THE CONCEPTUAL DESIGN OF INJECTOR II OF ADS IN CHINA

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Abstract

A 10 mA /50 MeV superconduction proton linac as the demo of an the Accelerator-driven System (ADS) driver is designing and constructing in China. One of 10 MeV segments and corresponding prototypes are designed and fabricating at Institute of Modern Physics of the Chinese Academy of Sciences. It consists of 2.5 MeV RFQ and superconduction structure from 2.5 to 10 MeV. The conceptual design and some simulation results are introduced in the paper.

INTRODUCTION

Nuclear energy as a kind of clean energy will be widely used in Chinese energy program in the future. But one of the serious problems is how to handle radioactive waste produced by nuclear plants. ADS, which is the effective tool for transmuting the long-lived transuranic radionuclides into shorter-lived radionuclides, is being studied in the Chinese Academy of Sciences. The roadmap of the project is shown in Fig. 1.

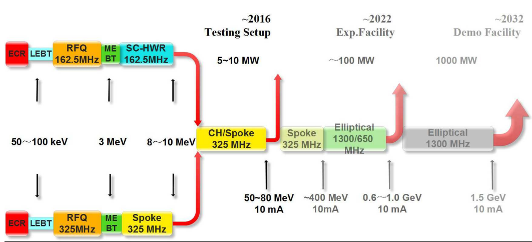

Figure 1: The roadmap of China CAS.

The linac will accelerate the proton with beam current 10mA to about 1.5GeV to produce high flux neutrons for transmutation of nuclear waste.

To ensure technical feasibility in the low energy section, two injectors for the superconduction linac are studded during the first step. One of the injectors, that is injector II, is been designed and fabricated at Institute of Modern Physics of the Chinese Academy of Sciences.

The basic parameters of injector II are listed in Table 1. In this paper, the conceptual design and some simulation results of injector II are presented.

THE CONCEPTUAL DESIGN OF INJECTOR II

Injector II is composed by LEBT, RFQ, MEBT and superconduction section. The proton with energy 35KeV will

Table 1: Basic Parameters of Injector II

Parameter	Value	Unit
Particle type	Proton	
Operation frequency	162.5	MHz
Operation mode	CW	
Beam kinetic energy	10	MeV
Beam current	10	mA

be extracted from ions source. Then the proton will be accelerated by RFQ to 2.1 MeV. After superaddition section, the ions will be accelerated to the final energy 10Mev.

The conceptual design of each section will be presented blew.

The Design of LEBT

For the design of the LEBT, fist of all is the selection of the extraction energy out from ions source. To reduce the space charge effect, higher extraction energy will be better. While considering for the benefit of RFQ and according to the experience of SNS, whose extraction energy is 50 KeV, the extraction energy 35 KeV has been chosen.

The layout of the LEBT is shown in Fig. 2.

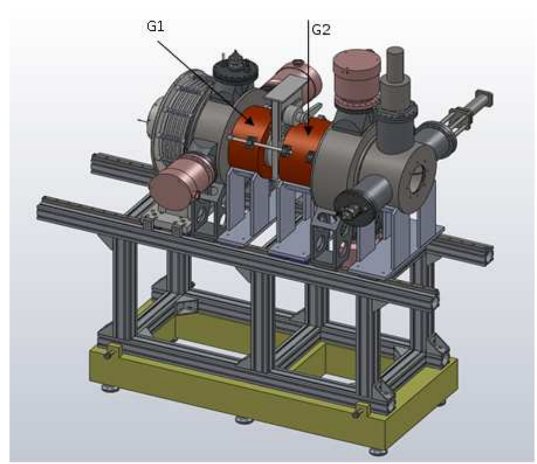

Figure 2: The layout of LEBT in injector II.

There are three main problems for the LEBT, which are space charge effect,matching to the RFQ and the elimination of aberration. Taking the above problems into account, the LEBT is designed as short as possible to reduce space charge effect. In our LEBT, there are just two solenoids and one DCCT, which is used to measure the beam current injected into RFQ. To increase the flexibility of matching ability, the drift between two solenoids and the drift between RFQ and second solenoid are adjustable. So adding with two solenoids, there will be four parameters to do matching.

