

DEVELOPMENT OF 1MV TANDEM PROTON ACCELERATOR*

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Abstract

A 1MV Tandem Proton Accelerator is being developed for the industrial applications such as high-energy implantation and explosive detection. The proton accelerator consists of a 10mA negative hydrogen ion source, two Einzel lens, accelerating tubes, a gas stripper, a 1MV 30mA Cockroft-Walton high voltage power supply, vacuum pumping system, and a high pressure insulating gas system. The large current proton beam can be accelerated in optical system, which is designed with simulation including space charge effect. The simple optical geometry is adapted for the optics design for the accelerator. The 2MV/m accelerating tube is being developed for this accelerator, and the detail of the accelerator development is reported.

1 INTRODUCTION

KAERI is developing a 1MV Tandem Proton Accelerator for high-energy implantation and explosive detection. The specifications for proton beam, which are given by the applications, are shown in Table 1. Due to industrial applications, proton beam with high current but poor quality is necessary. The size of the accelerator should be small, the cost should be cheap, and the control should be easy.

Table 1: Proton Beam Specifications

Particle	Proton
Max. Energy	1.8MeV @ 10mA
Energy Spread	± 2%
Max. Beam Current	10mA
Current Stability	± 5% @ 10mA
Beam Size	<20 mm diameter (1σ) @ Target
Beam Divergence	<10mrad @ Target
Off-Energy Beam	<1%
Impurity	< 0.1%

The best method to obtain the proton beam with the specifications in Table 1 is to use a tandem accelerator. Because the beam quality requirement is low, energy analysing components can be eliminated. As the result of the preliminary study, the proton accelerator consists of a negative hydrogen ion source, Einzel lens, accelerating tubes, a gas stripper, an 1MV Cockroft-Walton high voltage power supply, vacuum pumping system, and a insulating gas system. The detail design study has been done, and accelerating tubes, the most important parts of this accelerator, are fabricated and tested.

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2 TANDEM ACCELERATOR DESIGN

The main focus of the design is that the accelerator should be small and simple. The simplest way is that all beam components are in straight line. The design has been done with this concept.

2.1 Beam Optics Design

For small current electrostatic accelerators, the matrix method can be used. But, for proton beam currents of 10mA, the space-charge effect should be included for beam optics simulation. The beam tracking code (IGUN), which can simulate beam trajectory with space charge effect, is used. The simulation model is that a 10mA 30kV ion source, an Einzel lens, a 50cm accelerating tube with 900kV potential difference, a 80cm stripper, and a 50cm accelerating tube with 900kV potential difference are in the same axis. The minimum beam size, with which the proton beam can pass through the stripper, can be obtained with the adjustment of the Einzel lens potential. The beam trajectory can be seen in Figure 1.

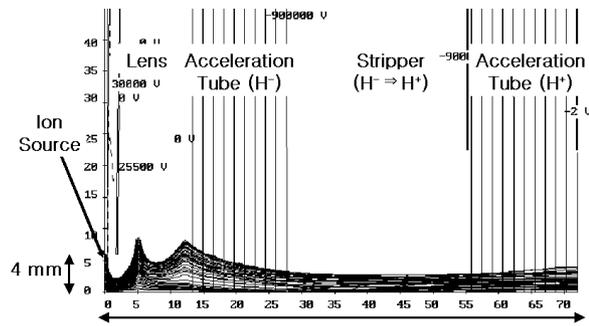


Figure 1: Beam trajectory simulation

The beam emittance from the ion source is 1.1cm-mrad with 8mm diameter, and it decreases to 0.4 cm-mrad at the exit of the accelerating tube due to the energy gain. The beam size and divergence is within the requirements.

The most important result of this simulation is that accelerating tubes with 2MV/m should be fabricated. For longer accelerating tubes, more protons can hit the stripper entrance. The diameter of stripper tube is 1cm, which is twice of the beam outermost size at stripper.

2.2 Stripper and Vacuum Design[1]

A stripper is put in the high voltage terminal, and changes negative hydrogen beam to proton. Due to large beam currents, a gas stripper is chosen. Considering vacuum pumping and stripping efficiency, nitrogen gas is

chosen, and the necessary nitrogen target density for >90% stripping efficiency is $2 \times 10^{16} \text{ \#/cm}^2$ (in vacuum unit, 1torr-cm). To obtain this target density, conventional differential pumping method using 50l/s turbo-molecular pump is used. The schematic diagram of the gas stripper is shown in Figure 2.

