Design and Simulation of a High Intensity Heavy Ion RFQ accelerator Injector

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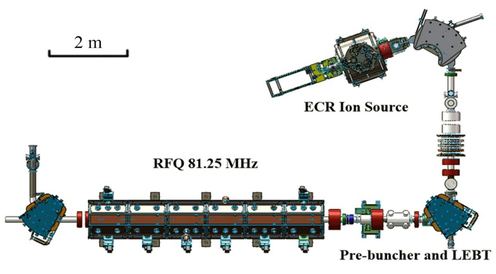
(1) LEAF-RFQ introduction

1.1 LEAF project



Sketch map of LEAF project

1.2 LEAF-RFQ design considerations

- Accelerating heavy ion: Frequency is low
- CW mode: Four vane for stability
- Frequency separation: π stabilizer loop
- Field flatness: undercut
- Frequency and field tuning: tuners
- Full length model simulations with modulations

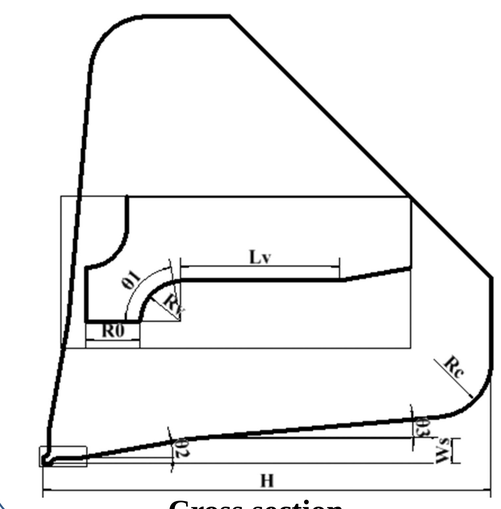
1.3 Design procedure

- **Electromagnetic design**
  - Tool: CST MWS
  - Design: π stabilizer loop, undercut, tuners
  - Full length model: frequency, Q factor, power loss
- **Error analysis:**
  - Tool: CST MWS
  - Simulations: error vs frequency shit

(2) Parameters and structure

LEAF-RFQ main parameters

parameters	value
Particle charge state	U^{34+} (q/A=1/7)
Operation	CW/pulsed
Structure 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
Paek current (emA)	2
Transmission (%)	97.2
Length of vane (mm)	5946.912
Average radius of aperture (mm)	5.805



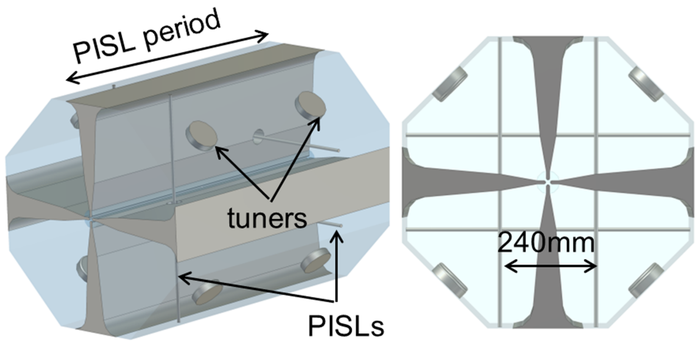
Cross section

parameters	value
R0	5.805 mm
Rv	4.354 mm
θ1	80°
Lv	17 mm
θ2	10°
Ws	20 mm
θ3	5°
Rc	50 mm
H	360.5 mm

Parameters of cross section

(3) 3D EM design and simulations

π stabilizer loop



Sketch map of PISL

Frequency separation comparison

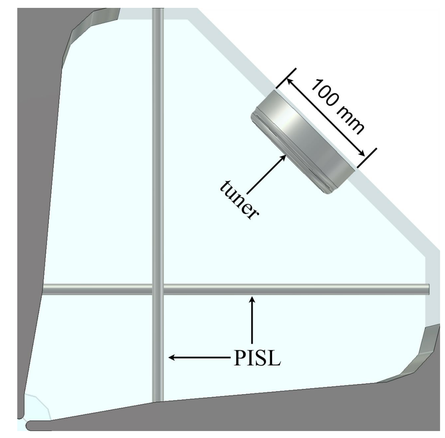
Parameters	Without PISL	With PISL
Frequency (MHz)	81.233	81.173
Dipole mode frequency (MHz)	78.765	86.739
Frequency separation (MHz)	-2.468	5.566

