DESIGN STUDY OF RFQ LINAC FOR LASER ION SOURCE

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Abstract

In order to accept intense pulsed beams from laser ion source, two types of beam injection systems to RFQ linac are proposed. One is to use low energy beam transport, which consists of pulsed electric quadrupoles and a solenoid magnet. Another system is not to use ordinary transport system. The target of the laser source would be placed just entrance of the RFQ linac. These two concepts are discussed. Also, a valuable frequency RFQ resonator is investigated.

1 INTRODUCTION

For MUSES[1,2] project at RIKEN, we began to study RFQ linac to accept beams from laser ion source[3]. Generally, this type of pulsed ion source can provide high intensity heavy ion beams with high charge state and is well suit for injections to synchrotron. However, the beams from the laser ion source have wide energy spread, strong space charge effect, and time variation of current, which consists of various kinds of charge states. Also, beam profile changes dynamically. In order to accept the pulsed intense beams from the laser ion source, a special attention should be paid to design the matching section to the RFQ.

2 INJECTION METHODS FOR RFQ

A test stand of the laser ion source, was just fabricated and first current was obtained. We have 8 J, TEA CO_2 laser with 100ns pulse duration. The irradiated power density is estimated as 10^{11} W/cm^2. Using aluminum target, the divergence of expanding ablation plasma is less than 20 degrees. The TOF measurement indicated extracted aluminum ions has 138 eV/u. The obtained peak current was 0.4 mA at 3.2 m away from the target with collimator which has 10 mm aperture. However, the detailed properties, charge states of the ions and its ratio, beam emittance and momentum distributions are not available yet. In this section, only simple concept will be showed.

2.1 LEBT with Electric Lenses

As mentioned above, the beams from the laser ion source have time variation of current and beam profile. To accept all the desired particles, a special RFQ, which has very large acceptance, can be made. However, in our case, the RFQ has to have reasonably small extraction emittance to provide beams to the existing and being constructed accelerator complex. Therefore the beam acceptance should be reasonable size. To eliminate this problem, we are designing a LEBT with electric quadrupole lenses, which would be controlled by pulsed power supplies. The pulse duration of the beam is from 10 to 30 μ s and the electric lenses can be driven and controlled within this time period. In our current design, the ion source will be on the 100 kV stage. The LEBT has single bending devise, three sets of doublets and solenoid magnet for final focusing to the RFQ. The two doublet will be before the bending and another will be after the bending.

2.2 Direct Injection to the RFQ

The beam emittance from the laser source is determined by emittance growth due to strong space charge effect. If we assume only expanding shape of plasma, 0.3 mm radius of the laser spot on the target and 20 degrees of divergence, the normalized beam emittance of ions in the plasma will be about 0.057 π mm mrad. In order to reduce space charge effect at the initial beam from the source, direct injection method has been proposed. A schematic view of the direct injection system is drawn at Fig.1. The laser target is located just entrance of the RFQ, and the ablation plasma goes directly into RFQ channel. At the fringe field of RFQ, the electrons in the plasma will be deflected and only the ion beams will be trapped by RFQ focusing force. Fig. 2 shows the results of a simple tracking at the entrance of the RFQ field. The assumed initial beam has 138 eV/u, 50 ns of beam length and 0.4 mm of the radius. The mass number is 27, aluminum, and the charge states are 2+, 3+ and 4+. Each charge state is represented by 1000 particles and also 9000 particles of electrons which corresponds to total plus charge of the ions, are considered.

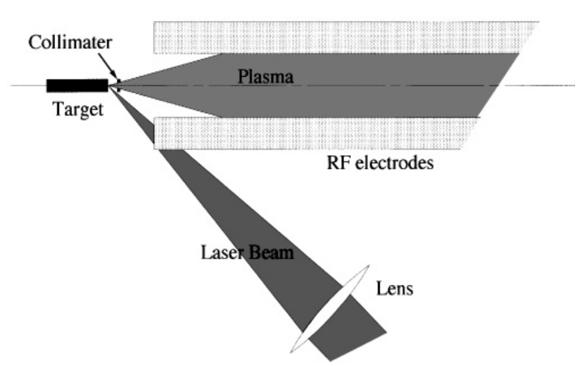

Figure 1: Schematic view of the direct injection.

