A HELIUM INJECTOR FOR COUPLED RFQ AND SFRFQ CAVITY PROJECT AT PEKING UNIVERSITY

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Abstract

A new acceleration structure named as coupled radio frequency quadrupole and separated function radio frequency quadrupole cavity (Coupled RFQ & SFRFQ) is under design at Peking University (PKU). A pulsed or CW He^+ beam injector will be needed to transport 30 keV 20 mA He^+ beam and normalized rms emittance less than 0.15 pi.mm.mrad for this composited type cavity. For pulsed mode, the factor is 1/6, the pulse width is 1 ms. Based on the experimental results obtained on the PKU LEBT test bench, an injector with a 2.45GHz permanent magnet ECR ion source and a 1.16 m long two-solenoid type low energy beam transport (LEBT) line was developed. In this paper we will address the 30 keV He^+ ion beam transportation experimental results on the test bench as well as the specific design on the helium injector.

INTRODUCTION

The development of advanced materials is a key to the achievement of nuclear fusion as a safe, environmentally attractive and economically competitive energy source [1]. Therefore, the study of material irradiation damage effects is increasingly important for advanced nuclear energy systems. An accelerator-based material irradiation facility with beam energy of MeV is a good choice to address the challenges presented by fusion wall materials andto study the form of the resulting waste. A coupled RFQ-SFRFQ accelerator for materials irradiation has been developed at Peking University [2]. It is a new acceleration structure that couples RFQ and SFRFQ electrodes in a single cavity. This material irradiation project is designed to accelerate the helium beam to 0.8 MeV with the peak current of 5 mA. In this paper we will address the general description of the He+ injector design in part 2. In part 3, we will present the bench experimental results on He^+ ion beam production and transmission efficiency on the space charge compensation with Ar gas. In part 4, we will give out the concept and specific design of the helium injector. A summary will follow at the end of this paper.

GENERAL DESCRIPTION

A helium injector is used to generate plasma, to create an expected ion beam and to transport it into an accelerator. It consists of an ion source and a low energy beam transport part (LEBT).

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Among sorts of ion source we choose a permanent magnet 2.45 GHz Electron Cyclotron Resonance Ion Source (PKU PMECRIS) for this coupled RFQ and SFRFQ accelerator at PKU. One reason is that this type of ion source has very unique features, such as high ion beam density, high reliability, ability to operate both in CW mode and in pulsed mode, good reproducibility and low maintenance and long lifetime. And those outstanding characteristic make 2.45 GHz ECRIS popular as a High Current Ion Source in the world [3-7]. Another reason of out chosen is that researchers at PKU are skilful on this kind of ECRIS [5,7]. By replacing the solenoid with permanent magnet, the ECR ion source body is more compact.

LEBT is used to transport and to match the beam created and extracted from the ion source to accelerator. Beam focus can be done with electrostatic or magnetic elements[8] within LEBT. Compared with electrostatic type LEBT, the advantage of magnetic LEBT is obvious on the neutralization of space charge, on the emittance growth suppressing and on the improvement of beam transmission efficiency within the injector [8]. When the injector dimension is not the limitation, magnetic type LEBT is a good choice for a high intensity low energy ion beam. Based on the above understanding and our experience on D+ injector design for PKUNIFTY[5], a magnetic low energy beam transport (LEBT) line with two solenoids is chosen to transport the He^+ beam into the coupled RFQ-SFRFQ. This injector must produce and transport at least 20 mA (peak current) of helium beam with energy of 30 keV to the entrance of RFQ, and the normalized rms emittance of the beam should be less than 0.15 πmm.mrad. Parameters of the injector are listed in table 1.

Table 1: Parameters of the Helium Injector

He+ beam current	mA	20
Energy	keV	30
Duty cycle	Hz	166
Pulse length	ms	1
Emittance(norm rms)	πmm.mrad	0.15

BENCH EXPERIMENTS

Nonlinear space charge force for low energy intense beam is a main reason of beam divergence and emittance growth, which leads to low transmission efficiency [4]. In LEBT line, the space charge effect is more obvious, especially for the beams with lower beam energy part. Compared with proton beam, the He^+ has lager mass and then the beam extraction and transport is more difficult. As the beam diverges a lot, electrode temperatures increase and the spark rate becomes important. Moreover, in these conditions, even after source extraction tuning, the LEBT transmission improvement is a big challenge [9].

In order to obtain the beam characteristics required at the entrance of the RFQ-SFRFQ cavity, beam transmission efficiency of He^+ has been carefully studied on the LEBT test bench (Fig. 1) [6]. The distances from the emission aperture of the ion source to FC1, FC2 and FC3 are 50 mm, 1195 mm and 1995mm.

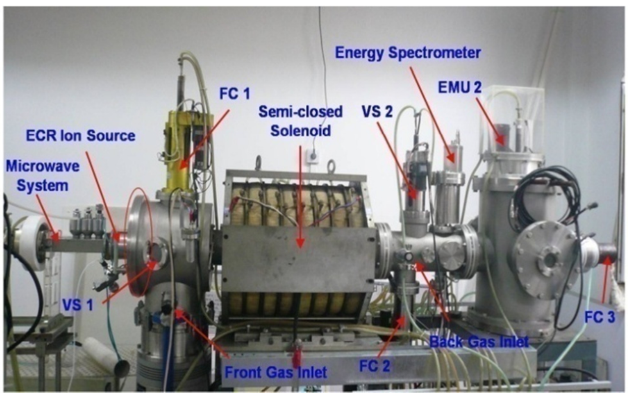

Figure 1: PKU LEBT test bench.

