DESIGN STUDY ON AN INJECTOR RFQ FOR HEAVY ION ACCELERATOR FACILITY *

Wei Ma a, b, Liang Lu a,†, Zhouli Zhang a, Xianbo Xu a, Yuan He a, Hongwei Zhao a
a Institute of Modern Physics, 509 Nanchang Road, Lanzhou 730000, China
b University of Chinese Academy of Sciences, Beijing 10049, China

Abstract
A Low Energy Accelerator Facility (LEAF) was launched as a pre-research facility for High Intensity heavy ion Accelerator Facility (HIAF). The LEAF consists of a 2 mA U^{34+} electron cyclotron resonance (ECR) type ion source with 300 kV extraction voltage, a low energy beam transport (LEBT) line with a multi-harmonic buncher (MHB), a CW 81.25 MHz radio frequency quadrupole (RFQ) accelerator which could accelerate heavy ions from 14 keV/u up to 500 keV/u, a triplet magnet for medium energy beam transport and an experimental platform for nuclear physics. After describing the selected structure, an octagonal cavity with π-mode stabilizing loop (PISL) type structure was adopted and simulated. In this paper, the detailed electromagnetic design and thermal simulation of the LEAF-RFQ will be reported.

INTRODUCTION
LEAF was proposed as a pre-injector research and commissioning study for HIAF [1,2], and the structure of the LEAF-RFQ will be totally adopted and used for the HIAF. The layout of LEAF project is shown in Fig. 1, the RFQ is concerned in this paper. The LEAF-RFQ will be operated as a CW injector with a capability of accelerating all species ions from proton to uranium up to 500 keV/u from 14 keV/u, and the operating frequency is 81.25 MHz which is not a high value comparing with other operating RFQs like SNS-RFQ [3] and TRASCO-RFQ [4].

PARAMETERS AND STRUCTURE
According to the requirements of HIAF project and results of beam-dynamics analysis, the parameters of LEAF-RFQ are listed in Table 1.

Table 1: Main Parameters of LEAF - RFQ

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle charge state</td>
<td>U^{34+}  (q/A=1/7)</td>
</tr>
<tr>
<td>Operation</td>
<td>CW/pulsed</td>
</tr>
<tr>
<td>Vane type</td>
<td>Four vane</td>
</tr>
<tr>
<td>Frequency (MHz)</td>
<td>81.25</td>
</tr>
<tr>
<td>Input energy (keV/u)</td>
<td>14</td>
</tr>
<tr>
<td>Output energy (MeV/u)</td>
<td>0.5</td>
</tr>
<tr>
<td>Inter-vane voltage (kV)</td>
<td>70</td>
</tr>
<tr>
<td>Kp factor</td>
<td>1.55</td>
</tr>
<tr>
<td>Peak current (emA)</td>
<td>2</td>
</tr>
<tr>
<td>Transmission efficiency</td>
<td>97.2</td>
</tr>
<tr>
<td>Length of vane (mm)</td>
<td>5946.912</td>
</tr>
<tr>
<td>Average radius of aperture (mm)</td>
<td>5.805</td>
</tr>
</tbody>
</table>

Octagon four-vane structure is employed in LEAF-RFQ for its strong deformation resistance and which is much more suitable for continuous waves (CW) operation compared with four-rod structure. The LEAF-RFQ cross-section has been optimized with the use of MWS. As a result, the cross-section geometry is shown in Fig. 2.

The LEAF-RFQ cross-section profile is defined with 9 independent variables as shown in Fig. 2. Their final optimized values are listed in the Table 2. However, in all subsequent 3D simulations these cross-section parameters are kept constant except H.

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† email: luliang@impcas.ac.cn.
ELECTROMAGNETIC SIMULATIONS

LEAF-RFQ models were studied using the CST MWS. The mode frequencies and RF fields were calculated by the tetrahedral eigensolver which provides more accurate surface approximations. Two models of LEAF-RFQ were studied: one is PISL period of LEAF-RFQ and the other is complete model of LEAF-RFQ. Effects of tuners and PISLs are studied with PISL period of RFQ. As is shown in Fig. 3, PISL period of RFQ includes two pairs of PISLs and eight tuners.

To separate unwanted dipole modes from the quadrupole mode, the PISLs are employed. After optimization, the PISLs have 10mm outer diameter and pass through 50mm holes in the vanes. Meanwhile, PISLs have a 120mm distance from center of beam and are uniformly distributed along axial direction. With simulations, the RF parameters are shown in Table 3, which includes a comparison between period structure with PISLs and without PISLs. From the simulation result, a 5.575MHz separation is obtained with the period structure with PISLs, which is much greater than cavity without PISLs.

For frequency and field distribution tuning, the RFQ will be equipped with 48 slug tuners, which have 100mm diameter and are uniformly distributed along axial direction. With linear fitting shown in Fig. 4, tuning sensitivity of tuners is obtained, which equals 15.21 kHz/mm.
The sketch map of complete RFQ model is shown in Fig. 7. LEAF-RFQ includes 48 slug tuners and 12 pairs of PISLs. What’s more, the length of vane is 5946.92mm and that of cavity is 5968.92mm. Through simulations with MWS, the final RF parameters are given in Table 5.

From the result, the power loss of the whole cavity is 56.56 kW. The simulated losses assume that the conducting surface and contacts between RFQ parts are perfect. Real power losses are expected to be higher up to 20% [10]. Combined the beam power, 100 kW is enough for LEAF-RFQ. Meanwhile the power losses for separate parts of the RFQ are summarized in Table 6.

The temperature frequency sensitivities for vane and wall are also simulated, which are shown in Fig. 9(a) and Fig. 9(b) respectively. From the linear fitting results, the temperature frequency sensitivities for vane and wall are comparable but of opposite signs, they are -14.5 kHz/°C for vane and +12.7 kHz/°C for the wall respectively.

CONCLUSIONS AND PLANS

LEAF-RFQ have been designed and simulated. Electromagnetic design was performed. The RFQ is an octagon four-vane type with 48 tuners and 12 pairs PISLs. It is about 6 m with good mode separation and flat field. In addition, the thermal simulation has been taken out and the temperature frequency sensitivities have been obtained. A complete model of LEAF-RFQ has been built and simulated successfully.

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