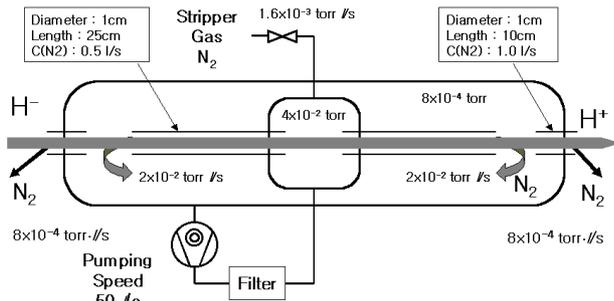


Figure 2: Schematic Diagram of Stripper

To reduce the beam loss due to the electron stripping with residual gases in the vacuum chamber and the accelerating tubes, the vacuum pressure should be less than 2×10^{-5} torr on the whole negative hydrogen beam path. The gas loads come from the ion source (H₂), the stripper (N₂), the accelerating tube (CO), and so on. To obtain this vacuum condition, 4 cryo-pump with 800l/s are used with apertures for the differential pumping. The schematic diagram of the vacuum pumping system is shown in Figure 3. For the vacuum calculation in the accelerating tubes with complex geometry, the Monte-Carlo method is used.

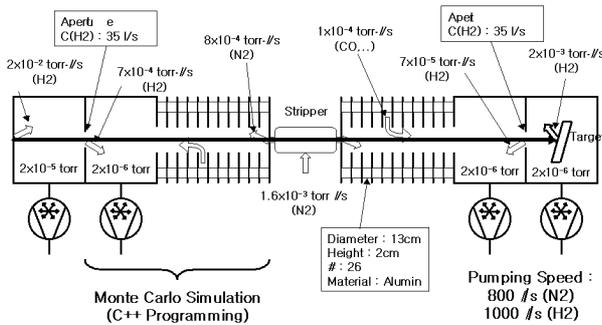


Figure 3: Schematic Diagram of Vacuum System

2.3 Accelerating Column[2]

The most important part of this accelerator is accelerating tubes, which have to hold 2MV/m electric field. Alumina has been chosen as insulator material because of its electrical insulating and mechanical property. The height of alumina ring is 2cm from optimisation of theoretical holding voltage and manufacturing problem as shown in Figure 4.

In accelerating tubes, a discharge starts on a triple-junction, at which the insulator, the vacuum, and the electrode meet. To suppress this discharge, the electric field strength at the triple-junction should be reduced. The alumina insulator is shaped to reduce the electric field in the triple-junction to 1/2 of flat geometry, as shown in

Figure 5. The accelerating tube is designed as shown in Figure 6.

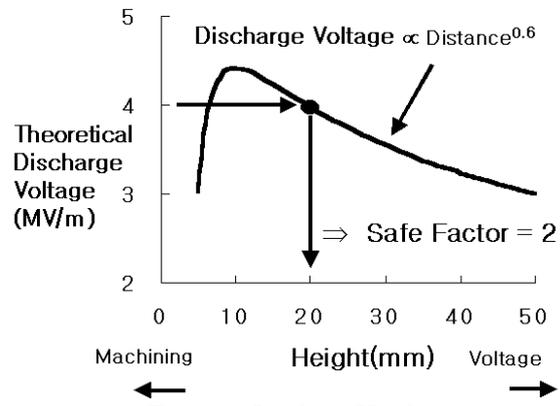


Figure 4: Insulator Height

Triple Junction E ~ 1/2 * Average E

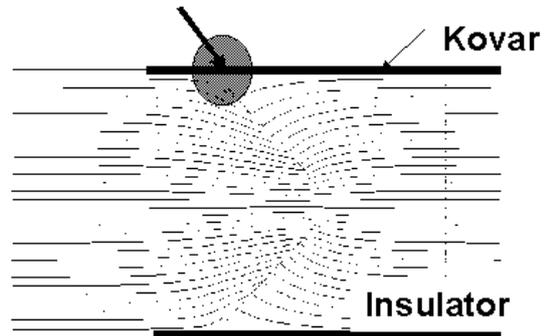


Figure 5: Insulator Shape

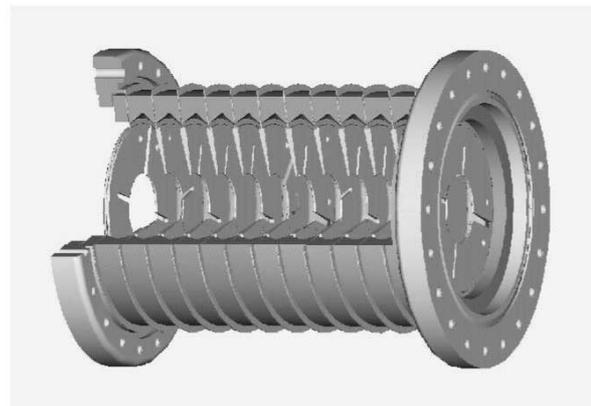


Figure 6: Designed Acceleration Tube

2.4 Design Summary

Figure 7 shows the schematic 3-dimensional drawing of the 1MV tandem accelerator. To increase the voltage holding capacity of the accelerating tube, hoops are put in each electrode. The accelerating tubes and the 1MV 30mA Cockroft-Walton high voltage power supply are put into the vessel with 0.5Mpa SF₆. The design value of insulating electric field in the pressure vessel is 100kV/cm. The total length of the accelerator is about 3m, which satisfies the size requirement of the accelerator.

