BEAM DYNAMICS DESIGN OF THE 3MeV RFQ FOR BISOL PROJECT

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Abstract

The Beijing isotope separation online (BISOL) facility will be used to study the new physics and technologies at the limit of nuclear stability. The facility can be driven by a reactor or a deuteron accelerator. The driver accelerator for the BISOL facility aims to accelerate a 50 mA D^+ beam to 40 MeV. As an injector for the downstream superconducting linac, a 4-vane RFQ operating at 162.5 MHz has been designed to accelerate the deuteron beam from 0.05 MeV to 3.0 MeV in CW mode. For the beam dynamics design of this high-intensity RFQ, a matched and equipartitioned design method is adopted in order to control beam loss. After the optimization, the simulated beam transmission efficiency is higher than 99%. The transverse normalized rms emittance growth is approximately 12%. Detailed results of the beam dynamics as well as the error study of the RFQ are presented in this paper.

INTRODUCTION

BISOL (Beijing Isotope Separation On-Line neutron beam facility) is proposed jointly by Peking University (PKU) and China Institute of Atomic Energy (CIAE) for basic science study and various applications [1], as shown in Fig. 1. It is a double driver system, utilizing both reactor driving (RD) and intense deuteron-beam driving (IDD). RD will rely on the existing high flux research reactor CARR in CIAE. IDD will make use of the (d,n) reaction to produce fast neutrons in the energy range 1 to 20 MeV. And IDD can be operated independently for neutron beam applications [2].

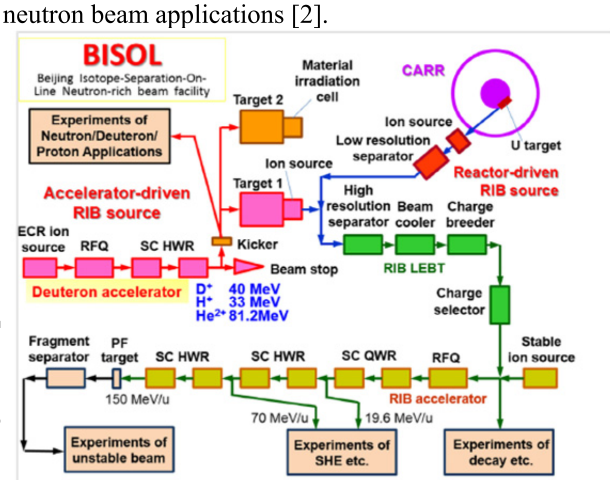

Figure1: Layout of BISOL project.

The driver accelerator aims to accelerate the deuteron beam to 40 MeV with a maximum beam current of 50 mA. The accelerator can be operated in either continuous wave (CW) mode or pulsed mode. Similar to many of the intense neutron facilities currently under construction or design, such as SPIRA2 [3], SARAF [4] and IFMIF [5], a 40 MeV deuteron linear accelerator (D-linac) is proposed for the BISOL facility as the driven accelerator. Figure 2 shows the layout of the high intensity deuteron driver accelerator. It is composed of three main sections: a low energy section, a medium energy section and a high energy section. The main components of the D-linac are an RFQ accelerator and two constant-beta half-wave resonator (HWR) superconducting (SC) accelerators working at a frequency of 162.5 MHz. The deuteron beam is accelerated to 3 MeV by the RFQ and to 40 MeV by the HWR accelerator.

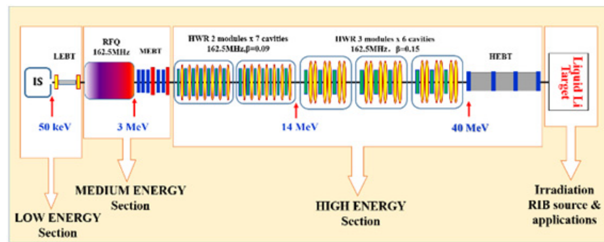

Figure 2: Layout of the high-intensity driver accelerator.

