STUDIES ON SUPERCONDUCTING DEUTERON DRIVER LINAC FOR BISOL *

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Abstract

Beijing isotope separation on line type rare ion beam facility (BISOL) for both basic science and applications is a project proposed by China Institute of Atomic Energy and Peking University. Deuteron driver accelerator of BISOL would adopt superconducting half wave resonators (HWRs) with low beta and high current. The HWR cavity performance and the beam dynamic simulation of the superconducting deuteron driver accelerator will be presented in this paper.

INTRODUCTION

In China, a new large-scale nuclear-science research facility, namely the "Beijing Isotope-Separation-On-Line neutron rich beam facility (BISOL)", has been proposed and reviewed by the governmental committees. In Dec. 2016, the government has officially announced the results for the 13th 5-year plan. BISOL was successfully classed into the list of the preparation facilities. This facility aims at both basic science and application goals, and is based on a double-driver concept [1]. Figure 1 shows the schematic view of the BISOL facility. The intense deuteron driver accelerator (IDD) can be used to produce radioactive ion beam for basic research. It can also produce intense neutron beams for the material research associated with the nuclear energy system.

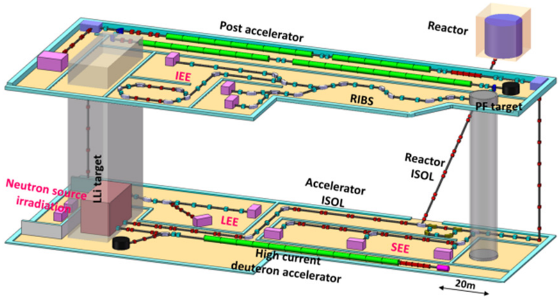

Figure 1: Schematic view of BISOL facility.

Figure 2 shows the layout of the deuteron accelerator. IDD consists of ECR ion source, low energy beam transport (LEBT), a radio frequency quadrupole (RFQ), a medium energy beam transport (MEBT), a superconducting rf (SRF) linac with four cryomodules, a high energy beam transport (HEBT) and a liquid Lithium target system (LLT). The deuteron driver linac of BISOL aims to accelerate the beam up to 40 MeV with maximum beam current of 10 mA in phase I. In the future, the facility will be upgraded to accelerate CW deuteron beams with current of 50 mA. Table 1 gives the main design specifications of the deuteron accelerator. The beam dynamic simulation of the IDD for the first stage and the progress of the linac preparation will be presented in this paper.

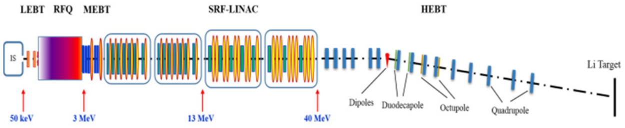

Figure 2: Layout of the deuteron accelerator.

Table 1: Design Parameters of the Deuteron Accelerator

Particles	Deuteron	
Energy	40	MeV
Current (Phase I)	10	mA
Beam power	400	kW
RF frequency	162.5	MHz
Duty factor	100	%
Beam loss	<1	W/m
Neutron flux	5×10^{14}	n/cm^2/s

BEAM DYNAMIC SIMULATION OF THE SRF DEUTERON LINAC

The deuteron beam is accelerated from 3 MeV to 40 MeV by the SRF linac after the RFQ and MEBT. Because its good mechanical properties and high performance, symmetric structure and thus has no dipole steering, HWR structure is adopted for the SRF linac. The SRF linac consists of two different families of half wave resonator (HWR) cavities with geometry beta β_g are 0.09 and 0.16, respectively. Table 2 shows the design parameters of the two families of HWR cavities.

Table 2: Properties of the Deuteron Accelerator

Properties	Low-beta	High-beta
Frequency (MHz)	162.5	162.5
β_g	0.09	0.16
Beam aperture (mm)	40	40

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Coupler port diameter (mm)	80	80
$L_{cav}=\beta\lambda$ (mm)	166	295
E_{pk}/E_{acc}	5.3	4.7
B_{pk}/E_{acc} (mT/(MV/m))	6.4	6.8
R/Q (Ω)	255	264
G (Ω)	39	58
Thickness (mm)	3.0	3.0
Operating gradient (MV/m)	6.0	6.5

The beginning two cryomodules are the same, each consists of seven periods of one solenoid and one low-beta HWR cavity. The third cryomodule consists of five solenoids and nine high-beta HWR cavities. And the last cryomodule contains three periods of one solenoid and three high-beta HWR cavities. The total length of SRF linac is 22.46 m and the length of three kinds of cryomodules are 4.99 m, 6.10 m and 5.60 m, respectively. The drift space between consecutive cryomodules has great influences on beam matching and it should be designed as short as possible. After considering space to install end covers of the cryostats, vacuum valves and beam instrumentation, the distance is set to be 26 cm.