For the elimination of aberration, the solenoids has been designed to make the magnet field as uniform as possible in the region where beam is located. To get the goal, the solenoids are composed by three independent coils and seven permanent magnets. Small beam aperture can also reduce aberration. So the drift between first solenoid and ions source is designed as short as possible.

The beam dynamic of LEBT has been done with code BEAMPATH, which has been developed since the early 1980s as a many-purpose tool for studying for 2D and 3D space charge dominated beam dynamics in linear accelerators and beam lines. The beam tracking alone LEBT is plotted in Fig. 3.

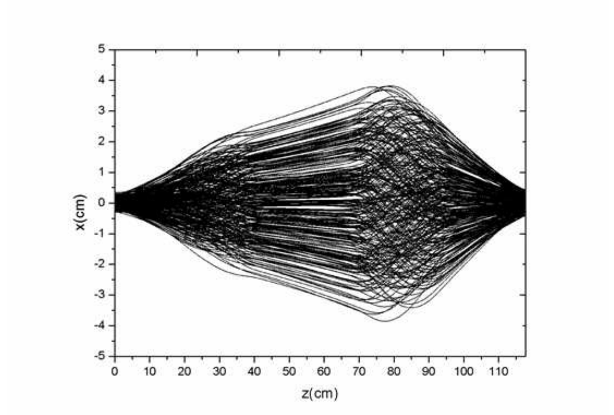

Figure 3: The beam tracking alone LEBT.

From Fig. 4, the max envelop is about 40mm, these particles are also in the uniform area of solenoid. So aberration is not a serious issue in our design.

The Design of RFQ

The RFQ will accelerate proton from 35 KeV to 2.1 MeV. The main specifications of RFQ are listed in Table 2.

Table 2: Main Specifications of RFQ

Parameter	Value	Unit
operation frequency	162.5	MHz
beam current	10	mA
average radius	0.75	cm
vane voltage	115.79	kV
vane curvature radius	0.6	cm
input energy	40	keV
output energy	2.1	MeV
vane length	617.12	cm
kilpatrick unit	1.4	

There are some requirements to be considered In the design of RFQ. The acceptance in both transverse and longitudinal should be large enough. The kilpatrick unit should be low than 1.4 for the CW machine. In the view of mechanical fabrication, the RFQ should not be too long and the average radius of vane should be keep constant. While the above requirements are contradictory, so the design is a compromise result.

The RFQ is designed by the DESRFQ code [1]. This code uses a Laplace equation solver, which takes into account the physical vane shape to generate the RFQ vane tip geometry in every cell and the RFQ parameters required for the final simulation via the TRACK code [2].

The beam dynamic results at 10mA is depicted in Fig. 4.

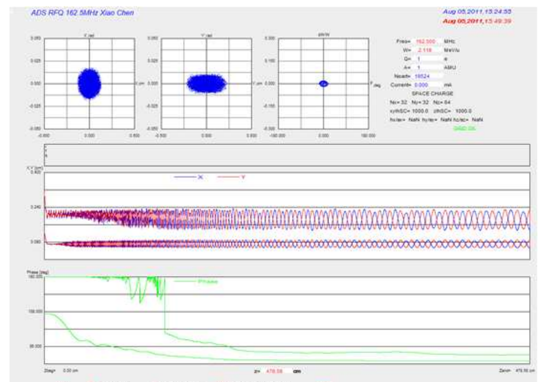

Figure 4: The beam dynamic of RFQ at 10mA beam current.

The Design of MEBT

The MEBT will be designed to have three functions.First is to match the beam between RFQ and superconduction section; second is to install beam diagnostic elements to study parameters of beam; third is to put collimation to scrape beam halo produced in LEBT and RFQ.

For the matching between RFQ and superconduction section, two bunchers and six quadrupoles are used to do the matching in longitudinal direction and transverse direction. The frequency of buncher is chosen to be 162.5MHz, and the gap voltage should be lower than 100 KV to maintain the cavity to operate at safe status. The two set of triplet has focused beam to wrist into cavities to reduce RF defocusing force. Beam dynamic of MEBT is done with code TRACK. The beam simulation result is shown in Fig. 5.

