BEAM ACCELERATION OF DPIS RFQ AT IMP*

Zhang Zhouli#, Zhao Hongwei, Sha shan, Liu Yong, He Yuan, Guo Xiaohong,
Sun Liepeng, Shi Aimin, IMP, Lanzhou730000, China
M. Okamura, BNL, Upton, New York 11973, U.S.A.
R.A. Jameson, A. Schempp, IAP, Frankfurt am Main, Germany

Abstract

Beam test of the direct plasma injection scheme (DPIS) is carried out successfully for the first time in China, by setting up a comprehensive test and research platform of RFQ and laser ion source. The C6+ beam is accelerated successfully, and the peak beam current reaches more than 6mA which is measured by a Faraday cup of unique structure. The RF power coupled into the RFQ cavity is also examined, and results reveal that RF power of about 195kW is required to produce the peak beam current.

INTRODUCTION

High energy and high current heavy ion beams are demanded by fundamental research and application research of nuclear physics, for example, single-turn injection into synchrotrons and industrialization of compact carbon ion cancer therapy facility, etc. Laser ion source (LIS) can produce many kinds of ion beams by laser light hitting solid targets, and it is the source of high intensity (up to ~100mA), short pulse length (~10us), and desirable pulse repetition rate (~1-10Hz), which well meets the requirement of single-turn and single-pulse injection of synchrotrons[1]. Usually, there is a low energy beam transport (LEBT) line between ion source and RFQ for beam transmission and emittance match, but there is always strong space charge effect due to the low energy and highly charged states of the beam. To eliminate the space charge effect in LEBT and to improve the emittance match a new acceleration scheme, direct plasma injection scheme (DPIS), was proposed by M. Okamura through a RIKEN-CNS-TIT collaboration, in which LIS and RFQ are connected together directly without LEBT [2]. As a R&D program which is dedicated to researches of a compact carbon ion cancer therapy machine and intense heavy ion beam injection for Cooler-Storage-Ring of the Heavy Ion Research Facility in Lanzhou (HIRFL-CSR) [3], Institute of Modern Physics (IMP) has also carried out the study of DPIS, and the first beam test has been realized in the beginning of 2011. Some preliminary results of beam test will be presented in the paper.

RFQ

The RFQ used for IMP DPIS is designed to accelerate C6+ ion beam from 30keV/u to 593.3keV/u in 2m length, and its working frequency is 100MHz. To control the strong space charge effects of the beam from LIS, beam dynamics design of the RFQ was performed with LINACSrfq code in which the 'Equipartitioning' design is embodied [4], and the parameters of the RFQ are listed in table 1. The RFQ cavity is a 4-rod type, whose Q_0 value and shunt impedance are 4400 and 84.3kΩm respectively. One 250kW RF amplifier has been prepared for the RFQ to produce the required inter-vane voltage.

Table 1: Main parameters of IMP RFQ

Ion	$^{12}C^{6+}$
Frequency [MHz]	100
Input/output energy [MeV]	0.36 / 7.12
Current [mA]	20
Voltage [MV]	0.12
Minimum aperture [cm]	0.707
Modulation parameter	1-2.1
Synchronous phase	-90 ° to -20 °
Transmission efficiency [%]	94.84
Electrode length [m]	2.0
Number of cells	100
Input trans. norm. RMS emittance [πmm mrad]	0.2
Output trans. norm. RMS emittance [πmm mrad]	0.3479

Laser ion source

Laser ion source is a simple ion source in structure, it produces plasma by laser beam hitting target material (such as carbon target), and ions are extracted from plasma by applying high voltage to extraction electrode. Fig. 1 shows the LIS target chamber at IMP, as can be seen, the target chamber consists of two vacuum boxes, one is the outer chamber and the other is the interior chamber, and they are isolated electrically. The drift tube is used to transport plasma from target, and it is connected to the interior chamber. The drift tube also serves as extraction electrode, and the pulse profile and beam density can be adjusted by changing the length of the drift tube [5]. To guarantee good reproducibility, the target can be moved to a new position after each laser shot.

