THE SYSTEM OF NANOSECOND 280-keV-He^+ PULSED BEAM

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Abstract

At Fast Neutron Research Facility, the 150 kV-pulses neutron generator is being upgraded to a 280-kV-pulsed-He beam for time-of-flight Rutherford backscattering spectrometry. It involves replacing the existing beam line elements by a multicusp ion source, a 400-kV accelerating tube, 45^o-double focusing dipole magnet and quadrupole lens. The multicusp ion source is a compact filament-driven of 2.6 cm in diameter and 8 cm in length. The current extracted is 20.4 µA with 13 kV of extraction voltage and 8.8 kV of Einzel lens voltage. The beam emittance has found to vary between 6-12 mm mrad. The beam transport system has to be redesigned based on the new elements. The important part of a good pulsed beam depends on the pulsing system. The two main parts are the chopper and buncher. An optimized geometry for the 280 keV pulsed helium ion beam will be presented and discussed. The PARMELA code has been used to optimize the space charge effect, resulting in pulse width of less than 2 ns at a target. The calculated distance from a buncher to the target is 4.6 m. Effects of energy spread and phase angle between chopper and buncher have been included in the optimization of the bunch length.

INTRODUCTION

At FNRF in Chiang Mai University, used to do the research about time-of–flight Rutherford backscattering spectrometry technique (TOF-RBS) for analyzing the material by using the accelerator which is produced pulsed D^+ ion at 140 keV [1]. The experiment has done for analyzing the Cu-Au/Si sample. The experimental result however does not show separation of Cu and Au element due to low resolution of the system [2]. To achieve higher resolution, higher mass or higher energy ion should be used. With a constraint of the existing components which limit of the width of the x-y deflector in the chopper and the dimension of the buncher, He^+ ion at 280 keV has been considered. To upgrading the accelerator to have more efficient some component will be change such as ion source, accelerating tube, 45^o of double focusing magnet and also quadrupole magnet. In this paper describe in the detail of each component in the beam line.

ION SOURCE SYSTEM

The rf ion source will be replaced by a filament–driven multicusp ion source (MIS). Furthermore, we will install a 400-kV power supply that will supply terminal voltage to the helium ion. The MIS has been reported to have a stable discharge, small beam emittance, low axial energy spread and high gas efficiency for single charge ion [3]. It plasma chamber has a diameter of 2.6 cm, is 8 cm long and is made from copper free oxygen. The two rows of 16 samarium-cobalt magnets which are located in the wall of the ion source will form a longitudinal line-cusp field configuration in the chamber. The hair pin filament is made from tungsten with a diameter 0.5 mm. The extraction hole has a diameter of 1.0 mm. The electrode static lens, which is of the decelerate-accelerate type, has three electrodes and is exclusively used for focusing. The focusing power of the lens is realized by applying the voltage to the second electrode. The first and the third electrode of the einzel lens are kept at ground potential. Since the ion source housing is kept at a higher voltage than the ground potential, the additional voltage that exists between the source housing and the first electrode is being used to extract ion from the source. Figure 1 shows a schematic drawing of the ion source system.

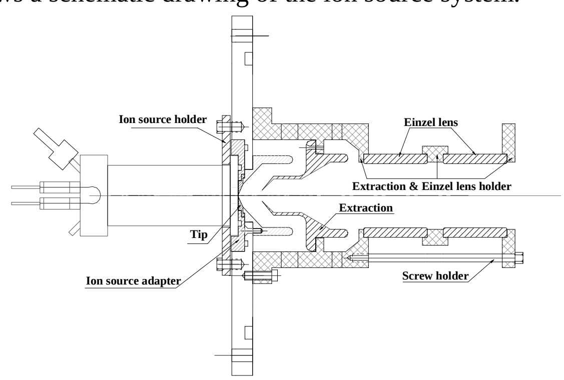

Figure 1: A schematic drawing of the ion source system.

All the geometry of the three electrodes has been designed with the computer code KOBRA3-INP [4]. KOBRA3-INP was used to simulate the behaviour of the ion source with the geometry of three electrodes, in order to give an electrode configuration. The three electrodes used are of various extracting voltage and have a different focusing power targeting the electrostatic ion. Figure 2 shows field lines and trajectories of helium ion with V_{ext} = 5, 10 and 13 kV with a V_{foc} = 3.5, 6.5 and 8.8 kV respectively. The extracted ion current was measured using the faraday cup (FC). The filament was fed with the current ranging between 15 and 16 A. The discharge current is 2 A. The result is that the maximum extracted current is 17.1 µA with 5 kV, 19.6 µA with 10 kV and 20.4 µA with 13 kV as shown in figure 3.

