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STUDY OF THE ENERGY MODULATED ELECTRON CYCLOTRON RESONANCE ION SOURCE FOR THE COUPLED RFQ-SFRFQ CAVITY

W. L. Xia, Z. Wang*, Y. R. Lu, K. Zhu, S. L. Gao, J. Zhao, S. X. Peng, J. Zhao, X. Q. Yan, Z. Y. Guo, J. E. Chen
State Key Lab of Nuclear Physics and Technology, Peking University, Beijing, China

Abstract

The coupled RFQ and SFRFQ cavity has been manufactured and tested recently. According to the beam dynamic design, the input He^+ beam within 120° phase width is designed for the cavity to achieve over 98% transmission efficiency. An energy modulated electron cyclotron resonance (ECR) ion source was proposed and simulated. To achieve the 1% energy modulation on the 30keV direct current (DC) beam, two simplified RF power feeding structures for beam bunching were studied. The simulations show positive results as well as the bunched beam is achieved by the energy modulated ECR ion source.

INTRODUCTION

We have developed a novel structure to build a more compact linac with higher energy gain by replacing the accelerating region of the radio frequency quadrupole (RFQ) with the separated function radio frequency quadrupole (SFRFQ) [1-3]. This coupled RFQ SFRFQ (CRS) linac can accelerate 5mA He^+ ion beam from 7.5keV/u to 201.2keV/u in 2.5m cavity. Figure 1 shows the schematic drawing of the CRS linac. The commissioning of helium injector including electron cyclotron resonance (ECR) ion source and low energy beam transport (LEBT) has completed [4] and the input beam was optimized for satisfying the requirements of CRS cavity [5].

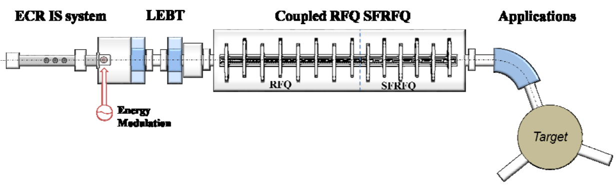

Figure 1: Schematic layout of CRS accelerator complex.

In CRS linac, the main accelerating SFRFQ region requires a well-bunched beam from the RFQ section. Comparing to the beam bunching internally inside RFQ, beam external bunching before RFQ can significantly shorten the RFQ region because the external bunching eliminates the pre-bunch section. Thus, the CRS cavity was designed for the longitudinal micro pulsed input beam with 120-degree phase width. The input beam parameters are listed in Table 1.

Table 1: Input Beam Parameters of the Cavity

Ion	He^+
Current (mA)	>5
Energy (keV)	30
Duty Factor	1/6-cw
Input beam phase width (degree)	120
Emittance (unorm,rms,x,y)(mm mrad)	37.3
Emittance (norm,rms,x,y)(mm mrad)	0.14
α	1.45
β (cm/rad)	7.7

DYNAMIC ANALYSES

For achieving the well bunched beam, a harmonic buncher is usually be used in the low energy beam transport region. However, this would require more space in the upstream beam line and raise the cost. In our former work, the energy modulated ECR ion source was proposed for generating energy modulation on the helium beam, thus we can get micro-pulsed beam with less than 120 degree phase width at the entrance of the CRS cavity [6].

Based on LMOVE code, the beam dynamic of a single gap buncher was analysed for the simulation of the energy modulation on ECR ion source. As shown in figure 2, the energy modulation range corresponding to the longitudinal phase width below 120 degree at entrance of CRS is from 0.7% to 3.0%, among which the 1.4% energy modulation indicates the minimal phase width 7.16 degree (0.78 nanosecond) and the corresponding focal length is equal to the length of LEBT section.

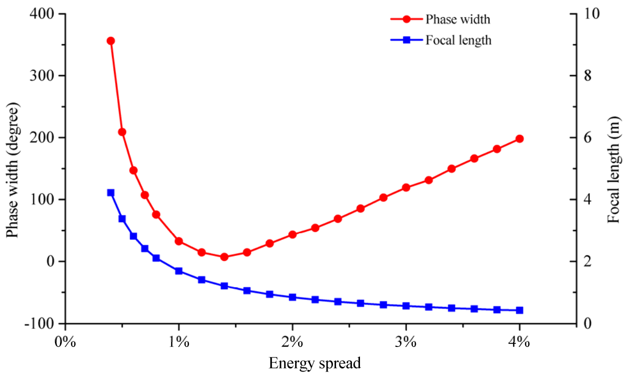

Figure 2: Longitudinal phase width at the entrance of crs and corresponding focal length as a function of energy

spread of helium beam (original energy spread 0.1%, modulation frequency 25.5MHz, drift length 1.16m).

