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THE PRGRESS OF THE CHINA MATERIAL IRRADIATION FACILITY RFQ*

Weiping Dou†, Zhijun Wang, Chenxing Li, Yuan He, Fengfeng Wang, Xianbo Xu, Shuhui Liu, Zhouli Zhang, Institute of Modern Physics, Lanzhou, China

Abstract

The design and low power RF measurement of the radio frequency quadruple (RFQ) for the front end of China Material Irradiation Facility (CMIF), which is an accelerator based neutron irradiation facility for fusion reactor material qualification, has been completed. The RFQ, which operated under CW mode, is specified to accelerate 10 mA deuteron beam from the energy of 20 keV/u to 1.5 MeV/u. To reduce the possibility of beam loss in supper conducting section, the output longitudinal emittance need be optimized. The idea of “Kick-drift” is adopted in beam dynamic design. The challenge for CW RFQ is not only the beam dynamic design but also in the design of cavity structure and cooling of structure. With the experience obtained in the design of the RFQ for CIADS injector II, the structure design and cooling design have been finished. The results of low power RF measurement show the flatness and asymmetry are below 4% for each module.

INTRODUCTION

The China Material Irradiation Facility (CMIF) will be established by the Institute of Modern Physics (IMP), Chinese Academy of Science. CMIF is a new compact neutron source with less cost and low level risk than the project IFMIF. The schematic diagram of CMIF is illustrated in Fig. 1. It consists of ion source, LEBT, RFQ, MEBT, superconducting section, HEBT, and granular beryllium alloy particle target [1]. The RFQ operated under CW mode, as a key equipment of the CMIF linac, is specified to accelerate deuteron beam with intensity high to 10mA from the energy of 20 keV/u to 1.5 MeV/u.

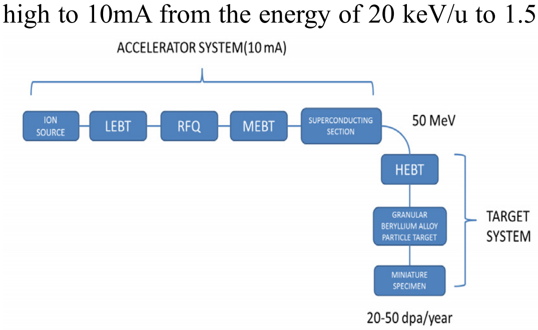

Figure 1: The schematic diagram of CMIF.

BEAM DYNAMIC DESIGN

The main RFQ parameters are shown in Table 1.

Table 1: CMIF RFQ Design Parameters

Particle	Value	Unit
Beam current	10	mA
I/O energy	0.02-1.5	MeV/u
Vane voltage	65	kV
Vane length	526.43	cm
Max.surface filed	19.01	MV/m
Transmission rate	98.2	%
Tr.n.r.emittace	0.203	pi.mm.mrad
99.99% long.emittace	3.5	pi.mm.mrad

These goals of RFQ beam dynamic studies usually are minimize the vane length, beam loss and emittance growth. For CMIF RFQ, two special goal are optimized Kilpatrick factor and output longitudinal emittance. PARMTEQM code [2], which was developed at Los Alamos National Laboratory, is used to generate RFQ parameters. The Kilpatrick factor was optimized to 1.4 computed by PARMTEQM code, which is small enough for avoiding any possible breakdown and reducing time of conditioning of the resonator. The output longitudinal emittance need be optimized to 3.5 pi.mm.mrad to reduce the possibility of beam loss in supper conducting section. The idea of “kick-drift” and Four-Section Procedure are adopted in beam dynamic optimized design. The “kick-drift” act as internal bunch system to bunch beam in short distance. The longitudinal emittance growth and bunch efficient with different electrode modulation factor and drift length have been studied in Fig. 2. The results show when max electrode modulation is 1.02 and the distance is appropriate, the longitudinal emittance growth is smaller and the phase spread is about ± 30 deg.

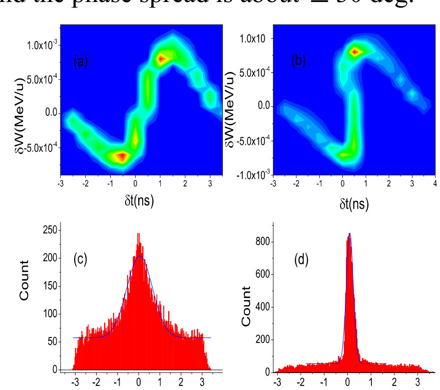

Figure 2: The evolution of longitudinal phase space with different electrode modulation factor and drift length.