The total ion beam current is set to 50 mA. The energy spread of ions was generated uniformly to x, y and z direction. The width of the spread on each directions is also 138 V/u which is as same as beam energy at gravity center. On this condition, initial beam divergence is about 14.5 degrees. The electrons contained by initial beam have same velocity distribution of ions. The RFQ field starts 10 mm away from the target and rises linearly within length of 5 mm. The field strength is set to 100 kV at 10mm radius. The frequency of RF is 20 MHz. Figure 2a, b and c show the trajectory of Al 2+, 3+ and 4+ ions respectively. The highly charged state ions have large divergence due to stronger space charge effect. If the RFQ has more than 25 mm radius of aperture, the almost of all ions would be trapped by the RFQ field. Figure 2d shows the trajectory of electrons. Before the RF field starts, electrons are captured by the potential of the ion beams. However passing through the fringe of the field, more than 95% of electrons are deflected by the field and cannot go into the channel. In this calculation, the vane modulation is not taken into account.

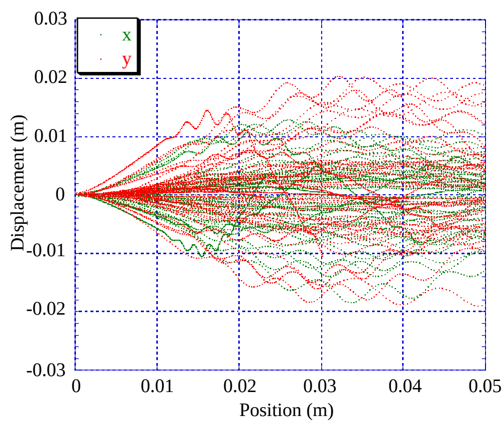

Figure 2a Trajectories of Al^{2+}

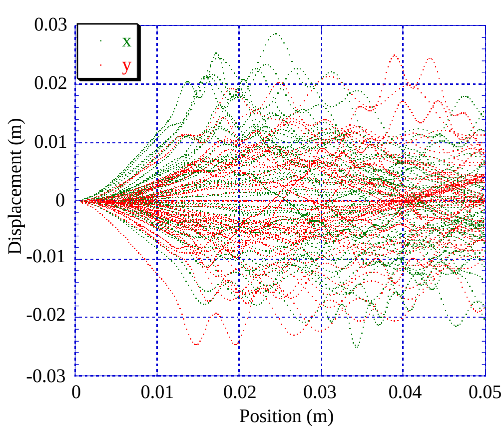

Figure 2a Trajectories of Al^{3+}

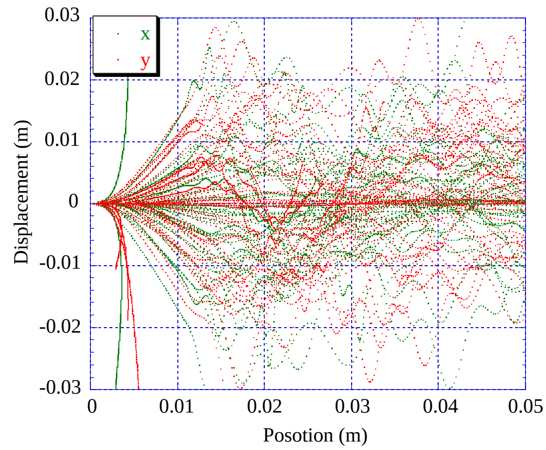

Figure 2c Trajectories of Al^{4+}

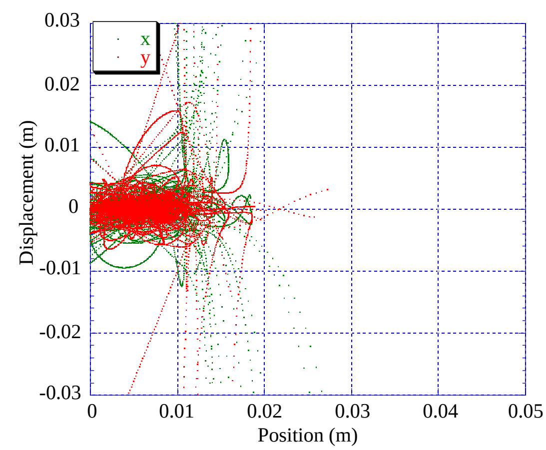

Figure 2d Trajectories of electrons

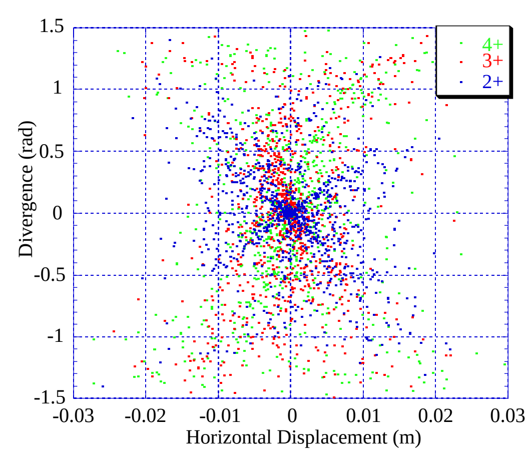

Figure 3 Phase plots of the ions (0.5 m from the target)

