DESIGN OF THE TUNING SYSTEM FOR THE HE^+ COUPLED RFQ-SFRFQ CAVITY*

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Abstract

The CRS (coupled RFQ-SFRFQ) cavity is a new type linac that couples traditional RFQ (radio frequency quadrupole) and SFRFQ (separated function RFQ) electrodes into a single cavity. The overall design of the CRS cavity has been completed and the linac is being manufactured currently. In this paper, we aimed to design a frequency tuning system for the CRS cavity, which will be used to explore the electromagnetic field distribution between RFQ and SFRFQ sections in the cavity. The frequency range, variation of Q value, power consumption and electric field distribution were investigated. Based on the beam dynamic program SFRFQDYNv1.0, we analysed the beam transmission properties of the cavity under the unbalanced electric field distribution. The optimized parameters of the tuning system were obtained.

INTRODUCTION

The radio frequency quadrupole (RFQ) is a suitable linear accelerator for high current beam and low energy beam acceleration [1, 2]. However, due to the restriction between the focusing and the accelerating in an RFQ accelerator, many post-accelerators have been developed all over the world, such as the RFI [3] and the hybrid RFQ accelerators [4]. For the same reason, the separated function radio frequency quadrupole (SFRFQ) structure, which combines the characteristics of RFQ and drift tube linac structure (DTL), was proposed by the RFQ group of the Institute of Heavy Ion Physics at Peking University [5], as well as the higher accelerating efficiency has been demonstrated by the prototype cavity [6, 7].

The CRS cavity is designed for material irradiation research in our lab. The linac is smartly shortened to 2.5 meters by replacing the accelerating section of the RFQ with the SFRFQ structure as shown in Figure 1. This cavity will be used to accelerate the He^+ from 7.5keV/u to 201.2keV/u with a current of 5mA. The feature of CRS cavity is that the structure coupled RFQ electrodes and SFRFQ electrodes into a single cavity, which obtains better accelerating efficiency and less cost of the linac comparing to the same length RFQ structure.

In the former work, the dynamic design of RFQ section and SFRFQ section was carried out by the program PARMTEQM and SFRFQDYN v1.0 [8, 9], and the structure of CRS cavity was simulated by Microwave Studio CST [10].

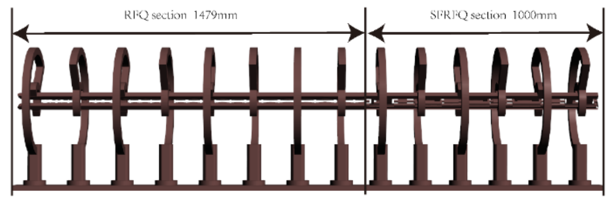

Figure 1: Inter structures of CRS cavity.

Because of the two different type structures in one resonant cavity, the rf properties, especially the unbalanced of the rf power distribution should be taken into consideration carefully. Firstly, the rf characteristics of the cavity was investigated based on rf structure simulations. Then a tuning system was designed for matching the designed frequency and balancing the rf power distribution between the RFQ section and the SFRFQ section. Secondly, the beam transmission property was analysed by using SFRFQDYN v1.0 code under the different inter-vane voltage of RFQ section and SFRFQ section.

INVESTIGATION OF RF CHARACTERISTICS OF THE CAVITY

The electromagnetic properties of the coupled cavity were simulated. The RFQ electrodes were modulated according to the vanes file derived from PARMTEQM. From the simulation results, firstly we made convergence analysis of the cavity, the variations of rf power & frequency and meth cells were plotted as shown in Figure 2. We can see that the frequency increases gradually with the mesh cells, and the trend of saturation shows a good convergence of the simulation. The rf power consumption is the calculation result scaled to the RFQ inter-vane voltage of 65kV. The Q factor variations satisfy the relation $Q = 2\pi f \cdot W / P$, where f is the frequency of cavity, W and P is the cavity stored energy and power consumption respectively.

The lower mesh cells are not enough to calculate the electric field distribution and result in inaccuracy of capacitance effect between electrodes. Based on the result, the CRS cavity should be calculated at least over 5 million mesh cells.