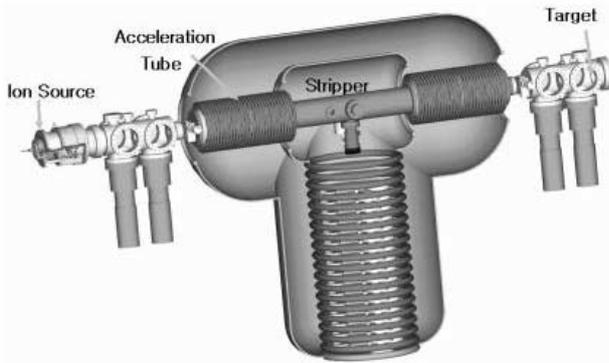


Figure 7: 3-D Drawing of 1MV Tandem Accelerator

3 ACCELERATING TUBE DEVELOPMENT

3.1 Fabrication and Vacuum Test

The accelerating tubes are fabricated with alumina rings and KOVAR electrode by brazing method. For reliable vacuum-tight brazing, the total height of brazing section is limited to 25cm. For 900kV accelerating tube, 2 sections are used with flange-connection. The accelerating electrodes are made of stainless steel, and installed to KOVAR electrodes like snap rings.

The vacuum property of the fabricated acceleration tubes, shown in Figure 8, is tested. The pressure reaches less than 10^{-8} torr within 100hr pumping-down with 50l/s turbo-molecular pump. The accelerating tubes have the sufficient quality for vacuum such as leakage and out-gassing.

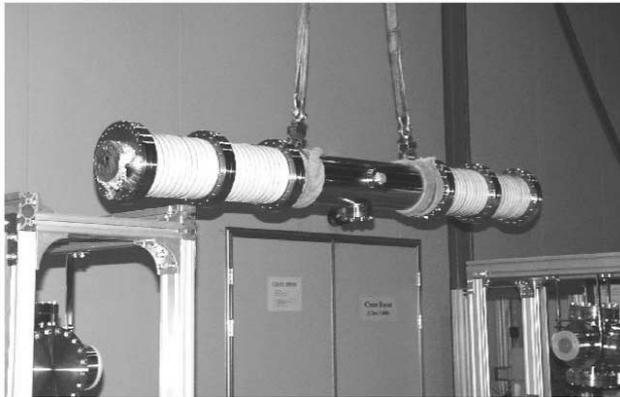


Figure 8: Acceleration Tubes

3.2 Assembly and High Voltage Test

The fabricated accelerating tubes are assembled with the stripper and the two vacuum chambers for the ion source and the target as shown in Figure 9. The pressure reaches less than 10^{-7} torr within 100hr pumping-down with 2 turbo-molecular pumps of 50l/s. The vacuum quality of the assembly is sufficient for the operation with 4 cryo pumps of 800 l/s.

For the high voltage test, a 150kV and a 400kV high voltage power supplies are used. The acceleration tube of one brazed section is tested to 150kV without any discharge in the air within 20min. This is 1/3 of the required voltage holding at 0.5MPa SF₆ vessel. The 400kV high voltage power supplies are used for high voltage test of the assembly, and the accelerating tubes are tested to 300kV without any discharge in the air within 20min. This power supply will be used for beam acceleration test after completion of ion source development.

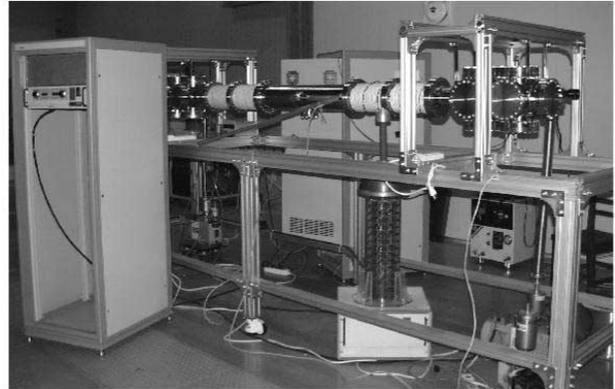


Figure 9: Acceleration Tube Test

4 SUMMARY

According to the specifications provided from the industrial applications and explosive detection, in which the beam quality is not considered, the 1MV tandem proton accelerator is designed. The size, the cost, and the simplicity of the accelerator are great concerns. The straight beam optics system is confirmed with beam trajectory simulation, and as the result the 2MV/m accelerating tubes development is important for the optics system. The designed accelerator satisfies the all requirements for the applications.

The most of the accelerator components are fabricated and test. The vacuum property of the acceleration tube is good for operation, and the high voltage property is also good in the air.

After the completion of ion source development, the beam acceleration test will be performed with 400kV high voltage power supply within this year. The experiments will show the validity of the beam optics calculation. The 1MV high voltage power supply will be manufactured within this year. And then the acceleration tubes will be tested completely. After the test, the beam acceleration experiments with the full voltage will be performed.

5 REFERENCES

- [1] A.Roth, "Vacuum Technology", North-Holland Publishing Company (1976).
- [2] V.N.Maller and M.S.Naidu, "Advances in High Voltage Insulation and Arc Interruption in SF and Vacuum", Pergamon Press (1981).