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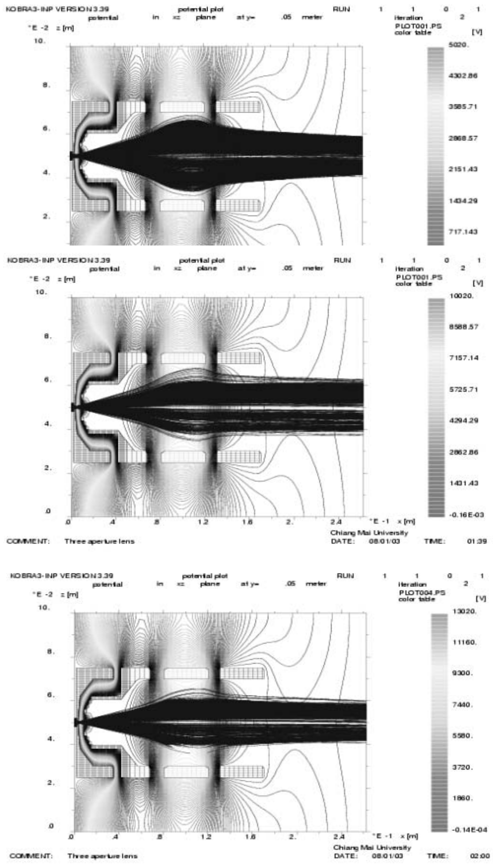


(a) (b) (c)

Figure 2: The simulation trajectory of helium ion by using KOBRA3-INP code and also the fields line of the ion source extraction and focusing system: a) at V_{ext}=5 kV, V_{foc}=3.5 kV b) at V_{ext}=10 kV, V_{foc}=6.5 kV c) at V_{ext}=13 kV, V_{foc}=8.8 kV.

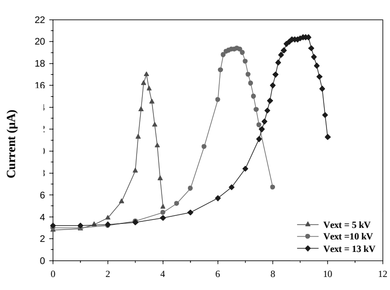


Figure 3: The helium beam current at different extracting voltage.

BEAM EMITTANCE

Accurate information of the quality of the beam is provided by the beam emittance; of which the value should be as low as possible. In the experiment different strengths of the quadrupole magnet result in different readings of the beam profile. The beam profile monitor has 16 wires in both the X and the Y-axis. The distance between the quadrupole magnet and the beam profile monitor is 10.7 cm as shown in Figure 5. The outcome of the experiment shows that using an extraction voltage is 13 kV, the resulting emittance beam of the helium ion is 11.7 mm mrad. The measurement also provide information about the beam x and the beam divergence x´ at the entrance of the quadrupole magnet of x=1.9 mm and x´=6.2 mrad, respectively. The additional results and measurements from the test furthermore provide information that the beam x is 1.9 mm and the beam divergence x´ is 6.2 mrad respectively, both of which are located at the entrance of the quadrupole magnet. Figure 5 shows a phase space diagram of the emitted helium ion at different locations of the beam, e.g. P1, P2 and P3 as shown in Figure 4.

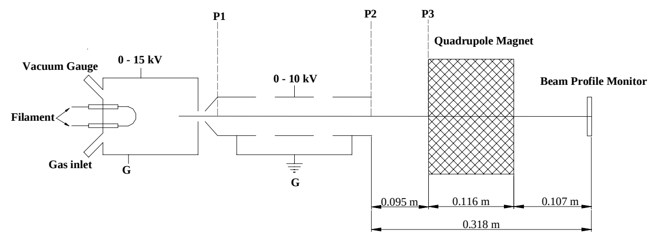
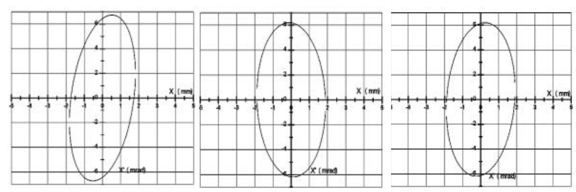


Figure 4: A schematic drawing of the set up of beam emittance measurement experiment.



(a) (b) (c)

Figure 5: A phase space of extracted helium at V_{ext} 13 kV at the position: a) P1 b) P1 and c) P3 as shown in fig 4.

