DEVELOPMENT OF A 13.56MHZ RF IMPLANTER AT PEFP *

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Abstract

In the RF linac, the RF system is roughly half of the total cost. The 13.56MHz rf generator is cheap and readily available. Therefore, an rf implanter which uses a cavity operating at the frequency of 13.56MHz has now been considered and developed at Proton Engineering Frontier Project (PEFP) - Korea. The implanter consists of a Duoplasmatron ion source, a triplet focusing magnet, an rf cavity, a bending magnet and an end chamber. It can accelerate particles up to 32keV/u for charge to mass ratio of 1/4. The implanter design concept, fabrication, testing and commissioning are presented in this presentation.

INTRODUCTION

Ion implanters are now widely used in many fields of science and technology. The main advantages of ion implantation are easy and precise control of the dopant concentration, elimination of the contamination and avoidance of the secondary phase. Therefore, an rf implanter which uses a cavity operating at the frequency of 13.56MHz has now been considered and developed at Proton Engineering Frontier Project (PEFP) - Korea. The implanter consists of an ion source, a compact magnetic quadrupole triplet acting as the focusing magnet, an rf cavity and a 90 degrees bending magnet. The total length of this structure is about 4m.

Our motivation was started from the split-ring resonator used in the Argonne National Laboratory (ANL) superconducting heavy ion linac which operates at 98 MHz [1]. In this paper, we present a new design of a cavity working at 13.56 MHz by adding an inductive coil to increase the inductance. The reason for choosing this frequency is that 13.56MHz generator is inexpensive and readily available. As we known, in the rf linac, rf system is roughly half of the linac cost. With this new concept, the beam cost and machine size are remarkably reduced.

ION SOURCE

A duoplasmatron ion source has been designed. It has three electrodes which are cathode, intermediate electrode, and anode. Plasmas are generated by arc discharges between the cathode and the anode. Arc plasma is generated by one mm diameter tungsten filaments. High-density plasmas are formed by being compressed geometrically in the 0.7 mm diameter hole of the molybdenum anode and then magnetically in the strong nonuniform magnetic field between intermediate electrode and anode. The intermediate electrode is made of soft iron to guide magnetic field lines and shield out the extraction zone. A ceramic expansion cup has been put in front of the anode to reduce plasma loss. Beam extraction geometry is simulated and confirmed by using IGUN code. The simulated beam profile with this extraction geometry shown in Fig. 1 provides beam currents of 10 mA at an extraction voltage of 30 kV. Arc currents of up to 15 A can be provided in this source.

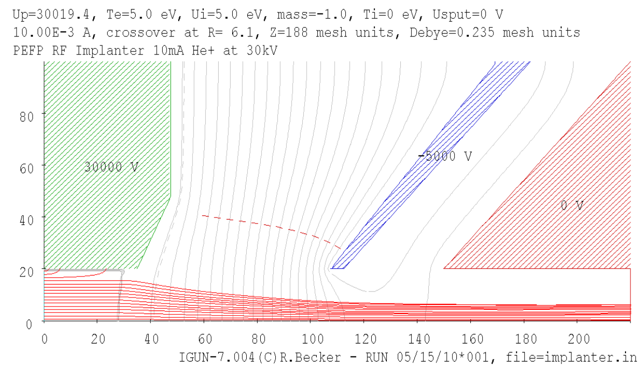

Figure 1: IGUN simulation for the ion source

FOCUSING MAGNET

The focusing magnet is a compact magnetic quadrupole triplet [2] consisting of 12 poles (low carbon steel), 8 coils (hollow oxygen free cooper) and 8 return yokes (low carbon steel). The gradient in centre pole and outer quadrupoles are 2.1 T/m and 1.12 T/m, respectively. The number of ampere – turns is 4000 and the power dissipation is 76W at 40A. The simulated and measured magnetic field of this focusing magnet is shown in Fig. 2.

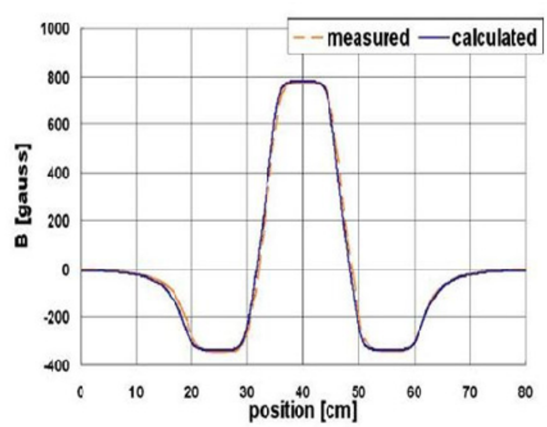

Figure 2: Magtic flux profile of the triplet [2]

ACCELERATION CAVITY

The cavity is based on TEM class cavities with the desired beta being 0.008. The operation frequency is the first term that should be determined. In this work, a frequency of 13.56MHz which is widely used for rf

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plasma generation was chosen. To minimize the power required to obtain a given electrode voltage, the product of the quality factor Q and the characteristic impedance Z must be maximized. The optimization was reached by varying all the geometry parameters and keeping reasonable characteristic impedance at a fixed outer diameter in order to get the highest possible shunt impedance and quality factor. The outer diameter was determined upon by the compromised considerations of costs, space and so on.