The effect of dipole mode to the quadrupole mode:

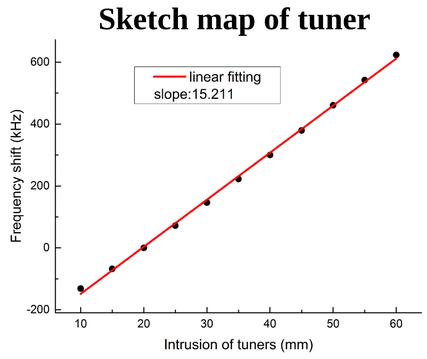
$$\alpha = 1/\sqrt{1 + (Q * 2\Delta f/f_0)^2}$$

To give α smaller than 0.1%, the frequency separation is greater than 3.22 MHz.
5.566 MHz is enough.

Tuners



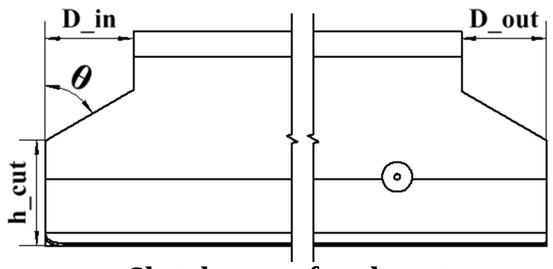
Sketch map of tuner



Tuning sensitivity for all tuners

Tuning sensitivity for all tuners is15.21 kHz/mm.

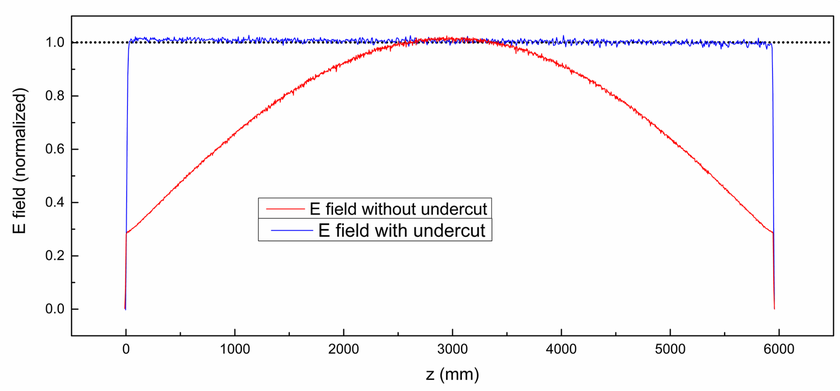
Undercut



Sketch map of undercut

Tuned undercut parameters

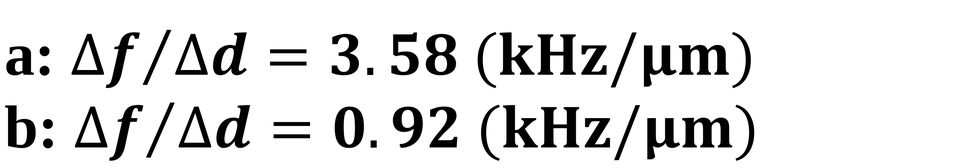
h_cut	θ	D_in	D_out
180 mm	60°	143 mm	139 mm



