Uludağ University Journal of The Faculty of Engineering, Vol. 23, No. 1, 2018 RESEARCH

DOI: 10.17482/uumfd.338184

DESIGN, CONSTRUCTION AND RESULTS OF A LOW ENERGY DC ION ACCELERATOR

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Received: 14.09.2017; accepted: 06.04.2018

Abstract: The main purpose of in this study is described to optimal design and construction of low energy DC ion accelerator with energy up to 100 keV. Initial measurements obtained are given. This small accelerator includes an ICP type ion source, an accelerator tube with 7 electrodes, two quadrupol magnet for focusing, one dipole magnet for bending and a faraday cup at the end of beam line to measure ion current. The existing technology was used to make the major components. Simulation results for ion source, DC accelerator tube and magnets are presented performed with SIMION, WINAGILE, GPT codes.

Keywords: Accelerator, Ion, Energy, Quadrupol, Dipol

Düşük Enerjili DC Iyon Hızlandıcısının Dizaynı, Yapımı ve Sonuçları

Öz: Bu çalışmanın temel amacı, 100 keV'a kadar enerjilerde DC iyon hızlandırıcılarının optimum tasarım ve yapımını kapsamaktadır. Elde edilen ilk ölçümler verilmiştir. Bu küçük hızlandırıcı, ICP tipi iyon kaynağı, 7 elektrotlu bir hızlandırıcı tüp, odaklama için iki kuadrupol mıknatıs, bükme için bir dipol mıknatısı ve iyon akımını ölçmek için demet hattının ucunda bir faraday kabı içerir. Önemli bileşenlerin yapımında mevcut teknoloji kullanılmıştır. İyon kaynağı, DC hızlandırıcı tüp ve mıknatıslar için benzetim sonuçları SIMION, WINAGILE, GPT kodlarıyla gerçekleştirilmiştir.

Anahtar Kelimeler: Hızlandırıcı, İyon, Enerji, Kuadrupol, Dipol

1. INTRODUCTION

In recent years, the studies of design and construction of a beamline and the beam parameter measurements have been preceded at the Turkish Atomic Energy Authority’s (TAEK) Saraykoy Nuclear Research and Training Center (SANAEM). As a result of these studies, 100 keV DC linear ion accelerator has been constructed [1]. As known, the low energy dc accelerators are used in many fields for research and application [2]. The main application areas of our interest are charged particle beam measurements, neutron production to study activation analysis techniques and use of pre accelerator for RFQ accelerator. With this purpose, the studies have started to design and construct of beamline to beam parameters measurements. Finally, a 100 keV DC Proton Accelerator has been designed and constructed at TAEK SANAEM for training and research purposes.

In this study, the design works for the ICP type ion source, the mechanism of accelerator and the results are given in the first, second and last section, respectively.

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2. THE ICP TYPE ION SOURCE

The radio frequency (RF) voltage to create plasma has used since the late of 1940's [2]. Ion source based on RF provides an important advantage because it allows the use of a wide variety of gases. RF ion sources are quite useful due to their long-lived and producing effective plasma. Especially, there are wide variety of application in the particle accelerators and industry [3].

In practice, necessary pressure value for the RF discharge in the gas-filled environment is around 10^{-2} -10^{-3} Torr. ICP is generated with installing an excitation coil around the gas vacuum tube. ICP type ion source that studied on it is given in Figure 1. Ion source is fed by 13.56 MHz max 1000 Watt RF. RF power transfer is near 66%. This value can be raised up to 99% by using of tuned capacitor. A turbo pump is used to rise up pressure to 10^{-6} mbar in system. A good vacuum value has necessary to extract and move of ion in the beam line. Sufficient pressure values for ICP ion source are 10^{-2}-10^{-3} mbar. These values can be provided by the gas given to plasma tube and extraction aperture. The extraction aperture of protons passing through to accelerator segment is about one millimeter in diameter installed to flange shown in the left side of the Figure 1.

