RF DESIGN OF A DEUTERON BEAM RFQ

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Abstract

In a material irradiation facility in IMP, a RFQ is required for accelerating deuteron beam from 20 keV/u to 1.52 MeV/u. The structure design of the RFQ is drawing on the experience of the RFQ of Injector II of China ADS LINAC. Four-vane structure is adopted and the operation frequency is 162.5 MHz. Inter vane voltage is 65 kV and the Kilpatrick factor is 1.4. Π-mode stabilizing loops are used to move the dipole modes away from the working mode. Slug tuners are used to compensate for capacitance errors induced by machining. Cutbacks and end plate are modified to reach reasonable field flatness. After the structure design and optimization, the simulation results of the cavity frequency is 162.459 MHz, the power loss is 109 kW. The multiphysics simulations are also performed to determine the frequency shift caused by the shift of the cooling water temperature.

INTRODUCTION

A project aimed to construct a fusion reactor material qualification facility has been launched in Institute of Modern Physics, Chinese Academy of Science. The facility, which named CMIF (China Material Irradiation Facility), is an accelerator based neutron source. As shown in Fig. 1, the facility will consisted of ion source, LEBT, RFQ, MEBT, superconducting accelerating section and target system. The accelerator will accelerate 10 mA CW deuteron beam up to 50 MeV. When deuteron beam collide with the granular beryllium alloy particle target, the neutron fluxes with the energy up to 14 MeV will be generated. The neutron fluxes will cause 20-50 dpa per year on specimens. In this paper, the RF structure design with the aid of the CST MWS [1] of the RFQ for CMIF will be introduced.

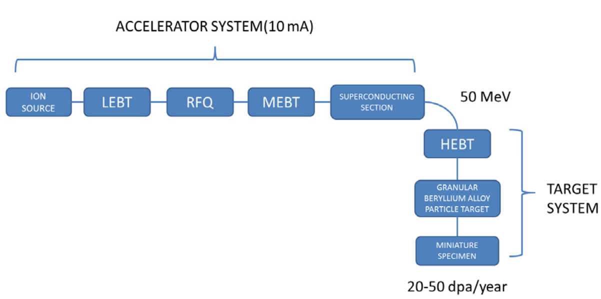

Figure 1: The diagram of CMIF.

MAIN PARAMETER OF CMIF RFQ

For the structure of the RFQ, four-vane type structure for the outstanding stability in CW operation. Based on beam dynamics design, some feature parameters and the vane tip modulation of the RFQ can be obtained, which are necessary for RF Design. The parameters are listed in Table 1. The RFQ will work at the frequency of 162.5 MHz in CW mode. The inter-vane voltage is selected to 65 kV and the Kilpatrick factor is optimized to 1.4.

Table 1: The Main Parameters of CMIF RFQ

Particle	D+ (q/A=1/2)
Operation	CW/pulsed
Vane type	Four vane
Frequency (MHz)	162.50
Kp	1.4
Inter-vane voltage (kV)	65
Vane length (mm)	5250.00
Mean aperture (mm)	4.807

RF STRUCTURE DESIGN

2D Cross Section Design

Before the RF simulation of the RFQ, the profile of the cavity's cross section should be determined. The cross section profile share a common profile with PXIE RFQ [2]. For the symmetry of RFQ, the cross section can be determined by a quadrant. The profile is shown in Fig. 2. And this profile can be determined by the parameters listed in Table 2.

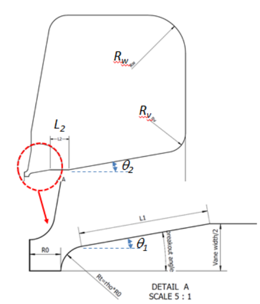

Figure 2: Profile and the parameters of cross section.

