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

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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].

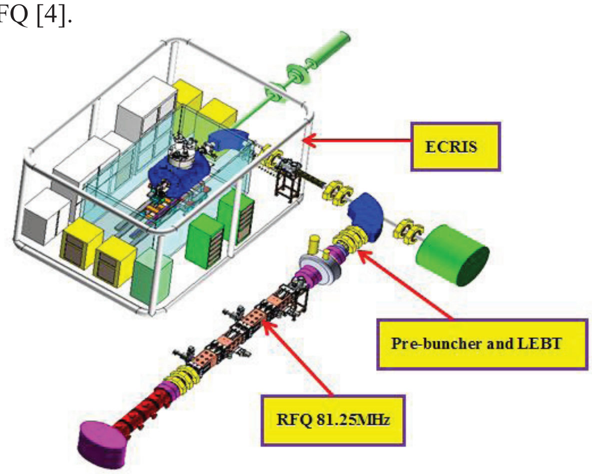

Figure 1: Layout of LEAF project.

The design goal is to design a compact type cavity which is fed lower power loss and operates stably. Considering that LEAF-RFQ will operate with CW mode, 4-vane structure is a better choice than 4-rod type [5]. Moreover, PISLs are employed for a good frequency separation and tuners are also used for the sake of frequency tuning and field flatness [6]. Meanwhile, cutbacks are very important for field flatness in RFQ [7].

In this paper we focus on the electromagnetic design and report detailed RF simulations using CST microwave studio (MWS) [8]. All details of the resonator such as PISLs, tuners, cut-backs and so on have been taken into account. Additionally, taking advantage of powerful computer, a complete RFQ model with modulation was been built and simulated. Besides the result of RF simulation, the thermal simulations of RFQ are given through ANSYS program [9].

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

Parameters	Value
Particle charge state	U34+ (q/A=1/7)
Operation	CW/pulsed
Vane type	Four vane
Frequency (MHz)	81.25
Input energy (keV/u)	14
Output energy (MeV/u)	0.5
Inter-vane voltage (kV)	70
Kp factor	1.55
Peak current (emA)	2
Transmission efficiency (%)	97.2
Length of vane (mm)	5946.912
Average radius of aperture (mm)	5.805

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.

* Work supported by NNSF and CAS
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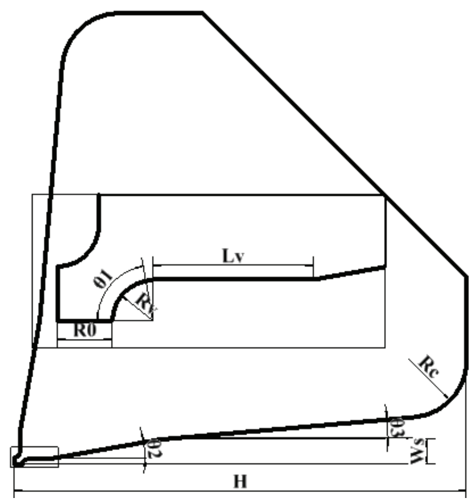

Figure 2: Cross-section geometry of LEAF-RFQ.

Table 2: Cross-Section Parameters of LEAF-RFQ

parameter	value	parameter	value
R0	5.805mm	Ws	20mm
Rv	4.354mm	θ3	5°
θ1	80°	Ws	20
Lv	17mm	H	360.5mm
θ2	10°		

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.

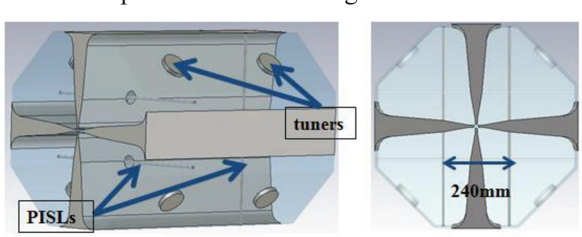

Figure 3: PISL period of LEAF-RFQ.

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.

Table 3: Frequency Separation Comparison

Parameters	Without PISLs	With PISLs
Frequency(MHz)	81.233	81.173
Nearest dipole mode frequency(MHz)	78.765	86.748
Q-D separation(MHz)	-2.468	5.575

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.

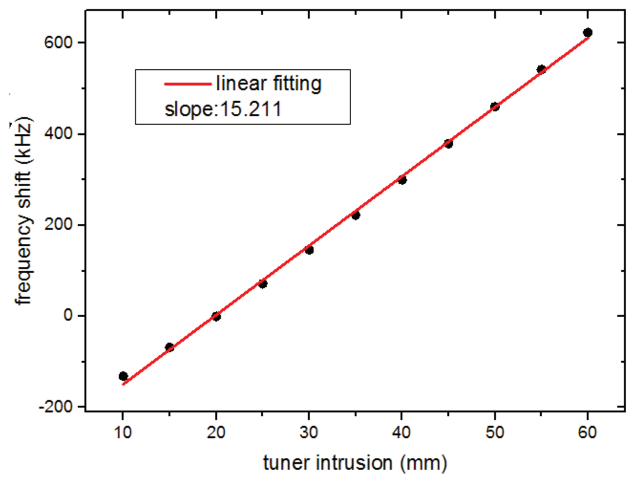

Figure 4: Tuning sensitivity for all tuners.