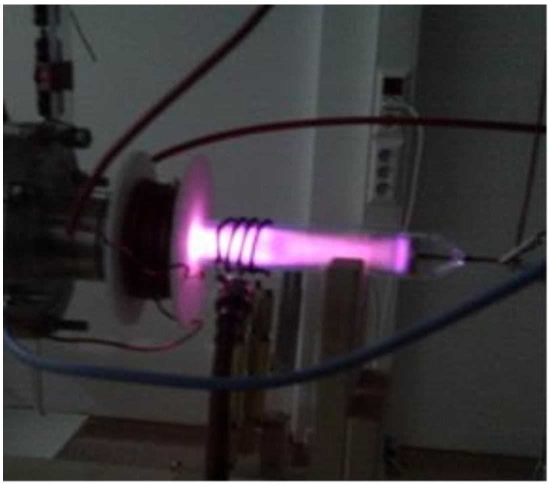


Figure 1:
ICP type ion source

The ion temperature and density have been computed using I-V curve resulting approximately 2.5 eV and 109 /cm^3, respectively. Simulation of ion extraction from ICP type ion source under 5 kV potential differences by means of SIMION is shown in Figure 2. Group of one thousand dots in figure shows the number of protons starting to travel through extraction aperture under the influence of pre-determined kick voltage.

The performance of ICP type ion source have shown that the working pressure, applied power of RF, impedance matching, applied external magnetic field and extraction potential are fatal parameters for optimal performance.

3. THE DC ACCELERATOR TUBE

SIMION [4], GPT [5], WINAGILE [6] computer programs have been used to design of 100 keV DC accelerator. SIMION simulation program has been used in the design of ion source and calculations of ion extraction from this source. GPT and WINAGILE have been used in design of beam transport line. Protons have been obtained from Inductively Coupled Plasma-ICP type ion source in the accelerator. Voltage divider (DC accelerator segment), quadrupole magnet, Einsel lens-solenoid, phosphor screen and faraday cup have been used for acceleration, focusing, monitoring of beam profile and current measurement, respectively.

The voltage divider designed by software is shown in Figure 3 as schematic and photo view. The resistances of 2 MΩ are used to divide the voltage in voltage divider. Final section shown in sketch has been connected to ground. The motion of protons at 50 keV potential difference are shown in Figure 4.

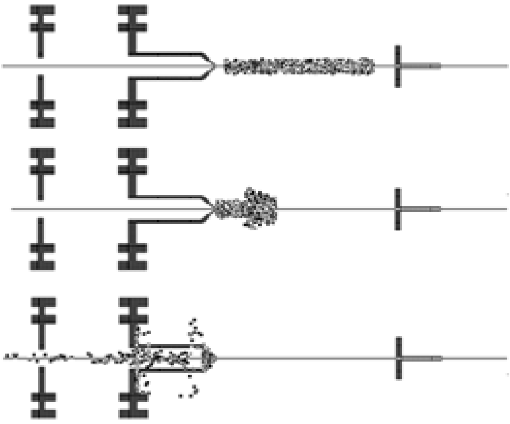


Figure 2:
SIMION code simulation of ion extraction from ICP type ion source under 5 kV potential difference

