ON APPROACH FOR RESONANT FREQUENCY TUNING IN DRIFT TUBE STRUCTURES ON THE DESIGNING STAGE

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Abstract

Current research considers the crossbar H-mode linear resonant accelerator with drift tubes mounted inside the cavity. The focus of the study has been on the dependence of resonant frequency on the parameters of the geometry. Since Alternating-Phase-Focusing (APF) type of accelerator is investigated, the efficiency of the operation depends on the synchronization of the charged particle velocity and accelerating field oscillations. Researchers can control it by the variation of longitudinal size of the cells of the structure (periods). On the other hand, the effective performance of this resonant system requires the equality of resonant frequencies of its cells, because it affects the uniformity of accelerating field distribution along the axis. The diversity of cells longitudinal sizes causes the deviation from the particular value of the resonant frequency. This aberration can be eliminated by the adjustment of other geometry parameters period's length, gap length and drift tube radii. We have conducted the study to analyze the relation between resonant frequency and these values. Using the this dependency we can tune the geometry parameters of each period in the structure. We first create the computer-aided design (CAD) geometry model of the accelerator cavity. Then, using Comsol Multiphysics, the platform for physics-based modeling and simulation, we conduct the calculation of resonant frequencies.

INTRODUCTION

On the first steps of linear accelerator production many parameters of the structure should be considered. One of the main parameters - period's lengths L is determined by the synchronous phase sequence. It is quite difficult for analytic field approximation model to embody many other structure parameters such as drift tube inner and outer radii and holder position and thickness. Of course, one can do a numerical simulation with any given geometry. Accelerator structure usually consists of dozens of periods, each one characterized by 5-6 parameters. The field computation of all acceptable combinations of parameters is severely time-consuming. Therefore, in the study we investigate the dependencies between electric field and some particular geometry parameters.

FREQUENCY CALCULATION

The resonant frequencies of the periods can be significantly different because length of periods are not equal. In this case the amplitude distribution of the electric field in the cavity is non-uniform, which requires considerable additional tuning. However, the resonant frequency of each period can be adjusted by means of gap length, drift tube radii and holder design [1]. With the appropriate choice of this parameters period frequency of some estimated value can be obtained. If we fix values of some basic parameters like cavity radius and holder design we can calculate the dependencies of resonant frequency from period's length, gap length, drift tube radii.

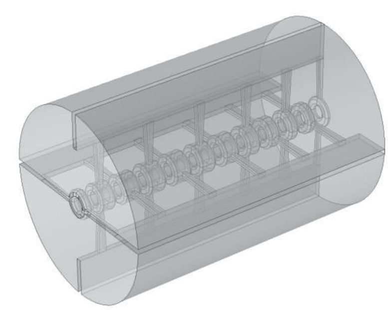

Figure 1: CAD model of the cavity with 11 periods.

In order to calculate the dependency we have created a computer-aided-design (CAD) geometry model of the cavity (figure 1). We are using COMSOL Multiphysics together with MATLAB. COMSOL Multiphysics is a general-purpose software platform, based on advanced numerical methods, for modeling and simulating physics-based problems. Its toolbox LiveLink for MATLAB allows us to utilize the full power of MATLAB as well as use COMSOL Multiphysics functions in the MATLAB script file (.m).

The volume of the cavity ω has a boundary surface S. The electric field E inside the volume satisfy the Helmholtz equation (1).

$$\nabla^2\mathbf{E} - \left(\frac{\omega}{c}\right)^2 \varepsilon_r\mu_r\mathbf{E} = 0. \qquad (1)$$

ε_r and μ_r are relative permittivity and relative permeability respectively. As for the boundary condition, we assume the perfectly conducting surface (2).

$$\mathbf{n} \times \mathbf{E}|_S = 0. \qquad (2)$$

To solve the problem (1)-(2) we use the finite-element solver of COMSOL Multiphysics - Radio Frequency, Electromagnetic Waves.

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DESIGN ALGORITHM

1. Assign cavity radius, drift tube inner radius and holder design. Decide on the range of geometry parameters that we want to analyze (Drift Tube Outer Radius, Pediod length and Pediod length). See Table 1.

Table 1: Analyzed Range of Geometry Parameters

Cavity radius (m)	0.0093
Pediod length (m)	0.020 : 0.01 : 0.035
Gap coefficient	0.2 : 0.1 : 0.7
Drift Tube Inner Radius (m)	0.0065
Drift Tube Outer Radius(m)	0.014, 0.017

2. Calculate the resonant frequency of one period corresponding to the each set of geometry parameters mentioned above and save all the data as a table. In this research we considered 2000 different sets.