PULSING SYSTEM

The proposed pulsing system has two main components, which are the chopping system and the bunching system as shown in the schematic diagram Figure 6. When the continuous He ion beam, which is derived from the multicusp ion source (1) with an energy of 10 keV, enters the accelerating tube (2) it will accelerate to energy up to 280 keV. The He ion beam passes through the 45^0 analyzing magnet (4), which will select the required He^+ component. After detailed analysis the beam will be chopped via the chopping system which consists of two slits and the chopper (7) itself which contains an x-deflector and a y-deflector. The first slit (6) will reduce the beam diameter, after which it travels into the x-deflector, which connects with 2 MHz radio frequency. The beam will henceforth change into the sinusoid wave in Y-axis after which the y-deflector will force the beam via a 1 MHz fast switch to the center of the second slit (9). After which the beam will be chopped to be a 50 ns pulse width and will continue to pass through into the bunching system. The buncher connects to 4 MHz radio frequency and 26 kV of the voltage. The pulsed beam passes through the buncher, which is then compressed when traveling along the drift space and it will reach the target with a 2 ns pulse width. The distance from the middle of the buncher (10) to the target is 4.6 m.

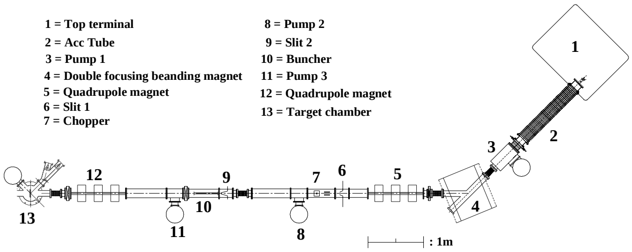


Figure 6: A schematic drawing of 280 keV He^+ pulsed beam accelerator.

BUNCH COMPRESSION

Bunch compression can be done using a buncher cavity, excited by RF fields. A long bunch with a small energy spread will pass through a buncher cavity, in which is excited the rf field which is phased in such a way that the center of the bunch will be unaffected, but the head of the bunch will be decelerating while the tail of the bunch will be accelerating. After exiting the buncher, the ion beam will transverse along a drift space during which compression of the bunch occurs due to velocity variations generated by accelerating and decelerating bunch fields [5]. Ions at the tail of the bunch having been accelerated have higher velocity, whilst the ions at the head of the bunch having been decelerated travel with slower velocity. Both will reach the ion in the bunch center. The bunch is shortest at the target point where the compression is completed, which is where we put the sample for analyzing. After passing through this point, the bunch length will be expanding again. The study to determine the proper distance between the middle of the buncher and the sample will be done through simulation and will be described as below in the PARMELA program.

The PARMELA program is one of the most efficient programs and tool in simulation of the ion beam and its design. The PARMELA program has been developed by the Los Alamos National Laboratory (LANL) [6].

In the numerical, the parameter used in the PARMELA program are the same parameters as are used at FNRF, such as the 3000 particles of He^+ ion at kinetic energy 280 keV with the energy spread ± 0.1%. A 4 MHz radio frequency of the chopper is inserted to produce 50 ns pulse width. The buncher operates at 4 MHz and has a maximum voltage of 26 kV. Simulation results indicate that the shortest bunch occurs at a distance of 4.6 m from the center of the buncher.

BEAM TRANSPORT

Beam transport: to calculate the position of the elements and monitor the behaviour of the particle beam along the beam line. The Beam Optics program was used to simulate the beam line as shown in figure 7. By using 2 triple quadrupole magnets, one located in front of the first slit and another one located in front of the target chamber, the resembled result shows that the beam size at the target is less than 2 mm, as shows in figure 7. The maximum magnetic strength is 26 m^{-1}. The MAGNET Program [7] was used for simulating the pole face geometry design and to calculate the resulting magnetic field. The outcome being that the magnetic field is 0.16 T/cm using a current of 10 A. The material for constructing the quadrupole magnets is low carbon iron, because it has a high permeability. The coil has strands of 400 turns.

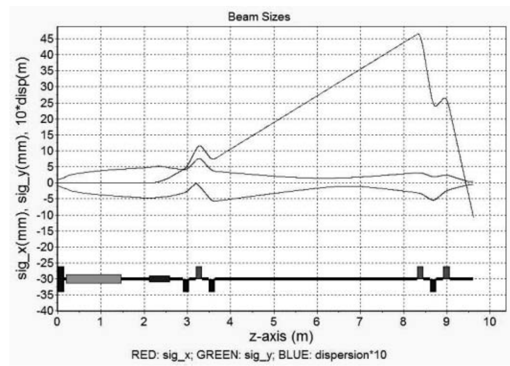


Figure 7: Simulation result of beam transport along the beam line by using Beam Optics Program.

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