The 3D model of this cavity is given in Fig. 3. It consists of an inductive coil having a circular cross section, the accelerating electrodes which are directly coupled to the beginning and end of the inductor and a ground electrode for the inductor. Each electrode is separated by gaps where the particles gain energy while passing the gaps. To prevent the coil from vibration while operating in high electric field, the windings are supported by ceramic rods. The radio frequency signal is capacitively coupled to the high-voltage end of the inductor via a coupling capacitor. From this model, it can predict an approximate capacitance from the parallel plate

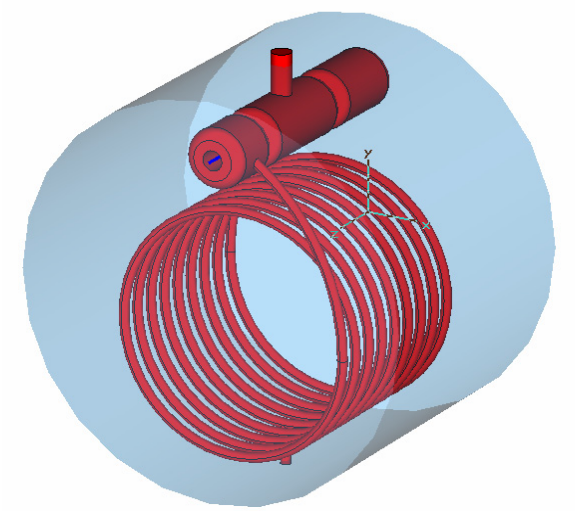

Figure 3: 3D model of the cavity

formula of $C = \varepsilon_0 \pi d^2 / 4g$ and the inductance of the coil can be calculated by $L = \mu_0 N^2 A / l$ where d is the electrode diameter, g is the gap length, ε_0 is the permittivity of the free space (8.854×10^{-12} F/m), μ_0 is the permeability of free space ($4\pi \times 10^{-7}$ H/m), N is the number of turns, A and l are the cross-section's area (m^2) and length (m) of the coil, respectively. The resonance frequency of the cell is given in this model by $\omega_0^2 = 1/LC$. The capacitance and/or the inductance can be increased to obtain the operational frequency as low as 13.56MHz. In this research, increasing the inductance is our choice because it is the easier way by means of adding more windings. The inductor which was made by hollow stainless steel with a cross section of 10mm was carefully designed by concentrating the mutual and proximity effects. The number of turn is nine and gap size is 6mm. As calculated, the inductance and capacitance in this geometry are 45 uH and 3pF, respectively.

The beam dynamics of this cavity was investigated with the aid of TRACE-3D. We defined the synchronous phase for a certain particle traversing a given field with respect to that of rf phase, thus, producing maximum energy gain. In this study, the synchronous phase was conveniently determined at -30^0.

The ^{4}He ion beam was chosen for a case study. For this configuration of the cavity, particles will travel in the first and third electrodes in half period and full period in the second electrode. For RF acceleration, the cell length L and energy gained are given by [3]

$$\text{Half period} \quad L_c = \beta\lambda / 2 \qquad (1)$$

$$\text{Full period} \quad L_c = \beta\lambda$$

where λ is the free space wave length of the rf and β is the particle velocity in units of the speed of light. For a synchronous particle, the energy per nucleon gained at the gap is

$$\Delta E = \frac{q}{A} V_{gap} T \cos\phi \qquad (2)$$

where q/A is the charge to mass ratio of the particle, Vgap is the peak voltage between the gaps, T is the transit time factor and ϕ is the synchronous phase. By applying (1) and (2), the basic parameters of the cavity were determined. The best values for this cavity are given in Table 1.

Table 1: Design parameters of the cavity

Parameter	Unit	Value
Operation frequency	[MHz]	13.56
Input beam energy	[keV/amu]	7.75 (for He-4)
Output beam energy	[keV/amu]	32.5 (for He-4)
Total length of cavity	[mm]	294
Cavity inner diameter	[mm]	400
Drift tube diameter	[mm]	60
Gap length	[mm]	6
Beam aperture	[mm]	2

From TRACE-3D simulation for $^4He^{+1}$ ion trajectory in the cavity, we determined the electrode lengths of 47, 128 and 73mm, respectively. The transverse emittance (normalized rms) was 0.2pi mm.mrad. The zero current phase advance per focusing period should be less than 90^0 in order to maintain the beam envelop stability. In our case, the phase advance was 68^0 fulfilling the requirement for beam stability.