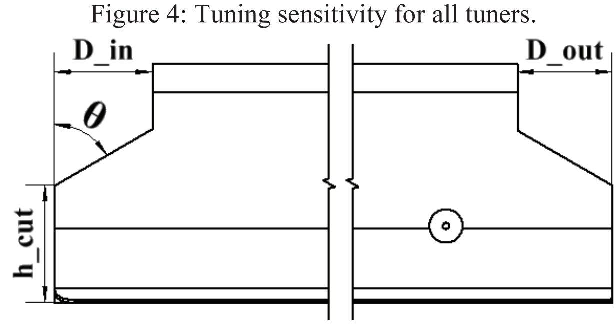

Figure 5: The sketch map of cut-backs.

Table 4: Tuned Cut-Backs Parameters

h_cut	θ	D_in	D_out
180mm	60°	143mm	139mm

Field flatness is always one of the most important tasks for RFQ design and tuning, which is very sensitive to the dimensions of cut-backs. With the improvement of powerful computers, full length RFQ model can be used to tune the cut-backs. The sketch map of cut-backs is shown in Fig. 5. For tuning the depths of cut-backs are the most influential parameters. Electric field amplitude distribution is monitored along line in the gap between vane tips. When tuned cut-backs parameters are shown in Table 4, there is a flat field distribution as shown in Fig. 6. Here is the depth of cut-backs: D_in equals 143mm and D_out equals 139mm.

ISBN 978-3-95450-147-2

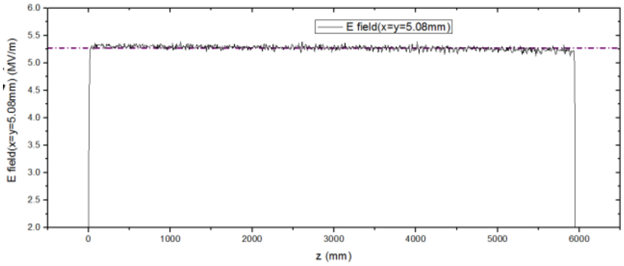

Figure 6: Electric field amplitude distribution along line in the gap between vane tips.

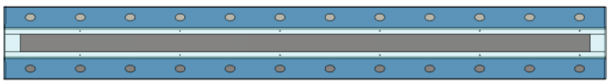
Figure 7: The sketch map of complete RFQ model.

Table 5: Final RF Parameters

frequency（MHz）	81.247
Q factor	17963
Power loss（kW）	54.433

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.

Table 6: Power Losses for Separate Parts of LEAF-RFQ

Part	%	Power loss	Unit loss
Vane	54.0	29.394 kW	4.943 kW/m
Tuners	3.85	2.096 kW	43.7 W
PISLs	6.48	3.527 kW	147 W
Wall	35.7	19.433 kW	3.268 kW/m

THERMAL SIMULATION

Thermal analysis was done with the ANSYS program to study the cavity cooling issues and to know about how to tune the cavity by adjustment of cooling water temperature. As shown in Fig. 8, due to the symmetry in the structure, only a quarter of RFQ needs to be simulated. There are totally 20 water-cooling channels distributed on the cross section of the RFQ and 1 water-cooling channel per PISL. In Fig 8, the temperature map of RFQ is given by program ANSYS. From the result, the difference in temperature in the RFQ is less than 2.4 ℃.

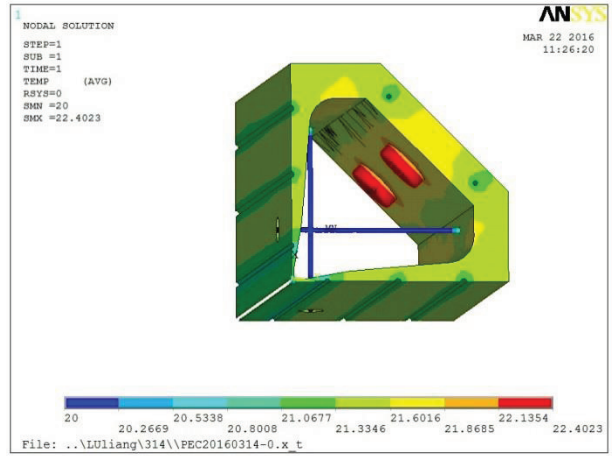

Figure 8: Temperature map of LEAF-RFQ.

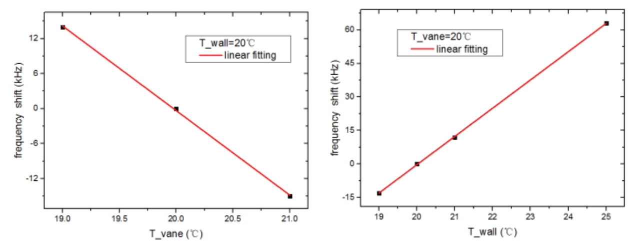

Figure 9: Temperature frequency sensitivities for vane (left-9(a)) and for wall (right-9(b)).

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/ ℃ for vane and +12.7 kHz/ ℃ 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.

The cavity design of LEAF-RFQ has been completed. The machining is underway currently. After manufactured, the commissioning and conditioning will be carried out.

ACKNOWLEDGEMENT

The author would like to thank Dr. Liang Lu and Dr. Zhouli Zhang for fruitful discussions and comments on the simulations of LEAF-RFQ, thank Mr. Xianbo Xu for help on thermal simulations. This work was supported by National Nature Science Foundation of China under Grant No. 11427904.

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ISBN 978-3-95450-147-2