Table 2: Parameters to Generate 2D Cross Section Profile

Variables	Value	Unit
R_0	4.807	mm
ρ	0.8	
L_1	27.82	mm
L_2	11.89	mm
θ_1	7.1	Deg.
θ_2	10	Deg.
R_V	20	mm
R_W	40	mm
H	169.3	mm
$R_t = \rho R_0$	3.85	mm

PISL Period Model

The Pi mode stabilized loops are introduced to separate the nearest dipole mode from the working quadrupole

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mode [3]. A period structure of PISL is simulated to investigate the influence on the RFQ. As shown in Fig. 3, the PISL period include 2 pairs of PISLs, the longitudinal distance between two pairs is 262.5 mm and distance between two rod centres is 120 mm. The diameter of the rod is 10 mm and the diameter of the pi rod hole is 40 mm. The RF simulation was done and the RF parameters of the PISLs period can be obtained (see Table 3).

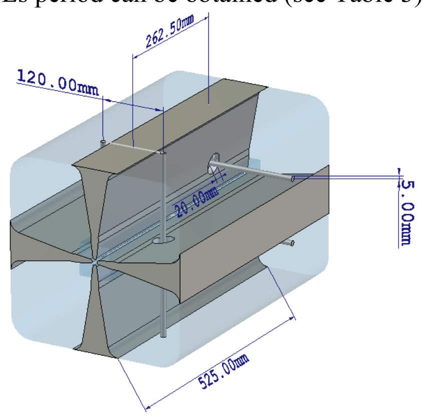

Figure 3: The period structure of PISLs.

Table 3: RF Parameters of PISLs Period

parameter	Value
H(mm)	168
Frequency (MHz)	162.498
Frequency shift due PISLs(MHz)	-5.464
Q factor	15159
Power loss per PISL(W)	199
Dipole mode frequency (MHz)	180.5
Dipole mode shift (MHz)	17.539

Tuner Period Model

100 tuners will be used to compensate the fabrication errors to maintain the uniform inter-vane voltage. So one period for tuner are modelled and simulated to study the properties of tuners period. As shown in Fig. 4, one tuner period is 210 mm length in the longitudinal direction. There are four tuners in a period and each quadrant with one tuner. The tuners are inserted into the cavity at a nominal depth equals to 20 mm. The structure was simulated to obtained RF parameters of the tuner period.

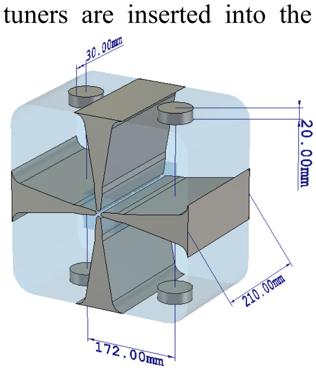

Figure 4: Period of tuner.

Table 4: RF Parameters of Tuners Period

Parameter	Value
H (mm)	174.33
Frequency (MHz)	162.497
Frequency shift due tuners	1.571
Q factor	15856
Power loss per tuner (W)	68
Tuning sensitivity for one tuner (kHz/mm)	22

Whole Length Model

The RF simulation of the whole length model with modulation can be done. Through the whole length model simulation, the tuning of undercut can be performed to maintain the electric field flat along the longitudinal direction. The parameters of cavity, such as the frequencies of quadrupole modes and dipoles, the Q factor of the cavity and power loss can be estimated. The results are listed in Table 5. The power loss of each part of the cavity are also estimated and listed in Table 6.

Table 5: RF Results of Whole Model Simulation

Parameter	Value(with modulation)
H (mm)	169.3
Quadrupole 1 freq.	162.459 MHz
Quadrupole 2 freq.	164.768 MHz
Quadrupole 3 freq.	171.371 MHz
Dipole mode 1 freq.	180.119 MHz
Dipole mode 2 freq.	184.154 MHz
Dipole mode 3 freq.	190.195 MHz
Q factor	14148
Tuning coefficient for one tuner (kHz/mm)	0.933
Tuning range (MHz)	1.865/-1.557 (160.901 ~164.323)

Table 6: Power Loss of Each Part of the Cavity

Part	Power loss (kW)	%
Walls	42.5	39
Vanes, 4 units	47.1	43.2
Input cutbacks, 4 units	1.5	1.4
Output cutbacks, 4 units	1.3	1.2
Tuners, 100 units	7.9	7.2
Total	109	100