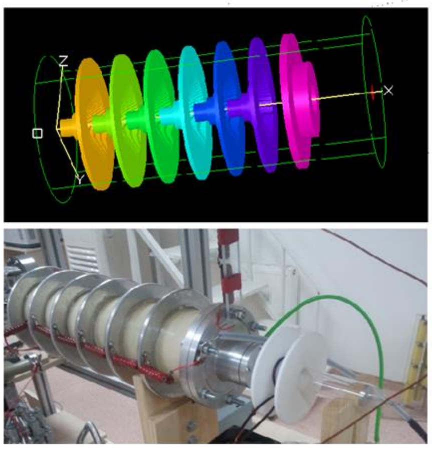


Figure 3:
The schematic and photo view of voltage divider

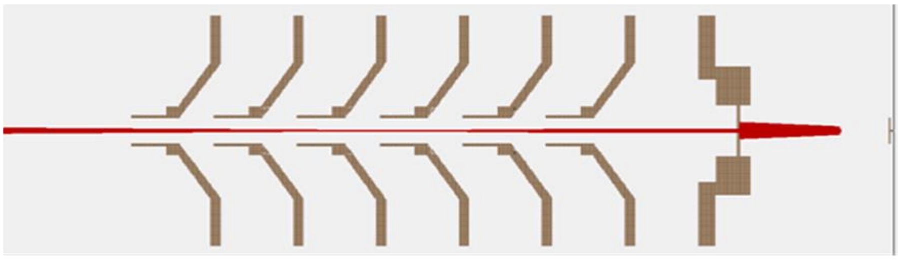
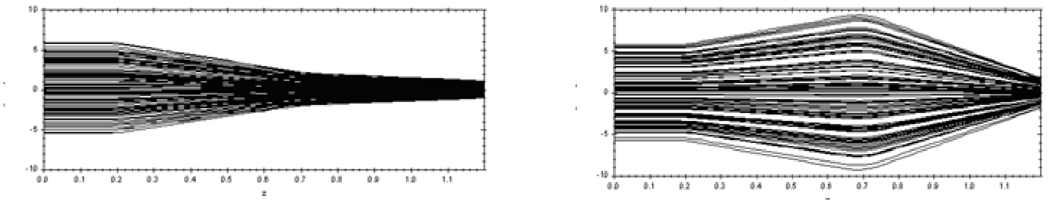


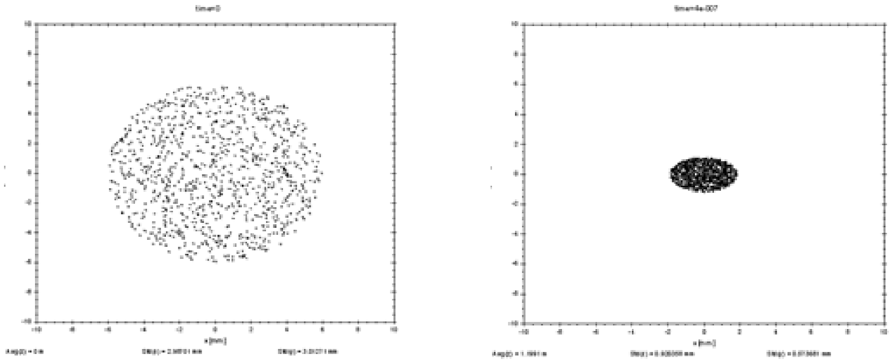
Figure 4:
The motion of protons at 50 keV (from right to left)

The result of simulation studies of input and output of proton beam passes through the quadrupoles are given in Figure 5. The length of beam line is ~2.2 meters and the distance between two quadrupoles magnet are 50 cm for 50 keV proton beam. The situation on xy plane is also shown in Figure 6.



a. b.

Figure 5:
The result of the simulated proton beam passes through the quadrupoles
a. *The horizontal direction* ***b.*** *The vertical direction*



a. b.

Figure 6:
a. *Entrance of charged particles to the beamline* ***b.*** *The position after passed two quadrupole magnet*

100 keV DC Lineer Proton Accelerator is shown in Figure 7. The magnets designed by SUPERFISH simulation program and phosphor screen for beam diagnostics are shown in Figure 8. Einzel lenses are used to adjust the beam diameter. Acceleration is provided by 100 kV power supply. The pressure gradient between ion source and accelerating segment (voltage divider), a circular aperture of approximately 1 mm has been installed. Eventually, the protons source has been created. Two current sources of 25 Amperes and one power supply of 5 kV are used for quadrupole magnets and Einzel lenses, respectively.