The MicroWave Studio program was employed to simulate the field distribution and the rf properties of the cavity. The Kilpatrick criterion (or rf electric breakdown) at 13.56MHz is 5.9MV/m. In our study, the peak field is 0.82Kil. The simulation results are summarized in Table 2.

Table 2: RF properties of the cavity

Parameters	Unit	Value
Number of cell	[ea]	3
Maximum gap voltage	[kV]	29.8 - 32.6
RF power	[kW]	1
Effective shunt impedance per unit length	[MΩ/m]	50
Surface resistance	[mΩ]	3.54201
Peak field	[MV/m]	0.817 Kil
Quality factor		2500
Transit time factor		0.94

When the RF is turned on, the power is mainly dissipated into the coil. The coil is cooled by two separate cooling circuits inserted via the coil supporter. The cooling line diameter is 3mm and the water velocity is assumed to be 0.5m/s. This structure will be mounted inside a vacuum tank that provides the high vacuum conditions required by the beam, the rf power, and the linac structure. The tank will be evacuated by a 280L/s turbomolecular vacuum pump and will typically operate in the $1x10^{-7}$ Torr range. The grills were installed to prevent the rf loss through the pumping port, but they also reduce the conductance of the port. The O-rings and c-shape seals were used for the vacuum and RF seal. The compression set of the viton is about 20% at below 200^{0}C, and the required compression force is about 1.6 kg/cm. Material of the seal is silver coated BeCu produced by the Bal Seal engineering. A picture of the cavity under construction is given in Fig. 4

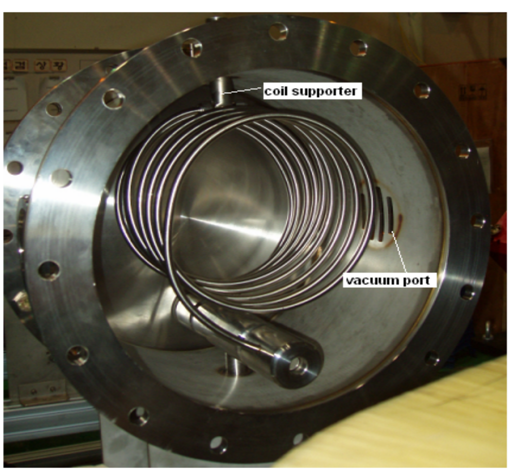

Figure 4: Picture of the cavity under construction

BEAMLINE

The beamline is composed of a bending magnet, a beam profile monitor and an irradiation chamber. The irradiation chamber is equipped with a Faraday cup and a target holder which has a cooling system. Bending magnet with edge focusing is installed to bend the helium ion into the target chamber. The radius of the magnet is 0.6 m and the beam defection angle is 90 degree. The inlet and the outlet edge angles of the magnetic dipole are 13 and 15 degrees, respective for vertical focusing of the ion beam. The measurement of magnetic field versus the coil current is presented in Fig. 5. Measurement of fluence distribution will be carried out after the test of the helium beam acceleration.

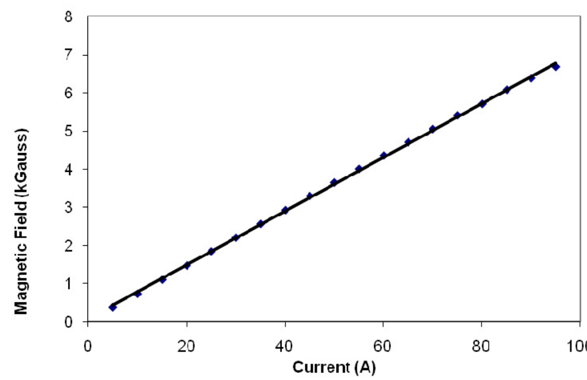

Figure 5: Magnetic field of the bending magnet

CONCLUSION

In this paper, a development of a 13.56 MHz RF implanter is introduced. The ion is first generated by a duoplasmatron ion source, focused by a triplet, accelerated in a 13.56 MHz RF cavity and then bended by a 90 degree bending magnet in to the target chamber. The total length of this system is 4m. The maximum beam energy gained is 100keV/ cavity. In the rf linac, rf system is roughly half of the linac cost. With this new concept of the rf cavity, the beam cost and machine size are remarkably reduced. This system can be used in the variety of applications such as semiconductor industry, catalyst, nuclear material as well as in health science researches

ACKNOWLEDGEMENTS

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