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Frequency and fields tuning of a heavy ion radio-frequency quadrupole accelerator

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A R T I C L E I N F O

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A B S T R A C T

A continuous wave heavy ion four-vane Radio Frequency Quadrupole accelerator (RFQ) is under construction for the LEAF project in the Institute of Modern Physics, Chinese Academy of Sciences. The operation frequency is 81.25 MHz and the inter-vane voltage is 70 kV. To separate the adjacent dipole frequency from the operation frequency, the π-mode stabilizing loops (PISLs) are utilized. After optimization, the RFQ cavity is equipped with 6 pairs of PISLs and the frequency separation reaches 5.54 MHz. With low power test and careful tuning, the cavity achieved the desired frequency and field. The relative error of the quadrupole field is less than 1% and the admixtures of the two dipole modes are within 1.5% of the quadrupole field. In this paper, the effects of the PISLs in the RFQ will be studied. Meanwhile, the low power test and tuning of the LEAF RFQ are presented.

1. Introduction

Since invented by I. M. Kapchinskii and V. A. Teplyakov in 1970 [1], the Radio Frequency Quadrupole (RFQ) accelerator always plays an extremely important role in proton and heavy ion acceleration. The Low Energy Accelerator Facility (LEAF) project, shown in Fig. 1, was launched as tools for irradiation material research, highly charged atomic physics and low energy nuclear astrophysics. As a part of the facility, an 81.25 MHz four-vane continuous wave (CW) heavy ion RFQ [2], shown in Fig. 2, has been developed. This RFQ with a constant inter-vane 70 kV voltage could accelerate the uranium beam from 14 keV/u to 500 keV/u within 5.97 m length. It is divided into six sections. The main parameters of the RFQ are listed in Table 1.

The frequency separation method is used to meet the desired parameters, such as frequency and field distribution in the RFQ. In addition, the low power test and tuning play an important role in modifying the parameters.

In this paper, the effects of the PISLs in the RFQ are analyzed. The low power test and tuning theories will be introduced. The followed is the process of the LEAF RFQ low power test and tuning.

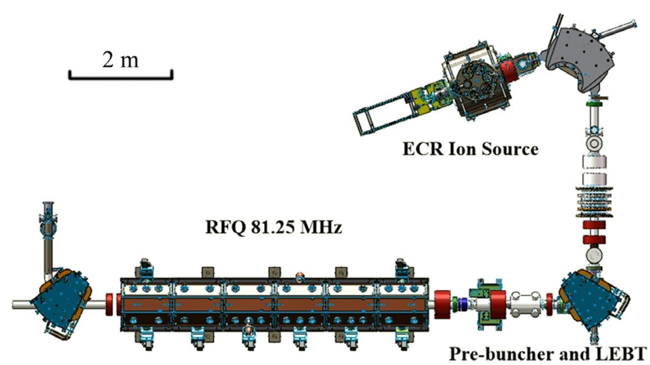

Fig. 1. The layout of the LEAF project.

2. Effects of the PISLs in the RFQ

In the conventional four-vane RFQ cavity, the lowest mode is the dipole mode (TE_{110} mode). The resonant frequency is slightly lower than the operation mode (TE_{210} mode) [3]. The transversal cross section sketches of the field are illustrated in Fig. 3 (TE_{210} mode) and Fig. 4 (TE_{110} mode). The field of the dipole mode will bend the beam and reduce the acceptance. The dipole field will be more easily mixed with the operation field when the resonant frequency of the dipole mode is closer to the operation frequency. Several methods were proposed to stabilize the operation mode against the dipole mode mixing, for

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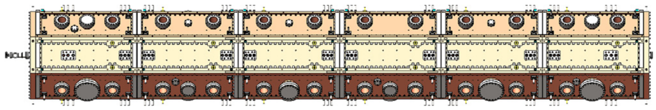

Fig. 2. The structure of the LEAF RFQ.

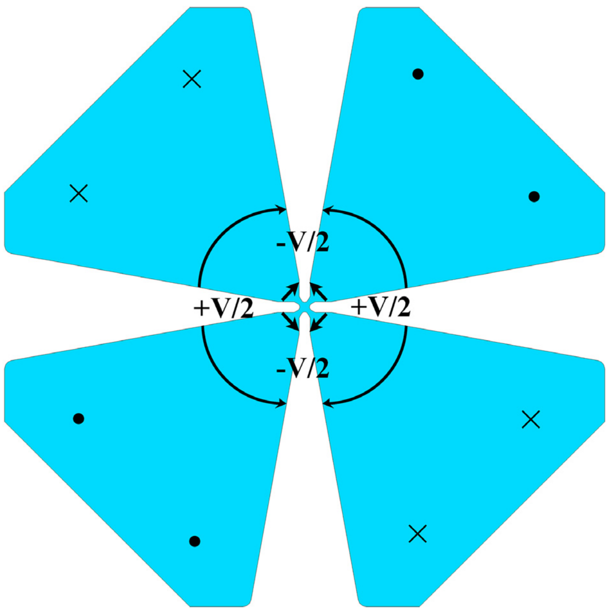

Fig. 3. The TE_{210} mode cross section with electric field line in the transverse plane and magnetic field in the longitudinal direction.

example, Vane Coupling Ring (VCR) [4], dipole stabilizer rod (DSR) [5] and π-mode stabilizing loop (PISL) [6], et al. The VCR could shift the dipole mode far away from the operation mode, but it is difficult to be cooled and fabricated. The DSR method is used in many RFQs, but it is generally used in the ramped-voltage RFQs and RFQs with coupling plates. Proposed by KEK, PISL has been utilized in many operating RFQs in the world for it could be easily fabricated and cooled, such as JHP RFQ [7], SNS RFQ [8], PXIE RFQ [9] and CADS injector II RFQ [10]. The LEAF RFQ is a constant-voltage and the length is within three times the wavelength, so it does not need coupling plates. Therefore, the LEAF RFQ also employed the PISLs to separate the frequencies.