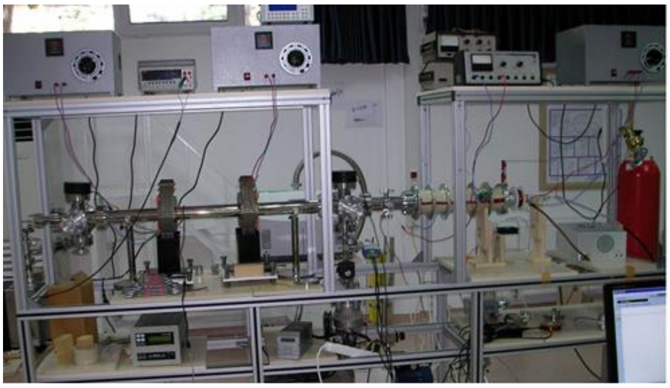


Figure 7:
Full view of 100 keV DC Linear Proton Accelerator

a. *b.*

Figure 8:
a. *Accelerator magnets* ***b.*** *Phosphor screen*

4. EXPERIMENTAL RESULTS

Firstly, it was examined the values of current versus applied voltage in the performed measurements. The measurement was repeated for 1x10^{-4} mbar, 4.2x10^{-4} mbar, 5x10^{-4} mbar and 8.2x10^{-4} mbar pressure values. The obtained results are shown in Figure 9. As the pressure value is increased, the ion current value increases in the Figure 9. This situation is attributed the reduction of particles in the accelerator tube and exposed to less collision of produced ions.

The ion current chart is plotted against RF power in the 20-50 keV acceleration voltages for 5x10^{-4} mbar constant pressure and this plot is shown in Figure 10. As per the graphic, the current remains constant after ~50 watts values. So there is no need to increase the RF power after this value for the 20-50 keV acceleration voltages.

When accelerator is applied 30 kV acceleration voltage, the current graph is plotted against the applied RF power by changing the number of ion source resistances for 10 kV, 6.6 kV, and 3.3 kV. This plot is shown in Figure 11. It is observed a rapid increase in current values up to about 30 watts RF power. When the RF power is increased, the variation of the current value changes to be less for all the resistances.

In the case where the acceleration voltage is kept constant at 30 keV, the current values are given for different pressures in Figure 12. It is seen that the results are consistent with expectations.

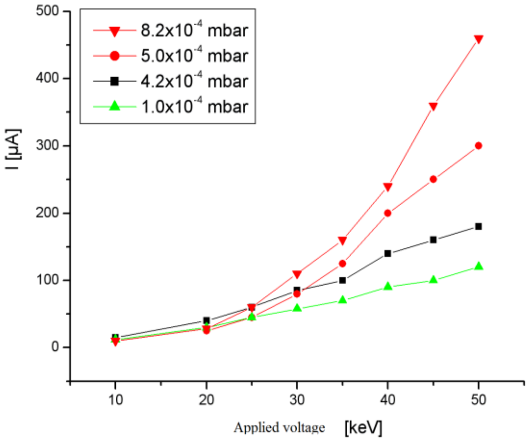


Figure 9:
The variation in current-voltage graph for different pressure values

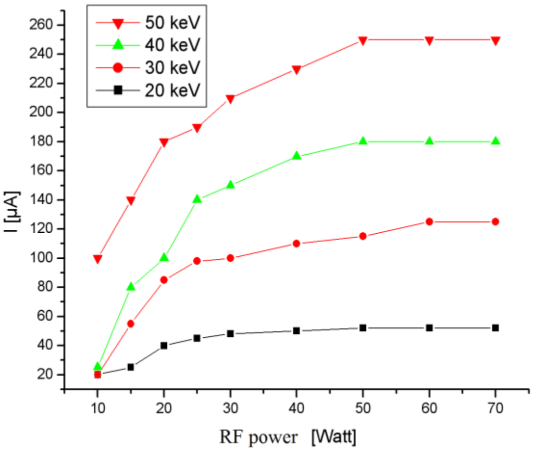


Figure 10:
The RF power versus current graph for acceleration voltages between 20 and 50 keV

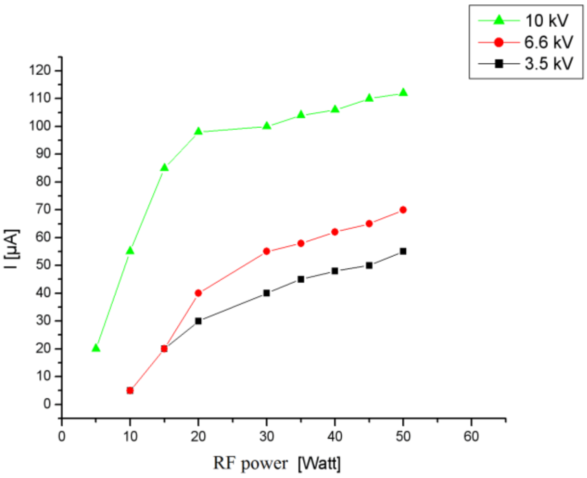


Figure 11:
The RF power versus current graph for acceleration voltages between 3.5 and 10 keV