Figure 3 presents the beam envelope at 3σ size in transverse and longitudinal plane through the SRF linac after optimization. The transverse rms beam size in SRF linac is approximately 2 mm and the beam pipe radius is 10 times the rms beam size. Particle phase space distribution at the exit of the SRF linac is shown in Figure 4. The normalized rms transverse emittances of the output beam are ε_x=0.23 mm·mrad, ε_y= 0.22 mm·mrad, and the longitudinal emittance is ε_z=0.26 mm·mrad. The emittance growths through the SRF-linac are 5% and 2% in the transverse and longitudinal planes.

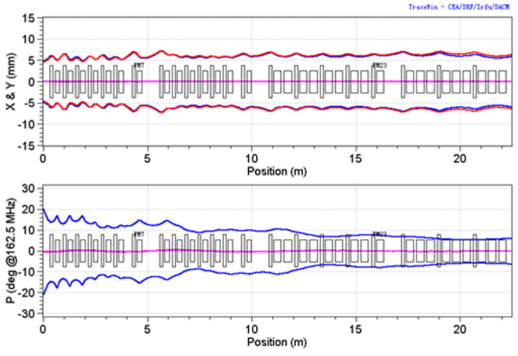

Figure 3: Envelope of deuteron beam along the SRF linac. Top: transverse envelope, x in blue and y in red. Bottom: longitudinal envelope.

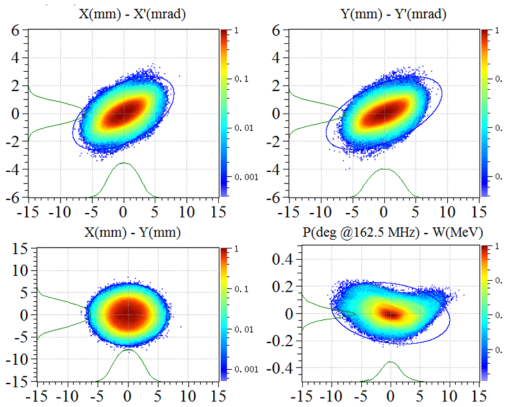

Figure 4: Particle phase space distribution at the exit of the SRF linac.

Multi-particles simulations from exaction of ion source to the end of SRF linac have been thoroughly carried out based on TraceWin code [2]. 10^7 macro-particles are used in the tracking and the normalized beam density is presented in Figure 5. In the transverse dimension, there is a comfortable margin between the beam external border and the pipe wall. The beam external border is relatively large in the drift space between consecutive cryomodules in the SRF linac. Almost all of the losses occur in the RFQ and MEBT and fulfill the requirement of beam loss. Figure 6 gives the normalized rms emittance along the BISOL deuteron linac. The emittance growth can be controlled well.

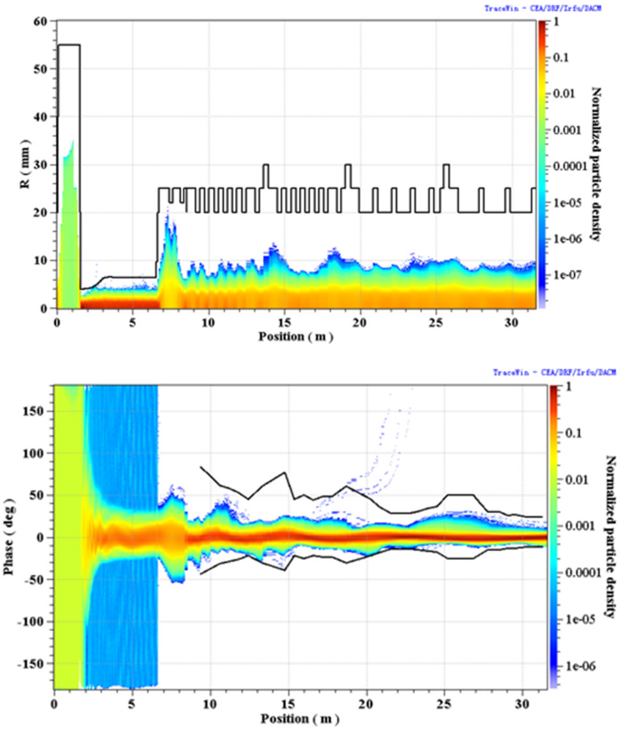

Figure 5: Beam density in transverse (top) and longitudinal (bottom) from start to end.