On the test bench we adopt a 2.45GHz permanent magnetic ECR (PMECR) ion source which has a compact structure, similar to the one reported before [5, 7]. Equipped with a tri-electrode extraction system, this ion source has ability to produce high-current ion beams of various gaseous elements, such as H^+, D^+, He^+, N^+, O^+, Ar^+ [7]. With pulsed mode about 65 mA peak current of He^+ beam can be extracted, and the normalized rms emittance is less than 0.2 π mm.mrad. There are two gas inlets on our test bench, named as the front gas inlet and the rear gas inlet. The front one can mainly contribute to the space charge compensation of ion beams around the region of extraction system, and the rear one mainly works behind the semi-closed solenoid. Fig. 2 shows the experimental results of He^+ ion beam compensated by Ar gas through the front or rear gas inlets. As shown in Fig.2, He^+ beam transmission efficiency (IFC3/IFC1) can be increased from 39% to 48% when injected Ar flow from 0 to 1.5 sccm at the rear injection location(rear case). Once when the injection location changes to the front that near the extraction system, He^+ transmission efficiency increases from 39% to 55%, 8% higher than the rear injection case when the gas flow increase up to 0.4 sccm. In the meantime, the current needed by the solenoid for front case is 3A less than that for the rear case. From beam dynamics point of view, less focusing force means higher beam quality[10]. This is understandable for the beam density within extraction region is the highest along the injector and the space charge force is proportionality to the beam intensity. And this phenomenon is co-accordant with the theoretical analysis in [8].

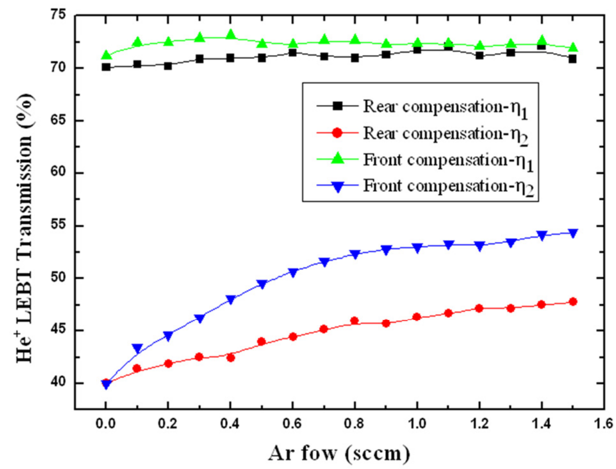

Figure 2: LEBT transmission of 30keV/65mA He^+ beam with front compensation and rear compensation.

HELIUM IN JECTOR

Based on the above experimental results, a He^+ injector with a permanent magnet 2.45 GHz ECR ion source and a two-solenoid LEBT with a front and a rear extra gas injection points was designed for Coupled RFQ & SFRFQ accelerator. Fig.3 is the schematic view of this injector. The entire LEBT length is about 1160 mm. It consists of five sections, drift 1: 280 mm, solenoid 1: 200 mm, drift 2: 200 mm, solenoid 2: 200 mm, drift 3: 280 mm. Two solenoids are more flexible than one solenoid for the beam match at the entrance of RFQ accelerator when beam extraction from the ion source is not in ideal condition.

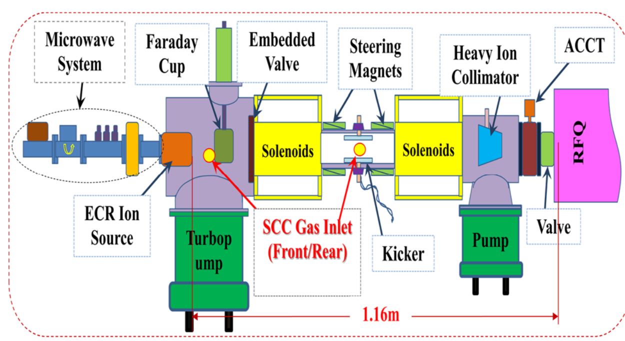

Figure 3: Schematic view of the helium injector.

Details of this injector are a 2.45GHz PMECR ion source with a tri-electrode extraction system for He+ beam producing, a Faraday cup for measuring the total current output, an embedded valve to break-up the vacuum between the ion source and the LEBT, two semi-closed solenoids for beam focusing, two steering magnets for beam trajectory adjusting, a kicker for pulse molding, a heavy ion collimator, an ACCT and a small valve at the entrance of RFQ to make the injector and RFQ cavity vacuum independent. Compensation gas can be injected

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from the extraction region and between two solenoids. The kicker will installed between two steering magnets and the kick-off beams will be absorbed at the water-cooling collimator just behind the solenoid 2.

SUMMARY

To satisfy the requirement of Coupled FRQ and SFRFQ accelerator, a 30keV/20mA He+ injector based on the PKU 2.45 GHz PMECRIS and two-solenoid LEBT is being developed at PKU. The experimental results obtained on PKU LEBT test bench give a strong support for this design. Fabrication is on the way and commissioning will start at the beginning of year 2013.

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