In the injector II, most diagnostic elements will be located at MEBT. The main beam diagnostic elements are listed as followings. (1) Emittance scanning, which is used to bunch emittance in transverse. (2) FCT,which is used to measure bunch length in longitudinal . (3) Strip line BPM, which is used to measure beam location in transverse, also can be used to measure beam energy. (4) Collimator, which is used to scrape beam halo produced in LEBT and RFQ.

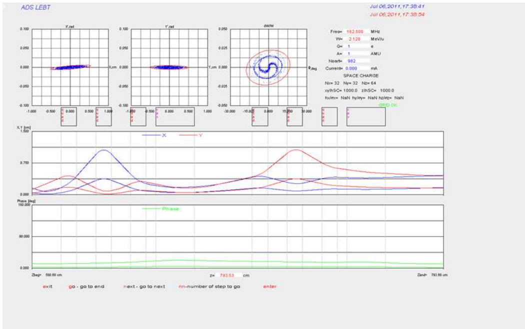

Figure 5: The beam dynamic of MEBT.

Design of the Superconduction Section

In the superconduction section, SC HWR cavity is selected for high accelerating gradient and successful beam commissioning. Superconduction solenoid is chosen to offer transverse focusing force at low energy section for these advantages. The SC solenoid can offer high focusing gradient with shorter length compared with quadrupoles. And another advantage, which is very important to the high current machine, is that solenoid is less sensitive to misalignments errors and beam mismatch.

For high beam current linac design, some rules should be followed to make the beam stable. These rules are as followings.

- The phase advance at zero current beam in transverse σ_{t0} and longitudinal σ_{l0} should be lower than 90° per focusing period to avoid envelope instability at high current.
- Avoid the nonlinear parametric resonance when $f_{particles} = f_{mode}/2$, where $f_{particles}$ is the betatron frequency and f_{mode} is the mode-oscillation frequency [3].
- The wave number in transverse and longitudinal, κ_{t0} and κ_{l0}, which means the strength of focusing force in each period, should change smoothly along the whole linac. The wave numbers κ_{t0} and κ_{l0} are expressed as fellows [4].

$$\sigma_{t0} = \frac{\kappa_{t0}}{L_0}, \sigma_{l0} = \frac{\kappa_{l0}}{L_0} \qquad (1)$$

where L_0 means the length of focusing period.
- To avoid the energy exchange between transverse and longitudinal direction by space charge resonances, the work point of each cell should be at the location far from the unstable area [5].
- The matching between transition section should be proper to avoid the formation of beam halo. The envelope should be as smooth as possible at the transition section and keep off high peaks in envelop along the linac.

The superconduction section will accelerate proton to 10 MeV by two cryo-modules. Each cryo-module is composed of 8 SC HWR cavities and SC solenoids.

The beam dynamics of the SC section is done by code TraceWin [6], which was developed by CEA Saclay.The initial emittance is obtained from the output of the RFQ simulation. 50,000 particles, that are initialized as Gauss distribution, are tracked at zero and 10mA. Some simulation and analysis results are presented in Table 3.

Table 3: Summary of Parameters in Injector II

Parameter	Value	Unit
ϵ_{it}	0.25	π∗mm∗mrad
ϵ_{il}	0.42	π∗mm∗mrad
Growth of ϵ_t	3.2	%
Growth of ϵ_l	2.0	%
Growth of 0.99 ϵ_t	10.0	%
Growth of 0.99 ϵ_l	6.1	%
A/t_{max}	8.49	
ϕ_s/l_{max}	7.78	
Length of per focusing period	630	mm
Number of cavities	16	
Number of solenoids	10	18
Total length	11.2	m

where, in Table 3, ϵ_{it} is the initial normalized rms emittance in transverse, ϵ_{il} in longitudinal; 0.99 ϵ_t is the normalized emittance including 99% of particles in transverse direction, 0.99 ϵ_t in longitudinal direction; A means the aperture of cavity and t_{max} means the max value of rms envelope in transverse along z, ϕ_s means synchronous phase and l_{max} is the max value of bunch length along z.

SUMMARY

In the paper, the conceptual design and preliminary simulation results of the ADS injector II are presented. The design is based on high beam current design rules, combined with experience from high current machine all over the world. Further work about front to end simulation and error simulation will be done in next.

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