An Nd/YAG laser system was used to produce laser beam of the IMP LIS, with maximum energy is 3J, wavelength and pulse width 1064nm and 8-10ns

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#jolly@impcas.ac.cn

respectively. The energy of 1.5J was measured on the carbon target in the experiment, and all charge states (from 1+ to 6+) of carbon ions can be produced with this energy, in which C6+ has the maximum quantity with the portion of 27.3%. Fig. 2 shows the particle numbers of different charge states for carbon beam

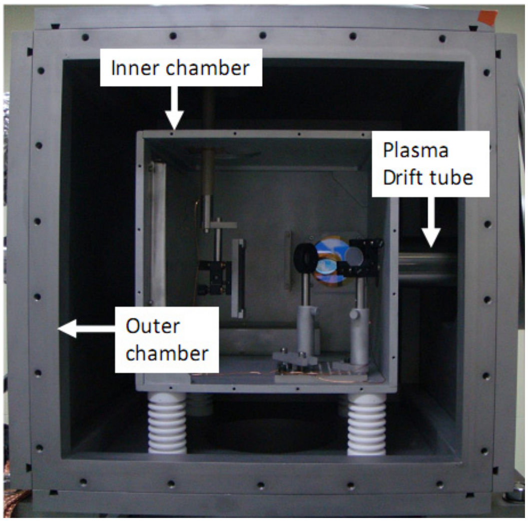

Figure 1: LIS target chamber at IMP

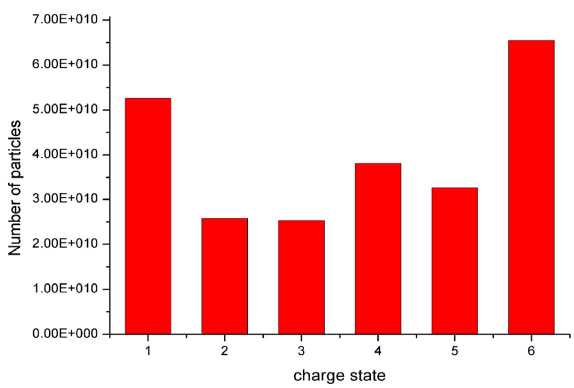

Figure 2: Particle number of different charge states for Carbon beam

DPIS facility

The DPIS facility at IMP is shown in Fig. 3. It mainly includes LIS and RFQ; a fast current transformer (FCT) and a fast Faraday cup (FFC) were also installed at the downstream of the RFQ to analyze the beam current and beam profile. The FCT was bought from the company of Bergoz. The inner diameter of FCT is 60.4mm, and 5V signal can be obtained on the oscilloscope when 1A beam passes through. The FFC has a coaxial structure, and the diameter of the inner conductor is 28mm. The impedance of the FFC is designed to be 50Ω in order to achieve impedance match between the FFC and oscilloscope. The FCT and FFC are shown in Fig. 4 and Fig. 5 respectively.

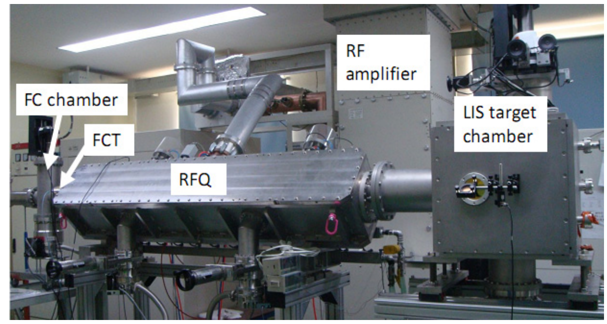

Figure 3: DPIS facility at IMP

Figure 4: FCT used for IMP DPIS experiment

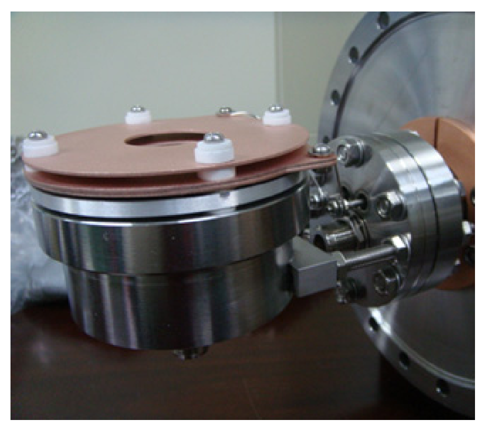

Figure 5: FFC used for IMP DPIS experiment

Beam test experiment

The voltage of 60kV was applied to the extraction electrode (6mm in diameter) in the experiment to make the energy of C6+ beam meet the input energy requirement of the RFQ, and the RF power coupled into RFQ was 180kW. Fig. 6 shows the beam signals obtained from FCT and FFC. Compared with the signals shown in Fig. 7 when there were no high extraction voltage and RF power, the rising edge time of the signals in Fig. 6 were shortened apparently from about 8.56us to about 3.2us, which demonstrates that beam could be accelerated by the RFQ when extraction voltage and RF power were applied, and the peak current reached 6.3mA. A lot of noise signal can also be observed in the signals of Fig. 6, and it can be seen that the beam bunch signal was superposed on a pulse signal with a width of 300us (as shown in Fig. 8) , which corresponded to the width of RF signal. Thus it can be concluded that the noise is from the RF signal leaked from RFQ cavity.