RFQ DESIGN STRATEGY

For the high-intensity deuteron RFQ dynamics, the most important design strategy is to minimize beam loss in the RFQ, especially in the high-energy section, because of maintenance of the accelerator without the use of remote manipulators is of primary importance [6]. In addition, another important parameter for RFQ design is the maximum electric field on the electrode surface. A low peak field is beneficial to the stability and reliability of RFQ in CW mode.

Equipartitioned (EP) of the beam along the RFQ could control the emittance growth and decrease beam loss. A partial EP design was realized in the IFMIF RFQ, which showed that the beam could be brought to a matched and EP condition in an RFQ [7]. This EP design method was also used in the BISOL RFQ design.

RFQ beam dynamics simulation and optimization has been performed using the PARMTEQM code [8]. Based on a matched and EP design method, the MATCHDESIGN [9] code has been developed and was used to generate the input file of PARMTEQM to verify design strategy and simplify the design process. In this code, the inter-vane voltage was fixed as a constant and the radial focusing strength was changed along the RFQ in order to achieve a quasi-constant beam size and to keep the beam EP in the buncher section.

The input matching between the initial beam emittance and the RFQ acceptance is realized through the radial matching section. Then the beam is gradually compressed in the longitudinal direction and an EP condition is achieved at the end of the shaper section. The EP equa-

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tion (1) is satisfied in the buncher section.

$$\frac{\gamma b}{a} = \frac{\varepsilon_{ln}}{\varepsilon_{tn}} = \frac{\sigma_t}{\sigma_l} \qquad (1)$$

where σ_t and σ_l are the transverse and longitudinal phase advance with beam current, ε_{tn} and ε_{ln} are the normalized transverse and longitudinal rms (root mean square) emittance, a and b are transverse and longitudinal rms radii (assuming an ellipsoidal distribution), γ is the relativistic mass factor.

RFQ DYNAMICS PARAMETERS

The main parameters are tabulated in Table 1. The inter-vane voltage is fixed at 65 kV. The maximum peak surface electric field is 23.45 MV/m, which equals 1.71E_k according to PARI and 1.69E_k according to Toutatis [10], and meets the criterion of Kilpatrick that the maximum peak surface electric field should not be larger than 1.8E_k [11]. The dynamic simulations of the RFQ were performed by the codes PARMTEQM and Toutatis. The simulated beam transmission results are 99.70% and 99.69% in PARMTEQM and Toutatis, respectively. Other simulation results such as Twiss parameters and emittance also agree between models. The input and output transverse normalized rms emittance are 0.20 mm·mrad and 0.223 mm·mrad, respectively, an increase of approximately 12%. The RFQ length is 595 cm and its estimated rf power loss is approximately 170 kW.

Table 1: The Main Parameters of the RFQ

Parameter	Value
Particle	D^+
Frequency [MHz]	162.5
Input energy[keV]	50
Output energy[MeV]	3.0
Beam Current [mA]	50
Inter-vane voltage [kV]	65
Vane length [m]	5.95
Maximum peak surface electric field [MV/m]	23.45
Kilpatrick coefficient	1.71
Minimum aperture radius [mm]	2.24
Average aperture [mm]	3.86
Synchronous phase [deg]	-32.5
Max. modulation factor	1.97
Trans. input norm.rms.emit. [mm·mrad]	0.20
Trans. output norm.rms.emit. [mm·mrad]	0.223
Longitudinal output emittance [MeV· deg]	0.150
Transmission efficiency (PARMETQM) [%]	99.70
Transmission efficiency (Toutatis) [%]	99.69
Estimated rf power loss [kW]	170

The main RFQ parameters along the RFQ are plotted in Fig. 3, where B is the radial focusing strength, a is the minimum radial aperture, φ_s is the synchronous phase, W_s is the kinetic energy of the synchronous particle and m is the vane modulation factor.

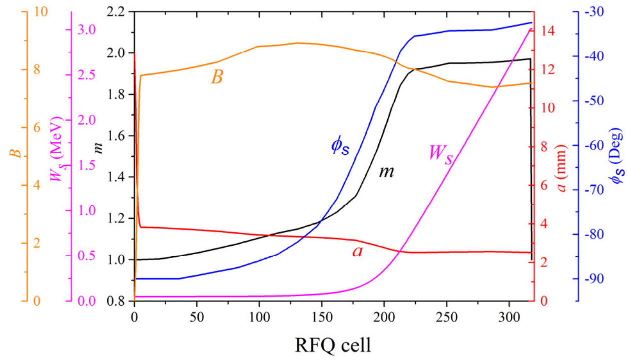

Figure 3: Main RFQ parameters.