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† email address: douweiping@impcas.ac.cn

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The beam simulation by PARMTEQM code is in Fig. 3. The initial beam is water bag. The beam transmission efficient is 98.2%. In Fig. 4, the longitudinal 99.9% emittance at the RFQ exit is optimized to 3.5 pi.mm.mrad. The longitudinal acceptance of downstream supper conducting accelerator is 27 pi.mm.mrad. The ration is 1 to 7.7.

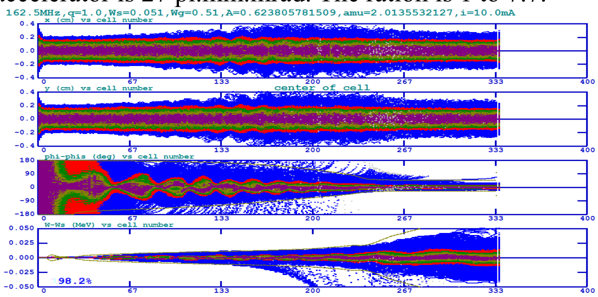

Figure 3: The beam simulation used PARMTEQM.

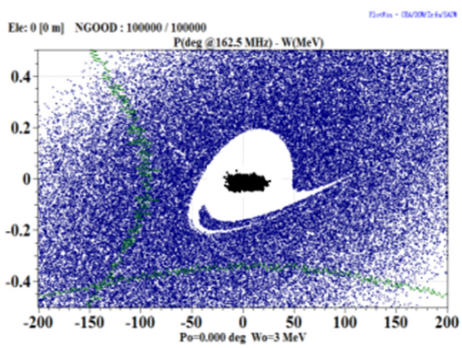

Figure 4: The 99.9% longitudinal emittance and longitudinal acceptance of supper conducting section.

RF DESIGN

The RF design and study have included the RF design of 2D cross section, 3D RF simulation of period structure and RF simulation of the whole length. Though the study of the 2D cross section, the mesh study is completed and the optimized cross section parameter to get low power consumption is got. The approximate 2D simulation can be performed by the 3D code CST MWS [3]. The geometry parameters of the cross section is shown in Fig. 5 and table 2. Finally the frequency is 162.491MHz. The dipole mode frequency is 157MHz. The power loss per length is 16.5 W/mm.

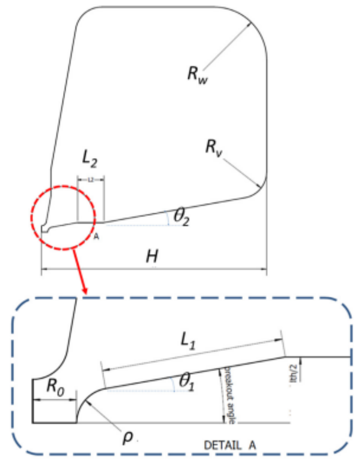

Figure 5: The cross section of CMIF RFQ.

Table 2: The Parameters of the Cross Setion

Variables	Value	Unit
R_0	4.807	mm
R_0/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
ρ	3.85	mm

The 3D RF simulation of period structure have included π-mode stabilizing loops (PISLs) [4] and tuner period structure. The parameters of PISLs are optimized to separate the frequency of the quadruple and dipole. The period structure of PISLs is shown in Fig. 6. The frequency shift of quadruple mode due to PISLs is 5.5 MHz and that of the dipole mode frequency is 17.5 MHz. The tuner will be used to compensate the construction errors after the cavity was brazed. The structure of the tuner period is shown in Fig. 7. For the tuner period, the tuning sensitivity for one tuner inserting one millimeter is 22KHz. The tuning range can be reached to about 1.5MHz for the whole length cavity.

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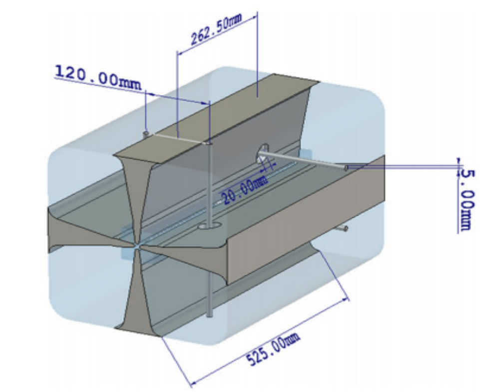

Figure 6: The period structure of PISLS.