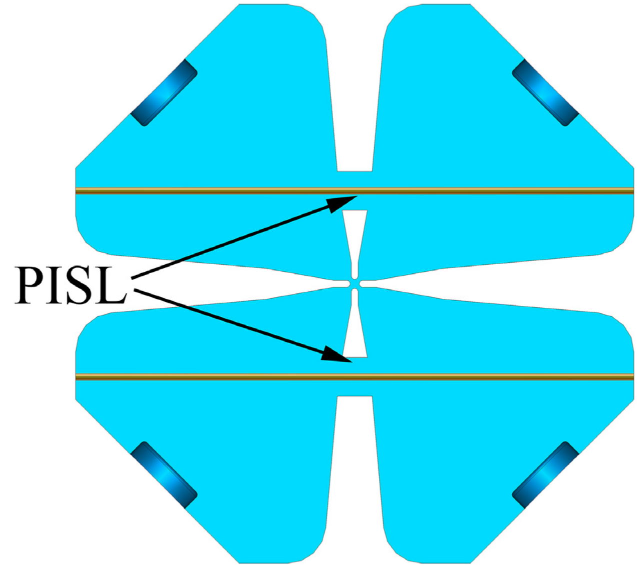

Fig. 5. The sketch map of the horizontal PISLs and the vertical PISLs could be obtained by rotating them by 90 degree.

As shown in Fig. 5, the concept of the PISLs is based on mode stabilization by magnetic coupling between two neighboring quadrants with closed loop. Magnetic field distributions of the TE_{210} and TE_{110} modes with and without PISLs are shown in Fig. 6. For the quadrupole mode, the magnetic flux will couple to the neighboring quadrants through the PISL holes and the resonant frequency will be lower than that in the cavity without PISLs. However, for the dipole mode, the magnetic flux will make a detour around the PISLs and the resonant frequency will be higher than that in the cavity without PISLs. In this way, the resonant frequencies of the quadrupole and dipole modes can be separated.

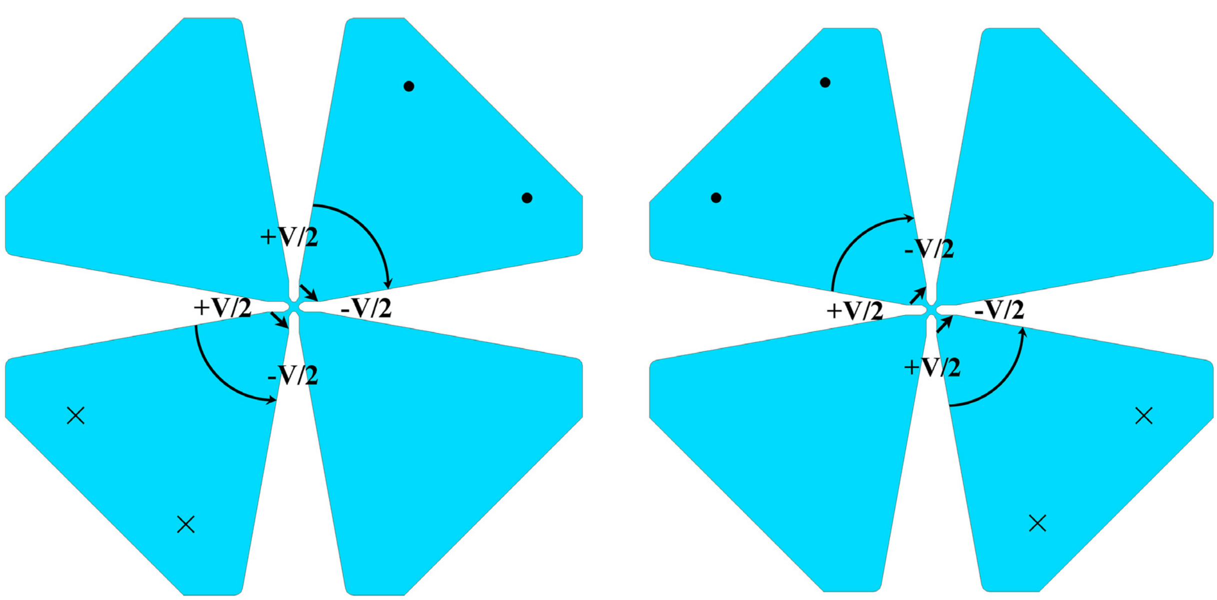

Fig. 4. The TE_{110} mode (the left is D_{13} and the right is D_{24}) cross section with electric field line in the transverse plane and magnetic field in the longitudinal direction.