The beam transmission along the accelerating cells simulated by PARMTEQM is shown in Fig. 4. The phase space output is shown in Fig. 5. The simulation used 100,000 macroparticles with a waterbag type initial distribution.

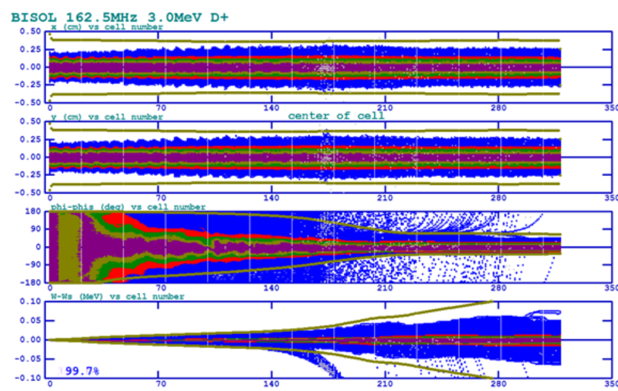

Figure 4: Beam transmission along the RFQ. (Plots from top to bottom are the beam profiles in x and y planes, phase and energy spectrums respectively).

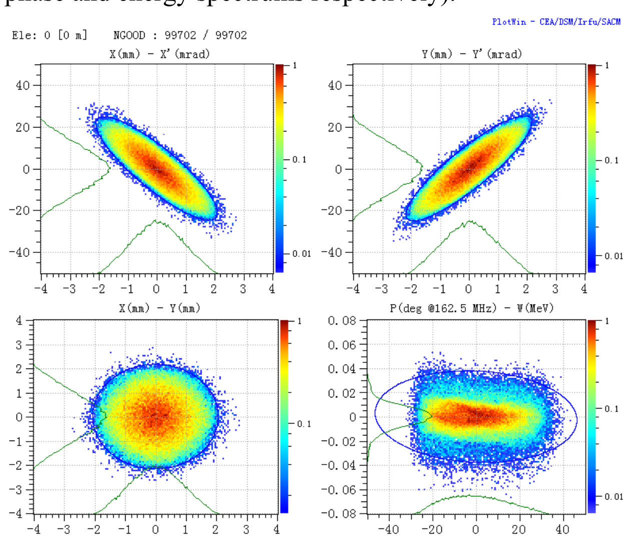

Figure 5: Phase space at the exit of the RFQ.

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The RFQ transmission from PARMTEQM and Toutatis is shown in Fig. 6 as a function of cell number. Toutatis runs 100,000 macroparticles with a waterbag initial distribution. The transmission difference between the two codes is less than 0.1%. Most of the beam loss occurs before 1.5 m, the corresponding synchronous energy is approximately 0.2 MeV. The percent of particles lost with energy greater 1 MeV is less than 0.1% and the total deposited power is only 96 W, which helps to reduce D-D reactions and therefore reduces the difficulty of radiation shielding.

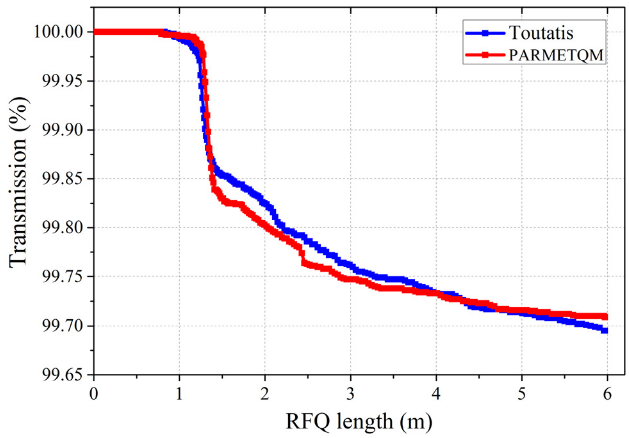

Figure 6: RFQ transmission from PARMTEQM and Toutatis as functions of length.

