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PARTICLE DYNAMICS OPTIMIZATION IN DTL

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Abstract

The research concerns ion dynamics in linear accelerators with drift tubes (DTL). Permanent quadrupole magnets are placed inside some of the drift tubes. Frequency of the field is 432 MHz. Electromagnetic fields and particle dynamics in the cavity are calculated using Comsol Multiphysics software. The input energy of the beam is 6 MeV, output 10 MeV. Initial beam is assumed to come from Radio Frequency Quadrupole accelerator (RFQ). The considered parameters are drift tubes radii, cavity diameter, gradient of the magnetic field from quadrupoles inside drift tubes and focusing lattice. Effectiveness is estimated by the emittance growth.

INTRODUCTION

The initial part of the injection system of a large ion accelerator often consists of injector, radio-frequency quadrupole (RFQ), drift tube linear accelerator (DTL). This structure is used, for instance, in the Spallation neutron source (SNS) facility in USA [1]. In this study we consider a similar tank with 22 drift tubes mounted inside (Fig.1).

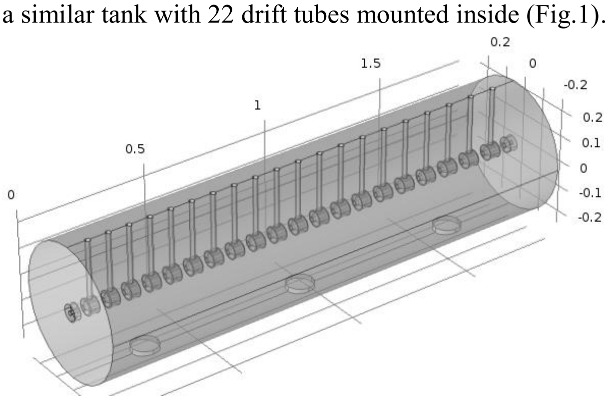

Figure 1: Tank model.

The parameters of the structure are listed in Table 1.

Table 1: DTL Parameters

Parameter	Value
Frequency	432 MHz
Particles	H^-
Input Energy	6 MeV
Output Energy	10 MeV
Cell length	$\beta\lambda$
Gap coefficient (L/L_{gap})	0.25
Drift tube number	22
Tank length	1.863 m
Channel diameter	16 mm

Tube walls are trapeze-shape in section with rounded corners to avoid breakdown. Focusing is provided by permanent magnet quadrupoles, placed inside some drift tubes. Some drift tubes are left empty without magnets. The configuration of the focusing lattice is discussed below. Magnets can be magnetized in two layouts which create focusing and defocusing field. 3 slug tuners are placed inside the cavity to adjust radio frequency.

DESIGN

The model of the tank is created using Comsol Multiphysics - a general-purpose software platform, based on advanced numerical methods, for modeling and simulating physics-based problems [2].

Field Distribution

In the model with preliminary calculated parameters, the first thing to adjust was a resonance frequency of the electric field. The working frequency is 432 MHz. To gain this value the following parameters were altered: cavity diameter, inner and outer diameter of drift tubes, slug tuners.

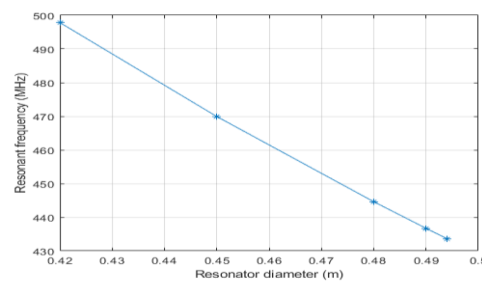

Figure 2: Dependence of the cavity resonant frequency on the cavity diameter.

At first, cavity diameter was estimated (Fig. 2). For the desired value of frequency the appropriate diameter was calculated as 49.6 cm.

To adjust the resonant frequency by means of drift tube diameter at first a constant value of inner and outer diameter was used. But the results were not satisfying. Later the drift tubes were divided into three parts of 11 drift tubes with increasing outer diameter value. Thus, the inner diameter of drift tubes is constant – 16 mm, and outer diameter is 58 mm for first part, 60 mm for second and 62 for third.

The calculation in Comsol Multiphysics of the resonant frequency of the structure uses finite element method. For this purpose the mesh of around 95000 tetrahedral elements was built. While solving eigenfrequency problem Comsol solver provide a number of eigenfrequencies nearest to the specified value. As for the case of desired 432 MHz nearest values were 422.57 MHz and 436 MHz. The gap between these values seems to be tolerable enough.