Field distribution with undercut and without undercut

Full model simulations

5946.92 mm



Sketch map of complete RFQ model

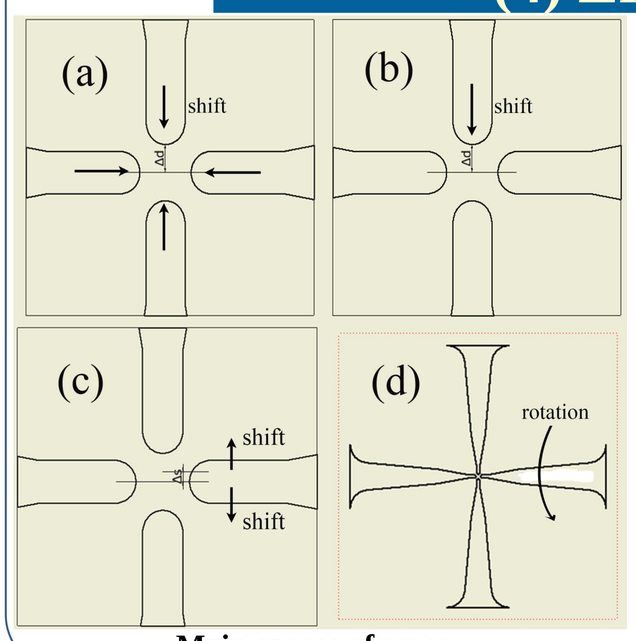
Final RF parameters

Parameters	Value
Frequency (MHz)	81.261
Dipole mode frequency (MHz)	86.827
Q factor	17963
Power loss（kW）	53.196

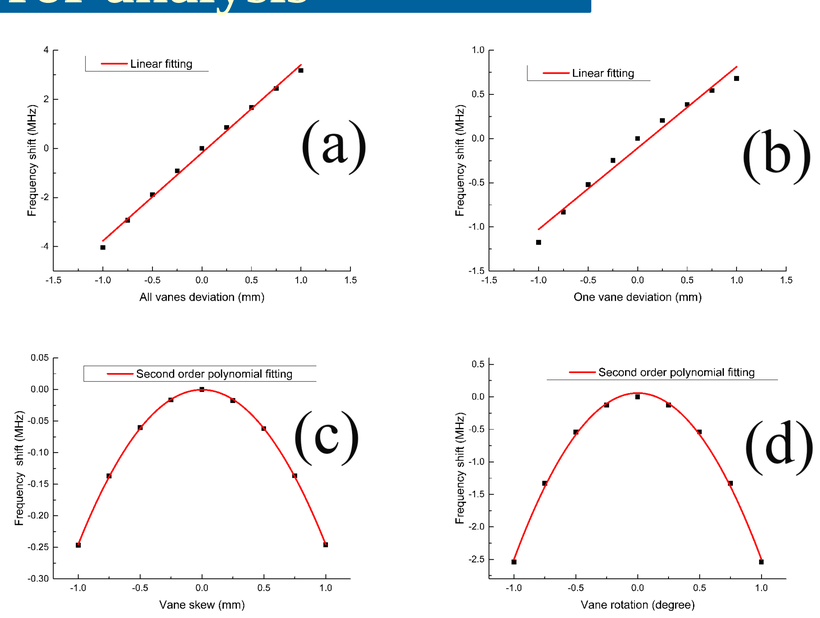
Power losses for separate parts of LEAF-RFQ

Part	Percent %	Power loss	Unit loss
Vane	54.0%	28.73 kW	4.81 kW/m
Tuners	3.85%	2.04 kW	42.7 W
PISL	6.48%	3.45 kW	144 W
Wall	35.7%	18.99 kW	3.18 kW/m

(4) Error analysis



Main causes of error



Effect of errors to frequency shift

$$\text{a: } \Delta f/\Delta d = 3.58\ (\text{kHz}/\mu\text{m})$$
$$\text{b: } \Delta f/\Delta d = 0.92\ (\text{kHz}/\mu\text{m})$$
$$\text{c: } \Delta f(MHz) = -0.244\Delta s(mm)^2$$
$$\text{d: } \Delta f(MHz) = -2.56\theta(degree)^2$$

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