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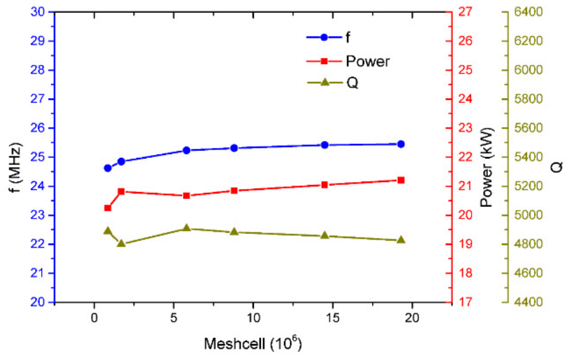

Figure 2: Simulated cavity rf properties via mesh.

To study the electromagnetic properties, the two structures in CRS cavity were analysed independently. The calculated cavity frequency is less than 26MHz (The practical cavity frequency is approximately 1% larger than simulated value according to the prototype cavity). The simulated rf power loss of the cavity is close to 20kW. The different shunt impedances show the RF efficiency of the RFQ is better than the SFRFQ, which results in a higher electrode voltage in RFQ section in the single CRS cavity. The main results are list in Table 1.

Table 1: Simulated Power Loss of RFQ and SFRFQ Section

CRS Cavity (25.48MHz)		
Structure (Mesh)	RFQ(10^7)	SFRFQ(10^7)
Length (m)	1.48	1.00
Power (kW/m)	6.42	7.13
Inter-vane Voltage (kV)	66.71	65
Shunt Impedance (kΩ·m)	691.98	592.10

The voltage difference from the designed value is caused by the unbalanced rf power distribution of the two type structures. To match the operating frequency and minimize the voltage difference, a tuning system was designed to satisfy the above requirements.

DESIGN OF THE TUNING SYSTEM

The CRS cavity contains two different structures in one cavity, the difference of capacitance and inductance features cause the unbalance of electric field distribution along the beam axis. Two independent tuning systems are designed and will be installed on the top of the supporting rings in the RFQ and the SFRFQ section as shown in Figure 3(a). Because of the cavity is a periodical structure, 4 rings (out of 14) are calculated to represent the tuning ability. The tuning plate size is given in Figure 3(b).

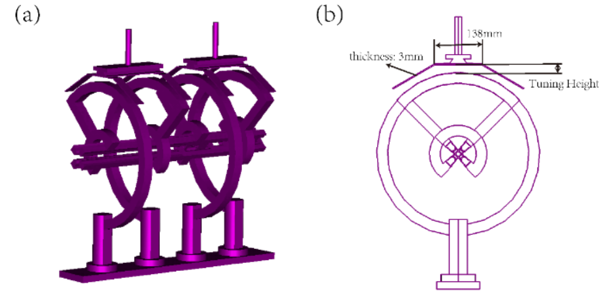

Figure 3: The tuning system in the CRS cavity.

Frequency Range

The tuning plates, which are driven by two stepping motors, bring the capacitance perturbation to the resonated cavity. To find out the tuning ability of the system, the short CRS cavity is simulated in the condition of the equal tuning height in both RFQ section and SFRFQ section. The frequency and Q factor are calculated with various tuning height, the results are plotted in Figure 4.

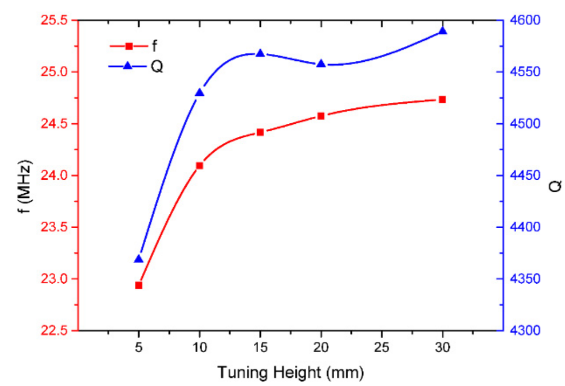

Figure 4: Frequency and Q as a function of tuning height.

Power Loss

The power loss of each section is investigated as shown in Figure 5 and Figure 6 respectively. According to Figure 5, the two sections show an approximate sensitivity when the tuning plates are driven identically in both sides, and the power loss per unit length of SFRFQ section is higher than that in the RFQ section. As the shunt impedance of RFQ structure is larger, the RFQ inter-vane voltage is higher. To minimize the difference of the inter-vane voltages between the two sections, the power loss in RFQ section should be decreased. In Figure 6, the SFRFQ side tuning plates are fixed in 30mm height, and the variation of RFQ tuning height shows an effect of balancing the energy distribution of the two sides, and when the RFQ tuning height is below 10mm, the inter-vane voltage difference is confined to 0.3%.