THE METHODS FOR EXTERNAL BUNCHING

The key problem is to apply 25.5MHz sinusoidal voltage on the extracting electrode of the ion source. There are two methods to achieve the beam energy modulation effect at the exit of the LEBT section. One is to apply the signal directly to the ion source body, where is under the high voltage at maximal 30 kV. The other is to apply the signal on the extraction electrode, which is separated from the ground potential by a Teflon ring, and use the RF electric field generated on the extraction electrode to achieve single gap bunching on the dc beam. In the first method, although there are some protections in the circuit including a capacitor for blocking the high voltage to the RF power source and an inductor for blocking the RF signal to the HV generator, it still cannot maintain the safety and stability of the devices exposed to the 30kV high voltage. Instead, the second method can achieve the same effect to the dc beam, and it smartly avoids the unsafe factor from HV condition. Figure 3 presents the principle schematic of the second method.

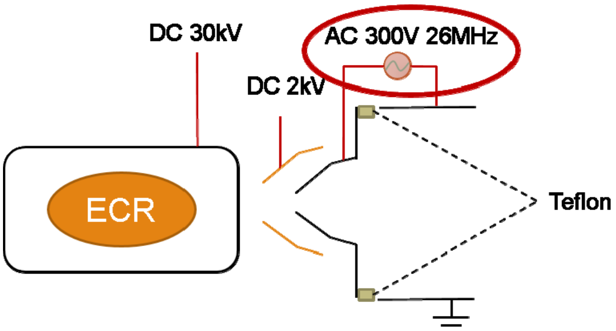

Figure 3: Principle of energy modulated ECR ion source.

Structure Design

We have proposed two kinds of RF structures shown in figure 4 including inner coupling and outer coupling to generate 25.5MHz sinusoidal signal on the extraction electrode of ion source. The coupling rings of the both structures were designed as quarter wavelength line. The inner coupling design uses the flat spiral line, however, the unsteady ring makes it harder for the handling of the structure. The outer coupling design can be considered as a room temperature quarter wavelength resonator (QWR), it is easier to implement for either manufacturing or power feeding. To increase the coupling efficiency the electromagnetic shield was added for the outer coupling method.

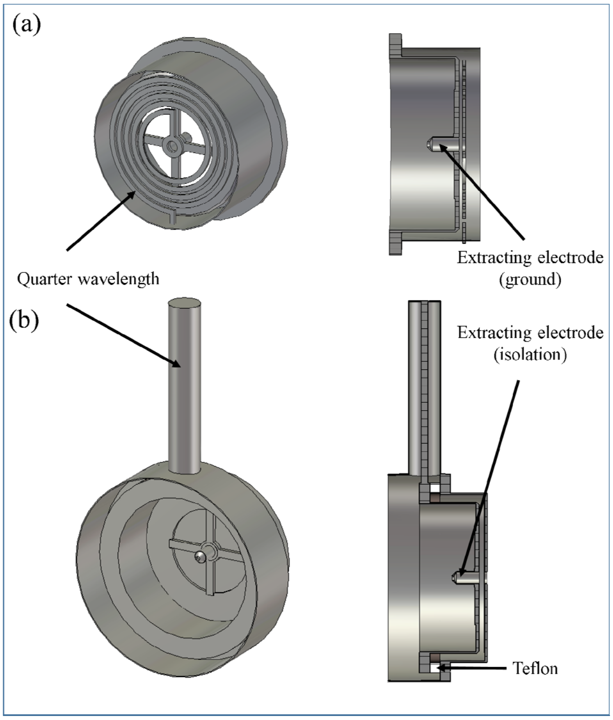

Figure 4: (a) inner coupling structure, the extracting electrode connects to the ground; (b) outer coupling structure, the extracting electrode is isolated.

RF Simulation

The two structures were simulated by MWS CST [7]. The simulation results were presented in Table 2, the both Eigen modes were close to the designed resonant frequency. The inner coupling method appears higher inductance than outer coupling method, thus higher Q factor is acquired in outer coupling structure.

As shown in figure 4 and figure 5, both structures use the gap for energy modulation, which can form the required electric field effectively due to the high transit time factor.

Figure 6 presents the comparison of axial electric field distribution between inner coupling and outer coupling methods with the same power consumption. The outer coupling method can achieve higher electric field.