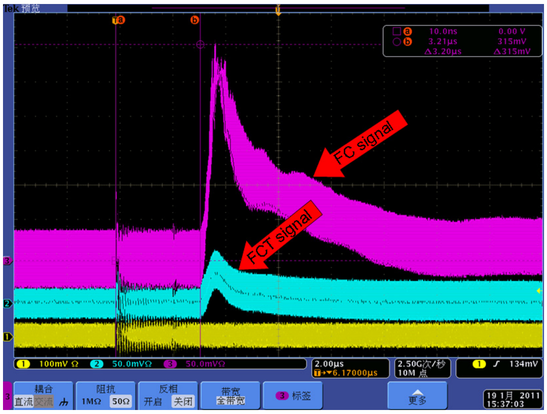

Figure 6: Accelerated beam signals from FFC and FCT

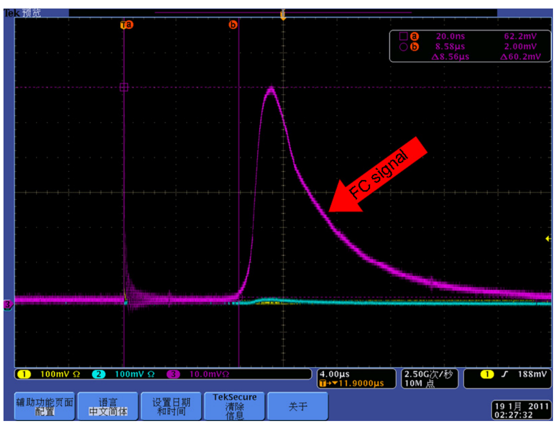

Figure 7: Non-accelerated beam signals from FFC and FCT

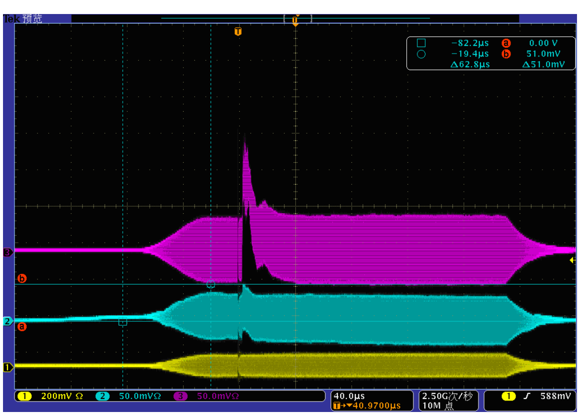
Figure 8: Signals of beam pulse and RF pulse

The transmission efficiency and beam current accelerated by a RFQ is very much related to the RF power coupled into the RFQ cavity. Dependence of beam current from the RFQ on the coupled RF power was studied to find the best working condition of the RF amplifier, and the test result is shown in Fig. 9. The beam current in the Fig. 9 was picked up from the FCT and the RF power was calculated from the pickup value of directional coupler of the amplifier. Fig. 9 shows that the RFQ has the maximum transmission efficiency when the RF power is about 195kW.

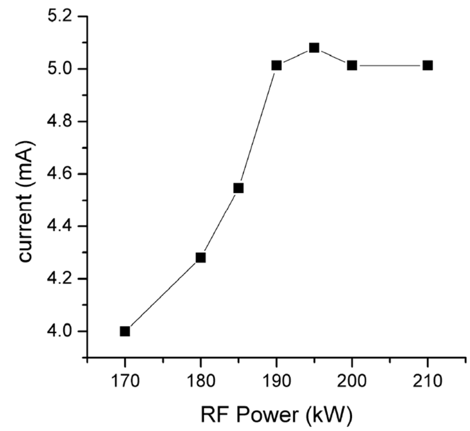

Figure 9: Beam current from RFQ vs. RF power of RFQ

CONCLUSION

The first beam test of a DPIS system with a laser ion source and a RFQ accelerator was carried out successfully at IMP and some preliminary test results were achieved. A few mA C6+ beam (mixed with C^{5+}) was measured at the downstream of the RFQ. However, the micro-bunches of the accelerated beam were not detected distinctly by the FFC or FCT due to the big RF noise. The accelerated beam has not been analyzed because an electrostatic ion analyzer (EIA) of appropriate energy has not been ready for installation and test. Further experiment tests will be conducted to improve the beam transmission efficiency of the RFQ and the beam current from the laser ion source when the EIA is installed. Emphasis of the near future work will focus on improving beam injection efficiency to the RFQ from the laser plasma and beam stability study from the laser ion source.

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