Three slug tuners are mounted inside, each one of 10 cm diameter. To make the field distribution more uniform slug tuners are set as 1 cm, 1 cm and 3 cm height. After adjusting cavity diameter, drift tubes radii and slug tuners, the

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final accelerating electrical field normalized distribution along the accelerator axis has the following shape (see Fig. 3):

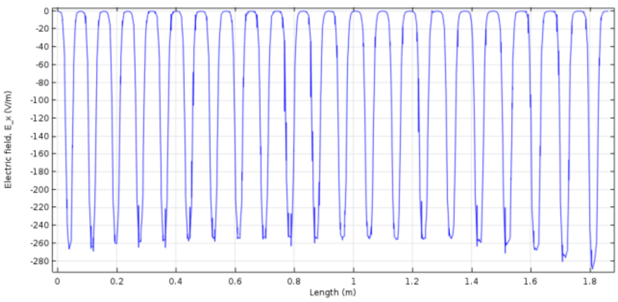

Figure 3: Accelerating electric field distribution along the axis, field frequency is 432.28 MHz.

Permanent Magnet

Permanent quadrupole magnets are placed inside some of drift tubes (Fig.4). All magnets are of the same length 5 cm.

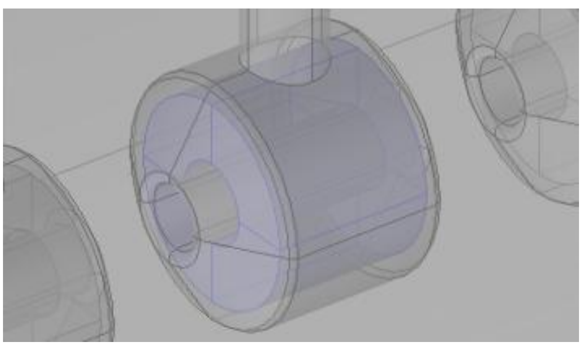

Figure 4: Permanent magnet inside drift tube.

The paper [3] presents the detailed analysis of the permanent quadrupole magnet lenses for the prototype of proton microscope for FAIR (GSI). The results from this work were used for the magnetic field distribution representation, magnetic field is assumed radial in the plane normal to the centre axis:

$$B_r = G(z) r \cos(2\varphi)$$

where $G(z)$ is a field gradient along the centre axis of accelerator and z, r, φ are polar coordinates with z-axis coincide with accelerator axis. Field gradient is approximately a rectangular function with smoothing on both ends. The variation of amplitude of the field gradient as well as magnets placing order were analysed with regard to particle dynamics.

DYNAMICS

Particles are presented as large particles with mass 10000 times bigger than real one. Particle dynamics is calculated using Newtonian 2 order equations. Forces taken into account are accelerating electric force, transverse magnetic force from lenses and Coulomb force for particle interaction. The amplitude of electric force necessary to reach 10 MeV was calculated as 10 kV/m.

The initial beam properties are shown in Table 2.

Table 2: DTL Parameters

Parameter	**Value**
Maximum transverse displacement	1.6 mm
Maximum relative transverse velocity	0.01
Transverse distribution type	KV
Phase space ellipse rotation angle θ	0.01 rad.
Energy spread	10%
Bunch length	10 mm

Two different types of focusing lattice commonly used were considered: FFDD00 and F0D0 (F – focusing, D – defocusing, 0 – empty drift tube). The variation of amplitude of the magnetic field gradient was studied in the range 2…10 T/m.

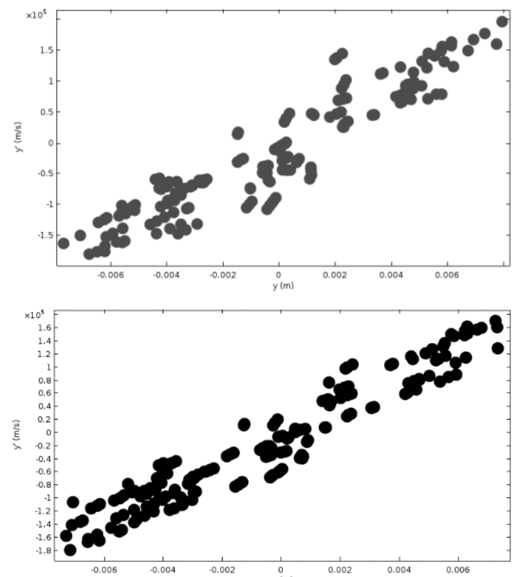

Figure 5: Transverse output beam emittance, magnetic field gradient (top) 4 T/m, (bottom) 2 T/m.

To compare the simulation results for these 2 lattices the output beam transverse emittance was estimated. The difference was negligibly small. The simulation showed than increasing the amplitude of magnetic field gradient over 4 T/m results in decrease of transmission rate. Best transverse emittance values were obtained at 2 T/m field gradient and were 10% better than at 4 T/m (Fig. 5).

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