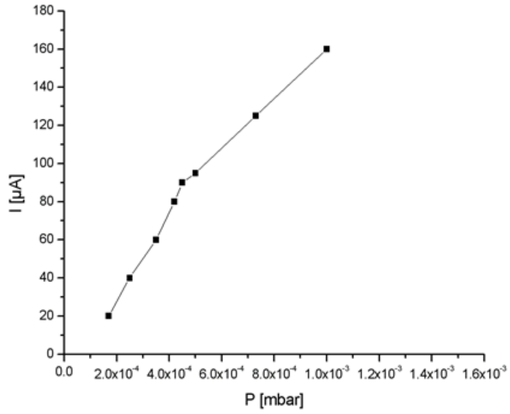
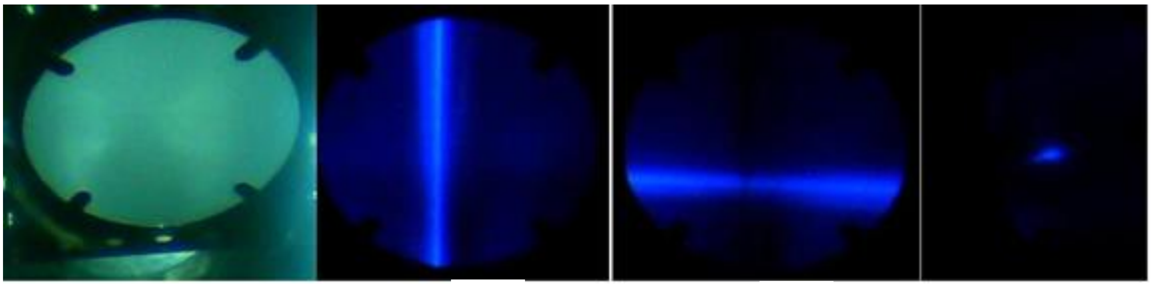


Figure 12:
Ion current values corresponding to different pressure values

The screen is placed to observe the ion beam at the end of the beam line. The conditions of the particle beam can be monitored with the cameras set on the phosphor screen at the entrance and exit of the beam line. Two quadrupole magnets were used for a clear focus. It was placed for quadrupole magnets at 20 cm and 50 cm positions after the acceleration section. The magnetic field and gradient at the pole tips of the first quadrupole were taken to 310 Gauss and 1 T/m, respectively. The magnetic field and gradient for the second quadrupole were taken to 465 Gauss and 1.5 T/m, respectively. The beam images obtained from phosphor screen for 50 keV proton beam are given in Figure 13. The simulation and the measurement results are expected for the beam line transmission.



a. *b.* *c.* *d.*

Figure 13:

a. *View of phosphor screen (no beam)* ***b.*** *Effect of first quadrupole* ***c.*** *Effect of second quadrupole* ***d.*** *Focus with two quadrupoles*

5. CONCLUSIONS

The first DC Proton Accelerator was designed at TAEK SANAEM [7]. A stable ion and electron beams are produced by designed ion source and accelerator tube. Accelerator components such as quadrupole magnet, dipole magnet, steering magnet, Einzel lens etc. have been designed and manufactured in the phase of low energy DC linear ion accelerator construction. Charged particles are accelerated by accelerator parts with a potential difference of 0-100 keV. Ion beam was obtained by means of accelerator parts. The phosphor screen at the exit of the beam line was used to measure beam characteristics. It has been found that the performance of the ICP type ion source depends on the working pressure, applied RF power, good impedance matching with plasma, applied external magnetic field and the extraction potential.

The results in the simulation programs are consistent with the images and measurements obtained through the phosphor screen.

As a result of these studies, experience is gained in high vacuum, magnet design for bending, focusing of charged particles and beam profile measurements. Given the important developments in recent years regarding particle accelerators in our country, it is very important to advance the work in these areas.

ACKNOWLEDGMENTS

This study is supported by TAEK under the Grant No TAEKTR-2014-1. The author is grateful to E. Recepoğlu, A. Alaçakır, Y. Akgün, S. Bölükdemir ve E. Durukan for their support, discussions and comments.

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