Table 2: Comparison of RF Features between the Two Structures

	Inner coupling	Outer coupling
Frequency (MHz)	26.09	25.90
Conductivity (S/m)	5.0×10^7	5.0×10^7
Q factor	189.1	2026.2

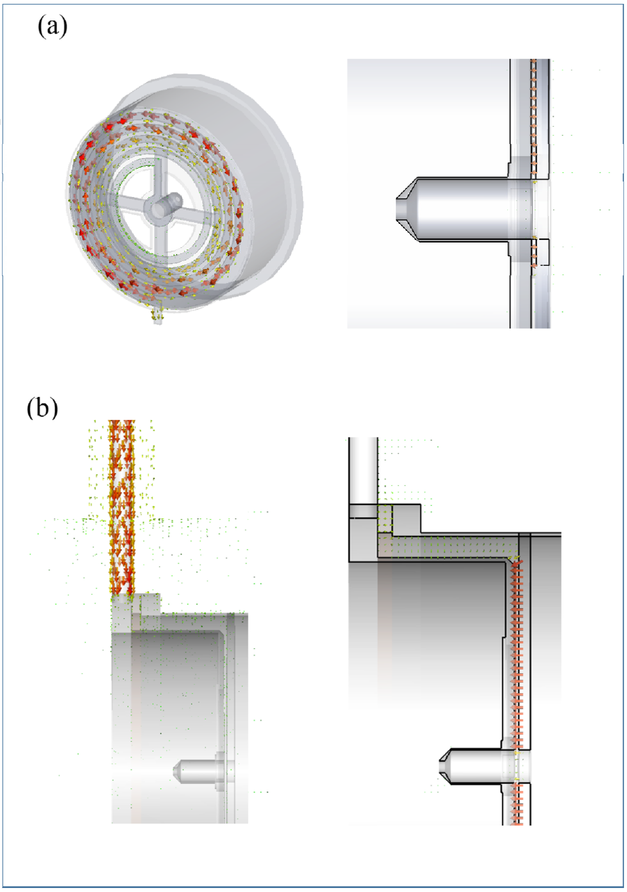

Figure 5: (a) The current and electric field distribution of inner coupling method (b) The current and electric field distribution of outer coupling method.

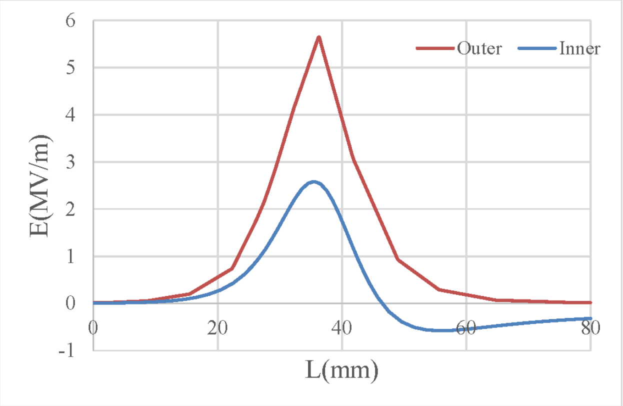

Figure 6: Comparison of axial electric field distribution between inner coupling and outer coupling methods.

SUMMARIES AND FUTURE PLAN

The input beam parameters of the CRS cavity were presented in this paper. The beam dynamic analyses of the input beam indicates the range of the energy modulation of the ECR ion source. Two methods for generating RF electric field on the DC beam were discussed. The RF simulation results show the structures could be resonant at the operating frequency as well as the required electric field were achieved.

The RF power feeding and beam measurement system were set up for the energy modulation experiments. The primary experiment of the outer coupling method shows that the RF signal has overlapped the ground potential and affected the beam measurement. RF shield will be considered in the next step. It should be notified that the high RF power may affect the operation of ECR ion source. Thus, for restraining power consumption the RF structure with high Q factor will be studied.

REFERENCES

[1] J. E. Chen et al., Prog. Nat. Sci. 12, 22 (2002).
[2] Z. Wang et al., Nucl. Instrum. Methods Phys. Res., Sect. A 607: 522-526(2009).
[3] M. L. Kang et al, Nucl. Instrum. Methods Phys. Res., Sect. A 640:38-43(2011).
[4] S.X. PENG et al., Rev. Sci. Instrum 85, 02A712 (2014)
[5] W.L. Xia et al., Nucl. Instrum. Methods Phys. Res., Sect. A 756: 55–61(2014).
[6] Z. Wang et al., Phys. Rev. ST Accel. Beams, vol. 15, p. 050101, 2012.
[7] http://www.cst.com