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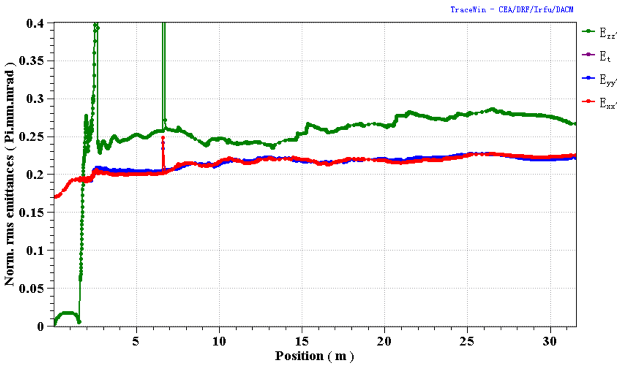

Figure 6: Normalized rms emittance along the BISOL deuteron driver linac.

The residual errors are inevitable because of the installation, manufacture and other reasons. The error study was also performed to prove the available and stability of the dynamics design.

HWR CAVITY PERFORMANCE

The HWR cavities were designed to accelerate 50 mA CW deuteron beams. We have finished the design, fabrication, surface treatment and vertical test of the β g=0.09 HWR cavity [3].

The β g=0.09 162.5MHz HWR cavity has large aperture of 40 mm for high current beam acceleration. It is taper type and has ring-shaped centre conductor to have low surface fields, high shunt impedance and better mechanical properties [4]. The cavity parameters are listed in Table 2. The cavity short plates have asymmetric flat structure to supress multipacting (MP) occurred at the short plates. Figure 7 shows the pieces during fabrication.

Figure 7: Fabrication of β g=0.09 HWR cavity.

After fabrication, the HWR cavity was polished 150 µm by standard buffered chemical polishing (BCP) treatment, then 800°C high temperature treated, followed by a slight BCP. At last, 100 bar high pressure rinsing (HPR) was performed to the cavity. A special nozzle with stem diameter of 20 mm and 13 holes was used to clean the HWR cavity efficiently through 8 ports.

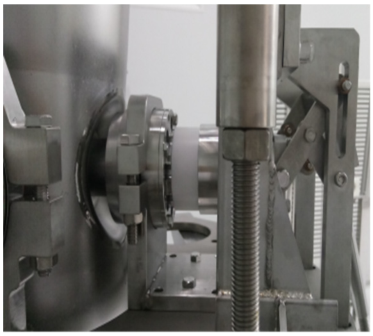

Figure 8: Adjustable Q_e coupler structure for HWR cavity vertical test.

Figure 8 shows the external quality factor Q_e adjustable structure which can make the vertical movement into horizontal movement during Q_e adjustment. The antenna moving range is ±20 mm and the corresponding Q_e adjustment range is about four orders of magnitude. At the first test, the RF power was coupled into the cavity through the beampipe and the antenna was inserted deep into the cavity for the proper Q_e. The cavity gradient only reached 10.7 MV/m at 4.2 K limited by strong field emission. Then we did another HPR and coupled power to the cavity through the large coupler port and tried the second vertical test of the HWR cavity. Figure 9 gives the vertical test results of the cavity at 4.2K and 2 K. The maximum gradient of the cavity reached 14.5 MV/m at 4.2K and 17 MV/m at 2 K, which is much higher than the operating gradient.

