89 MHz in the environment of 22°C and 10% humidity. The frequency spectrum is shown in Fig. 6. It can be seen that the frequency difference between the operating quadrupole mode and the nearest dipole mode is 4.85 MHz. And we have measured the resonance frequency of operating mode in the environment of 23°C and 0.25 Pa inside the cavity later. It shows that the frequency rises to 325.02 MHz, and the frequency becomes 325.01MHz when the environment is converted to 25°C, vacuum. The difference between the frequency converted and target value is only 10 kHz.

The final coupling coefficient measured is 1.03 while the quality factor Q_0 is 7300. Peak cavity power with this Q_0 should be 457 kW and peak beam power is 18 kW. The desired coupling coefficient should be $\beta = 1 + P_{\text{beam}}/P_{\text{cavity}} = 1.04$. The attenuation of all pickups falls in -59.5 dB~ -60.5 dB area after adjusting.

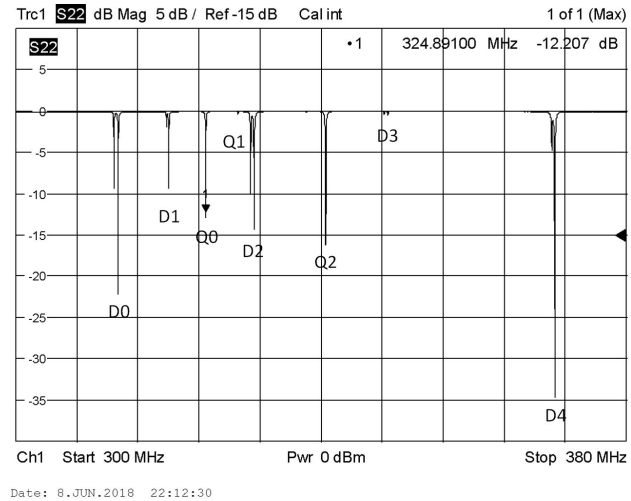

Figure 6: Frequency spectrum of XiPAF RFQ after final tuning (22 °C, 10% humidity).

CONCLUSIONS

One 325 MHz four-vane RFQ accelerator with ramped inter-vane voltage has been manufactured for the 7 MeV linac injector of the XiPAF project. The machining, assembly, and RF tuning of the RFQ cavity has been completed successfully. The magnetic field distribution near the outer wall is obtained by the bead-pull method. The RFQ is tuned twice to meet the requirements, pre-braze tuning and final tuning. The relative error of the operating quadrupole mode field is within ±2.7%, and the dipole mode component is within ±1.9% of the quadrupole mode. The final measured coupling coefficient of the RF power coupler equals 1.03, with the desired value of 1.04.

REFERENCES

[1] Q. Z. Xing et al., "Delopement Progress of the 7 MeV Linac Injector for the 200 MeV Synchrotron of Xi'an Proton Application Facility, in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, p. 426, doi:10.18429/JACoW -IPAC2017-TUPVA104

[2] L. M. Young, "An 8-meter-long coupled cavity RFQ linac", in Proc. 1994 International Linac Conference, Tsukuba, Japan, Aug 21-26, 1994, Paper MO52, pp. 178.

[3] M. Browman, G. Spalek, and T. Barts, "Studying the end regions of RFQs using the MAFIA codes", in Proc. 1988 Linac Conference, Virginia, USA, Oct. 3-7,1988, Paper MO3-11, pp. 64.

[4] Y. Lei et al., "Power-conditioning cavity design and measurement of the coaxial coupler for the injector of XIPAF project", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, p. 4218, doi:10.18429/JACoW -IPAC2017-THPIK055

[5] L. Du et al., "A fast tuning method for a RFQ accelerator with ramped inter-vane voltage", Nucl. Instrum. Methods Phys. Res., Sect. A 726, 91, 2013.