Figure 3 shows phase plot of the ions at 0.5 m away from the target. We are planning to build a test RFQ to investigate this injection method. The most severe expected problem, we expected, is discharge between the vanes. A small collimator will be placed just after the target to prevent exceeded ions causing secondary emissions of electrons from vanes. Therefore a collimator with small aperture can be used. In this calculation, only 50 mA of beam current was assumed. We believe that much more particles are generated and can be injected to the RFQ. We are planning to built an RFQ with non-modulation vanes to examine this method.

3 RFQ CAVITY

To design vane parameters, we have to obtain more detailed information about the initial beam from the laser source. Then only resonator design is discussed here.

For MUSES project, the RFQ cavity has to be frequency valuable type, which resonates from 18 MHz to 38 MHz. In order to achieve such a low frequency with wide range, a new resonator, which has TE_{110} mode, was proposed.

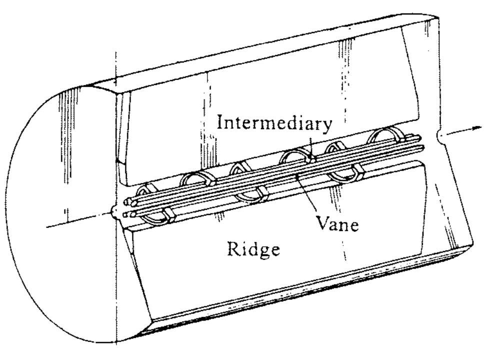

Figure 4 Scheme of the RFQ operated with the TE_{110} mode. (frequency fixed model)

Figure 2 shows the scheme of the new resonant structure operated with the TE_{110} mode of which fundamental idea is based on one of the author's patents [4,5]. This cavity is mainly composed of four vanes, two ridges and many intermediaries. One pair of opposite vanes is connected to the upper ridge by the one group of intermediaries and another is to lower ridges similarly. When the TE_{110} mode is excited, the voltages of the opposite vanes always become same. Thus, if there is no dimensional error in the distance between the adjacent vanes, a uniform quadrupole field is obtained along the beam axis. Comparing with 4-vane structure operated with the TE_{210} mode, this structure has two features. The first one is that the frequency of the TE_{110} mode never corresponds to the other mode, because the frequency is the lowest in all modes. We have been released from a problem of the mode mixing. The second is that a higher Q-value is expected because of shorter current path. This structure was modified to be a valuable frequency type. Figure 3 shows half cross sections of the valuable frequency model at the two axial positions, which were used in a simulation with MAFIA.

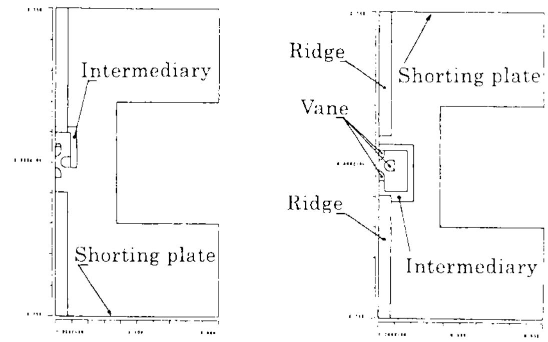

Figure 5 Half cross sections

The full cross section are square shapes of 1.6 m in width and 1.5 m in height. Movable shorting plates will be put at the upper and lower boundaries in an actual cavity to adjust the frequency. The design parameters of the field analysis of the cavity are summarized in Table 1.

Table 1 Design parameters of the RFQ

Vane length (m)	5.0	
Bore radius (mm)	26.79	
Resonance frequency (MHz)	35.4	17.4
Quality factor	8700	18000
Inter-vane voltage (kV)	260	260
RF Power (kW)	721	174
Height of the cavity (m)	0.7	1.5
Width of the cavity (m)	1.6	1.6

5 CONCLUSION

In order to capture the intense ion beams from the laser ion source, the new LEBT system and the direct injection method are being studied. The test RFQ will be fabricated to examine the direct injection method using the new cavity structure with TE110 mode.

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[5] K. Sawada,"Linear Accelerator Operable in TE11n Mode", E.P. Patent No 514 832, May. 19 (1992).