DESIGN, SIMULATION AND OPTIMIZATION OF A SOLENOID FOR ES-200 ELECTROSTATIC ACCELERATOR

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Abstract

Solenoids have an important role from the viewpoint of focusing the beam in drift tube of charged particle accelerators. In order to optimize the beam current in ES-200, an electrostatic proton accelerator at Shahid Beheshti University (SBU), design and simulation of a suitable solenoid has been performed. The CST Studio package has been used for simulation and design. Simulation results from the CST have been validated in comparison with theoretical formula and equations. According to the results we optimized the design to have minimum lost beam current on drift tube.

INTRODUCTION

ES-200, an electrostatic proton accelerator at SBU, is a compact and portable electrostatic accelerator, which includes the basic components of a Cockcroft-Walton high voltage terminal, accelerating column, vacuum system, electromagnetic lens, drift tube, control system and etc. In this system a radio frequency ion source has been used to generate positive ions. Extraction voltage (adjustable from 0 to 5 kV) applies to the anode electrode for leading the ions to the entrance of accelerating column. Accelerating column has been composed of thirteen electrodes that can be divided into two main parts. The first part includes four electrodes for extracting, focusing and accelerating the ion beam. The second part includes nine electrodes with uniform shape which provide homogeneous field to accelerate and steer the beam. The maximum beam current on the target is about 500μA with the maximum energy of 200 keV. [1].

In order to optimize the beam current in ES-200, designing and simulation of a focusing system seems to be necessary. Magnetic lenses such as Solenoids, Quadrupoles and electrostatic lenses like Einzel lens are devices that are used as a focusing system in accelerators. In this paper, for minimizing the lost beam current on drift tube and changing the beam diameter on the target, design and simulation of the solenoid has been done by using the CST package.

DESIGN CONCEPTS

As it can be seen in Figure 1, On-axis longitudinal magnetic field for a single solenoid with the internal radii (r_1), external radii (r_2) and length of (l) is given by:

$$B= \frac{\mu_0 in}{2(r_2-r_1)} \left[x_2 \ln \frac{\sqrt{r_2^2+x_2^2}+r_2}{\sqrt{r_1^2+x_2^2}+r_1} - x_1 \ln \frac{\sqrt{r_2^2+x_1^2}+r_2}{\sqrt{r_1^2+x_1^2}+r_1}\right] \quad (1)$$

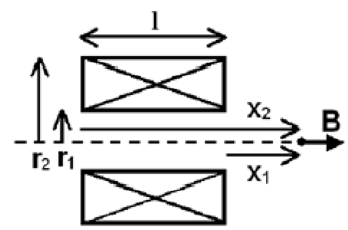

Figure 1. Solenoid in cross section view.

Where B is the magnetic field on the axis, μ_o is the permeability constant, (i) is the wire current , n is the number of turns of wire per unit length of solenoid, and x_1 and x_2 are the distances, on axis, from the ends of the solenoid to the magnetic field measurement point [2].

Some of electromagnetic codes have been used to solve Maxwell's equation with the specified boundary conditions. CST was introduced as software that analyses the structure with Finite Element Method. In this paper, CST PARTICLE STUDIO has been used to simulate charged particles travelling through electromagnetic fields [3]. Figure 2 and 3show an overview of a desired solenoid on the drift tube which was done by CST for a proton beam with energy of 200 keV (after passing through the accelerating column). The length and thickness of solenoid was considered 180 mm and 100 mm, respectively. Solenoid was set at distance of 450 mm from the end of accelerating column. Beam diameter was investigated at distance of 768.5 mm from the solenoid where the target was placed.

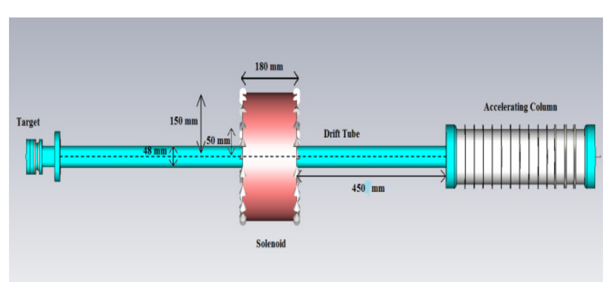

Figure 2. Simple model of a typical ES-200.

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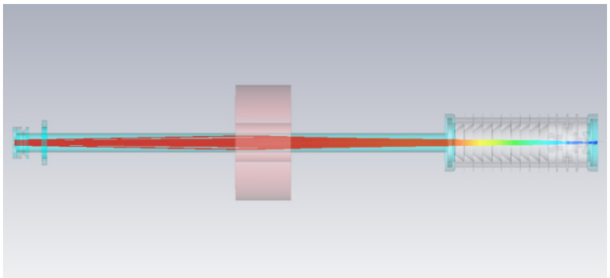

Figure 3. Focusing of the beam on the drift tube by desire solenoid in CST.

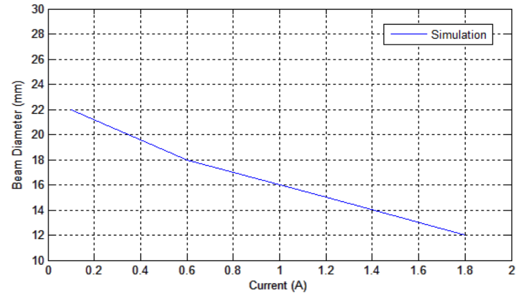

Figure 5. Beam diameter as a function of current in CST.

RESULTS

Behaviour of the B-field at different distances on solenoid axis has been shown in Figure 4. It can be seen that there is a good agreement between simulation results and theoretical calculations.

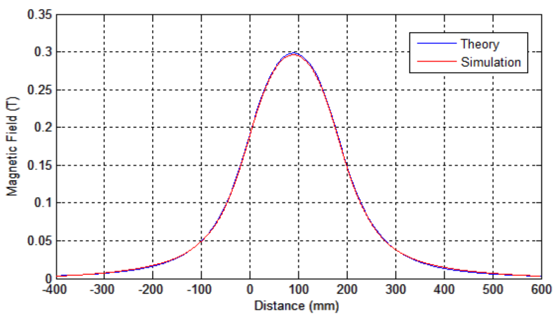

Figure 4. Simulated magnetic field by CST (red) in comparison with calculated magnetic field (blue) at different distance on the axis of solenoid

Beam diameter as a function of current has been shown in figure 5. It can be seen that an increase of the current was accompanied by a decrease of the beam diameter measured at target position. Changing the solenoid current from 0.1 to 1.8 Ampere, beam diameter was varied from 22 to 12 mm. finally the design was optimized for minimum beam loss.

CONCLUSION

In this work, for minimizing the beam current loss on drift tube and changing the beam diameter on the target, designing and simulation of a solenoid was studied. Maximum B-field was found in the solenoid centre. Changing the solenoid current from 0.1to 1.8 Ampere, the diameter of the beam can be change from 22 to 12 mm. This paper covered the basic methodologies used to obtain an identical solenoid so that it is ready to be constructed for our proton electrostatic accelerator.

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