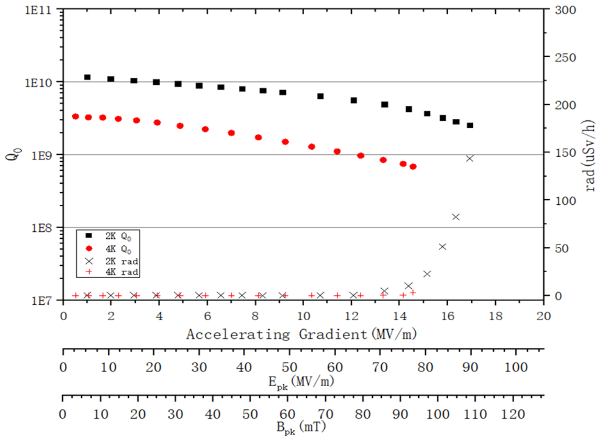

Figure 9: Q v.s. E_{acc} of the β g=0.09 HWR cavity at 4.2 K and 2 K.

MP conditioning was done to the cavity before the Q v.s. E_{acc} measurement. Simulation result shows that there might be MP between the middle part of inner conductor and the outer conductor at very low gradient of about 0.02-

0.15 MV/m. Figure 10 shows the MP conditioning signal at frequency sweeping modes at 4.2 K. It normally takes half a day to eliminate MP.

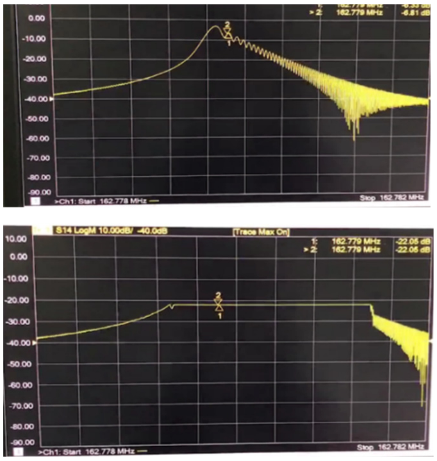

Figure 10: MP conditioning at frequency sweeping modes at 4.2K. Top: No MP. Bottom: MP was on.

During the vertical test, we also measured the mechanical parameters of the cavity. Figure 11 gives the frequency shift as the pressure or the gradient. We can get the Lorentz force detuning coefficient K_L=-1.56 Hz/(MV/m)^2 and df/dP= -7.43 Hz/mbar.

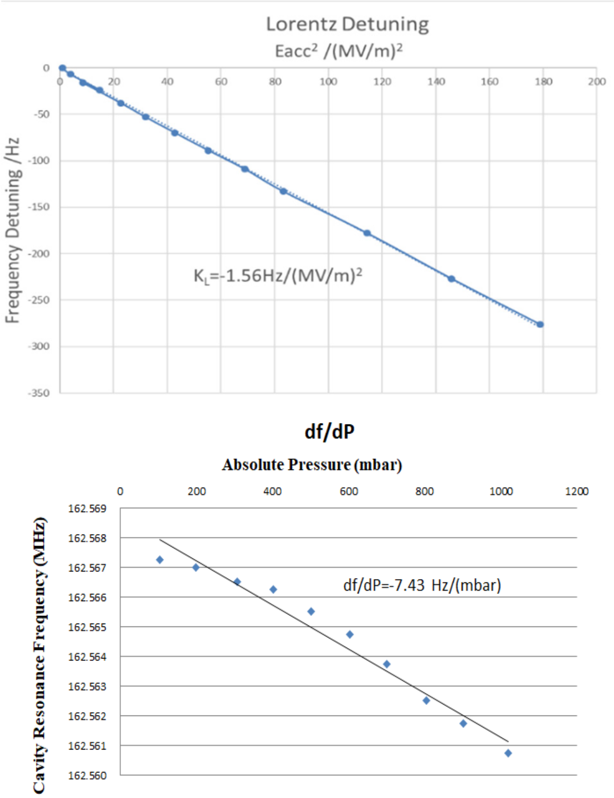

Figure 11: Lorentz force detuning measurement (top) and df/dP measurement (bottom).

CONCLUSION

Primary beam dynamic simulation of BISOL high current deuteron accelerator has been carried out. The simulation results predict that the proposed design can accelerate safely a 10 mA deuteron CW beam at 40 MeV. And the emittance growth and halo formation are under control. Error study was also performed to prove the available and stability of the dynamics design. We have designed, fabricated and vertical tested a β_g=0.09 162.5MHz taper type HWR cavity. The cavity was designed to accelerate deuteron beams with CW current of 50 mA. The vertical test showed it had high gradient and good mechanical properties. The maximum gradient reached 17 MV/m and Q value at low gradient is about 1×10^{10}.

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