The location and energy of lost particles are also important. To study the beam loss in the RFQ, the deposited power and proportion of lost particles along the RFQ are shown in Fig. 7. Although most of the lost particles lost are in low energy section, the deposited power is dominated by a few high energy lost particles.

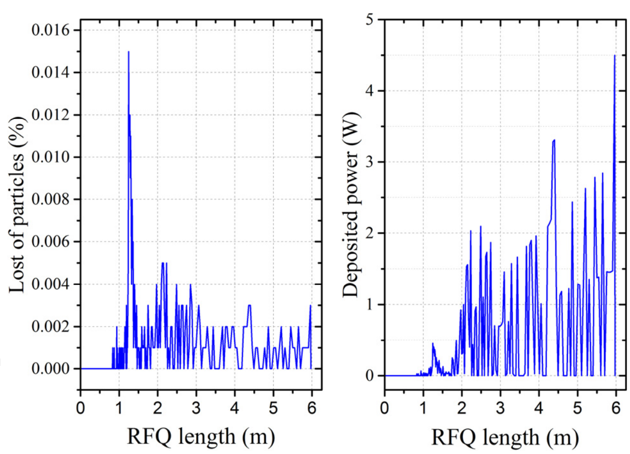

Figure 7: Lost particles (left) and deposited power (right) along the RFQ.

ERRORS STUDY

Errors caused by fabrication imperfections, installation misalignment or a mismatched beam from the LEBT have been studied. Non-ideal input beams have been simulated using PARMTEQM code to check the sensitivity of this RFQ design. A number of error types were considered and studied, including the input beam Twiss parameters,

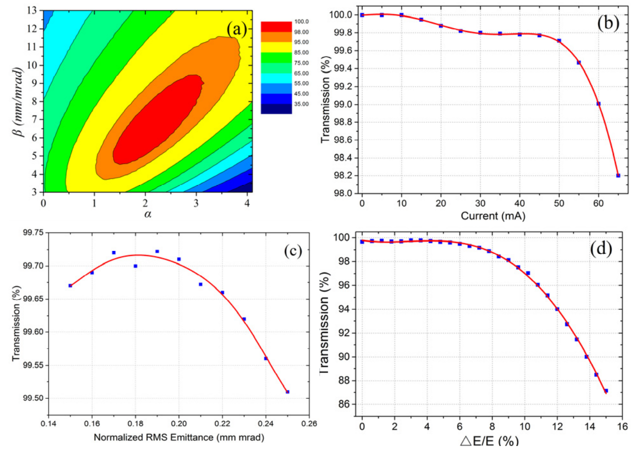

Figure 8: Transmission efficiency of the RFQ behavior versus (a) beam Twiss parameters; (b) beam current; (c) beam emittance and (d) beam energy spread.

the beam emittamce, energy spread and beam current, as shown in Fig. 8.

Figure 8 (a) is the contour map of the transmission efficiency for different input Twiss parameter, which shows the influence of the transverse input beam quality on the beam transmission efficiency. The effect of input beam current on transmission was also studied as shown in Fig. 8. (b), the beam transmission stays above 99% for beam currents less than 60mA. The influence of the input beam emittance and energy spread on the transmission is shown in Fig. 8 (c) and Fig. 8 (d), respectively. For normalized rms emittance between 0.15 and 0.25 mm·mrad, the transmission change is less than 0.5%. The energy spread has little influence on transmission within 5%.

The results of error analysis show that this design is not very sensitive deviations from the ideal input beam parameters.

CONCLUSION

A 3.0 MeV 50 mA deuteron RFQ operating in CW mode has been designed for BISOL project. The beam dynamics design has been completed using a matched and equipartitioned design method. The transmission efficiency is 99.7% and the total deposited power caused by lost particles is 96 W. The length of the RFQ is 5.95 m and 170 kW estimated rf power is needed. The tolerance analysis verifies that the design parameters are reliable.

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