MULTIPHYSICS ANALYSIS

Multiphysics analysis is necessary for the operation of RFQ because the frequency-temperature shift coefficients

ISBN 978-3-95450-169-4

are important for the fine tuning during the operation. The multiphysics analysis was performed by ANSYS code [4] on a cross section model of a quadrant of the cavity. Generally, the cooling channels of the cavity can be divided into two types, vane cooling water and wall cooling water because these two cooling channel have contrary effects on the frequency. So the frequency shift coefficient of vane cooling water and wall cooling water can be estimated (see Table 7). As shown in Figs. 5 and 6, several cases of different vane positions were analyzed to investigate the relationship between the transverse position of vane cooling channel and the frequency-temperature shift coefficients.

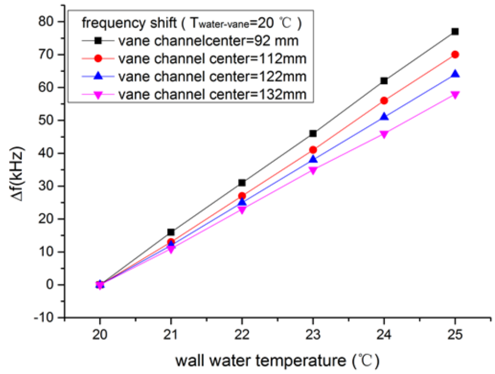

Figure 5: Frequency shift caused by changes of wall cooling water with different vane channel positions (Vane cooling water keeps 20°C).

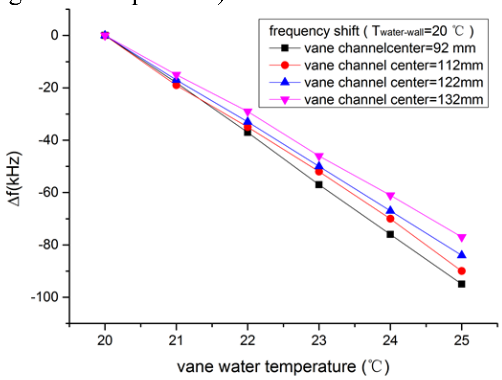

Figure 6: Frequency shift caused by changes of vane cooling water with different vane channel positions (wall cooling water keeps 20°C).

MECHANICAL DESIGN AND FABRICATION

The mechanical design is completed and the mechanical diagram is shown in Fig. 7. The whole length RFQ cavity divided into five modules with equal lengths. In order to reduce the risk of failure of couplers, there will be four couplers set at module 2 and module 3 to couple the RF power into the cavity.

Table 7: Frequency Shift Coefficient of Different Vane Cooling Channel Position

Vane cooling channel position(mm)	Δf for ΔTwall	Δf for ΔTvane	Δf for ΔTwall & ΔTvane
92	15.4	-19.1	-3.7
112	14.1	-17.7	-3.6
122	12.9	-16.8	-3.9
132	11.6	-15.4	-3.8

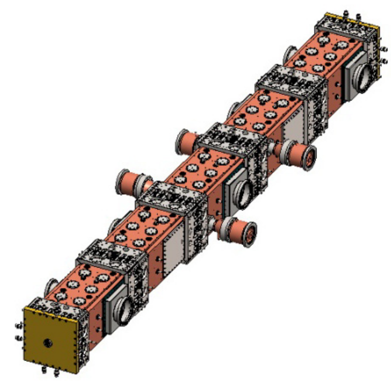

Figure 7: Assembly drawings of CMIF RFQ.

CONCLUSION

A RF structure design of a CW RFQ, as a part of an accelerator based neutron source named CMIF, has been done. Through the tuning of the cavity, the simulated frequency of the cavity is 162.459 MHz, and the power loss will be 109 kW. The multiphysics analysis is done to obtain the frequency-temperature shift coefficients under the completed layout of cooling channels. Mechanical design has been completed and the fabrication and braze of the cavity are in progress on schedule.

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