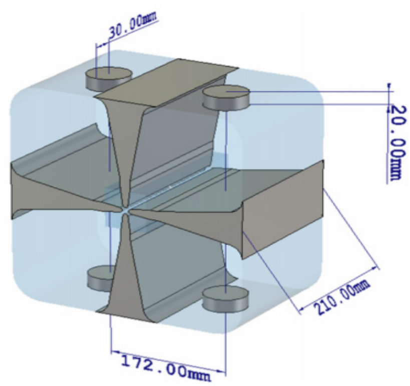

Figure 7: The period structure of tuner.

After the period simulation, the precise RF simulation of whole length model with modulation is performed. Some dimensions are adjusted to reach the design targets including frequency and field flatness. The dimensions of the inputs cutback and output cutbacks are shown in Fig. 8. The distance between vane tips and the surface of end-plate is adjusted to get optimized filed flatness. Finally the filed flatness is in range of 2%.

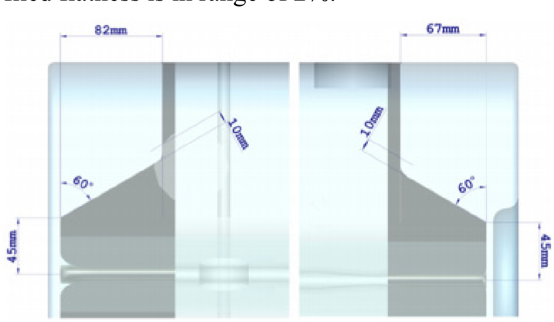

Figure 8: The dimensions of input (left) and output cutbacks (right).

COOLING DESIGN

The thermal analysis and cooling design have been carried out by the the software ANSYS [5]. The water cooling channels and their positions are shown in Fig. 9. Inlet temperature of cooling water is 20 ℃, the velocity of the cooling water is 2.29 m/s. The temperature distribution is shown in Fig. 10.

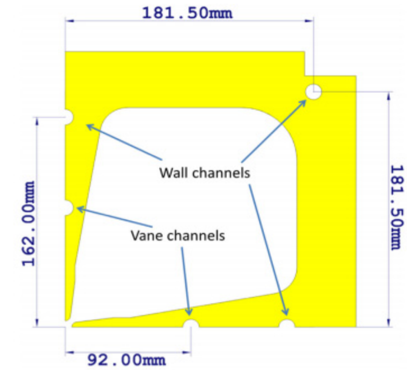

Figure 9: The water cooling channels.

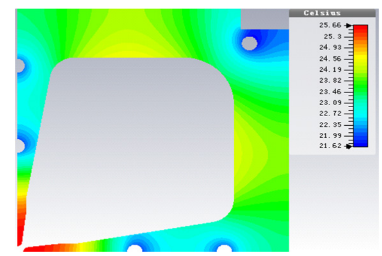

Figure 10: The temperature distribution.

LOW POWER RF MEASUREMENT

Before braze and after braze, the cold model tests were performed for each module. The results of low power RF measurement show in Figure 11, it show the flatness and asymmetry are below 4% which is within the tuning range. The discrepancy between simulated frequency and measured frequency is below 500 kHz which is also within the range of tuning.

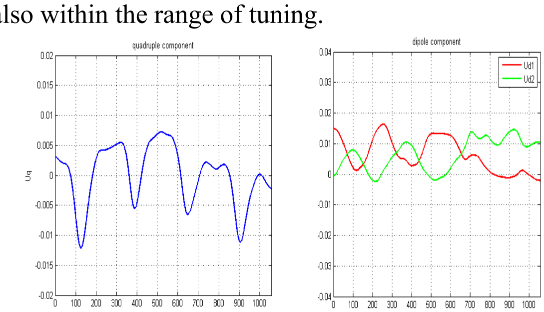

Figure 11: The flatness and asymmetry.

SUMMARY AND PLAN

The beam dynamic design, RF design and cooling design of RFQ for CMIF project are presented. The results of low RF measurement show the flatness and asymmetry are below 4% for each module. The whole length cold model test and tuning is under progress and will be finished this month. The high power conditioning will be on October.

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