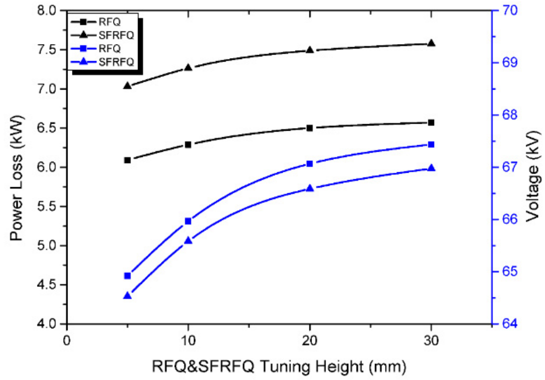

Figure 5: Power loss and inter-vane voltage as a function of RFQ&SFRFQ tuning height.

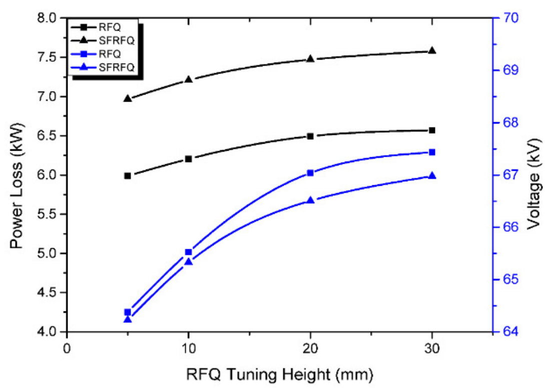

Figure 6: Power loss and inter-vane voltage as a function of RFQ tuning height.

BEAM TRANSMISSION ANALYSES UNDER UNBALANCED ENERGY DISTRIBUTION

The synchronous phase is affected by the fluctuation of the inter-vane voltage, as well as the energy gain and TWISS parameters of the beam will be changed. In this part, the beam transmission property under the different inter-vane voltage variations of the two sections is analysed by the dynamic programs SFRFQDYNv1.0. The dynamic simulation is under the condition that the inter-vane voltage of RFQ section is fixed in the designed value 65kV and the SFRFQ section is calculated in the various values in the range of ±10% of the designed value. The simulation result is shown in Figure 7.

The results show a good beam transmission in the condition of 10% inter-vane voltage change in SFRFQ section. However, in this case the energy spectrum will change, thus the tuning system is a necessary part to deal with the problems.

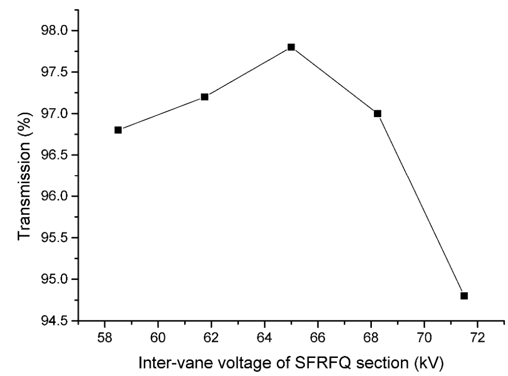

Figure 7: Transmission as a function of SFRFQ inter-vane voltage.

SUMMARIES AND FUTURE PLAN

The properties of the CRS cavity are investigated in this paper. The power loss and frequency variation with mesh cells is presented, the shunt impedance of the two sections in CRS cavity is obtained as well. The simulation results of tuning system, designed for matching the operating frequency and minimizing the difference of inter-vane voltages between RFQ and SFRFQ section, presents a good tuning ability in adjusting electric field distributions. In the final part, the beam transmission property under unbalanced energy distribution is analysed by SFRFQDYNv1.0 code.

The CRS cavity is under manufacturing and will finish assembling in this May. The following work in this year will be firstly the cold test of the cavity, and then processing the high RF power experiment, after finishing the ECR ion source energy modulating experiment, the He^+ acceleration experiment will be finally implemented.

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