3. Using the synchronous phase sequence calculate period's lengths.

4. From the previously made table choose the drift tube radii and gap length corresponding to the specified period's length and operational frequency (figure 2).

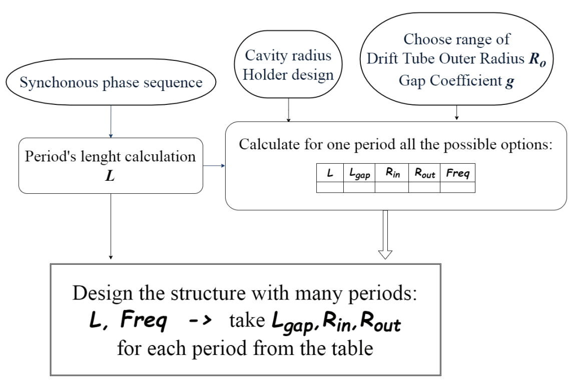

Figure 2: Design algorithm.

RESULTS

Computation of the resonant frequency for one period for 2000 different geometry parameters sets takes about 24 hours. Numerical simulation revealed that the resonant frequency of one period increases when period length and gap coefficient increases. But it diminishes with the increase of drift tube outer radius. The dependencies are shown in figure 3 and 4.

Period's length were calculated using synchronous phase sequence obtained before [2]. The questions of synchronous phase optimization are discussed elsewhere [3]. Target frequency is 433 MHz. Inner radius was fixed, gap length and drift tube outer radius of each period were chosen following Tuning Algorithm. The results are shown is the figure 5.

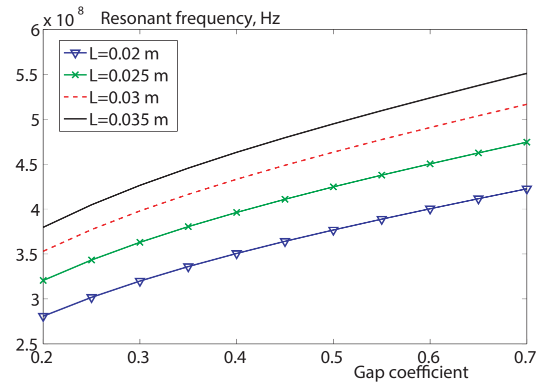

Figure 3: Dependence of resonant frequency on gap coefficient, $R_{outer} = 0.014m$ (for one period, 4 different period's lengths L considered).

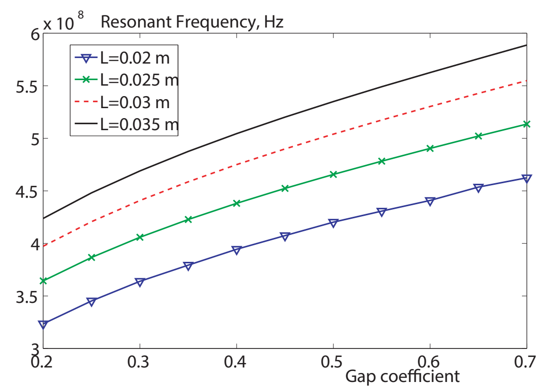

Figure 4: Dependence of resonant frequency on gap coefficient, $R_{outer} = 0.017m$ (for one period, 4 different period's lengths L considered).

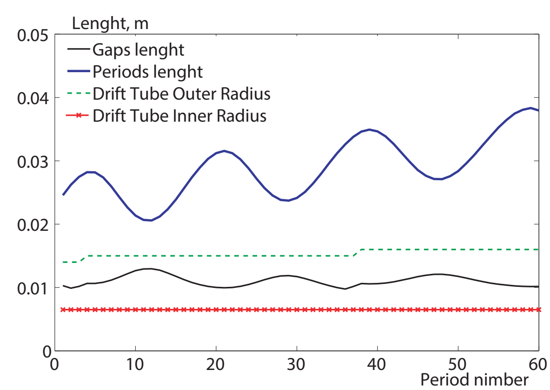

Figure 5: Calculated geometry parameters.

To check the efficiency of the method, electrical field was calculated in the obtained geometry. For the whole structure of 60 periods we made it in two ways: a) with constant gap length - figure 6 and b) with gap lengths, obtained by the algorithm - figure 7. To ensure the results, distribution of electric field was also calculated in electrostatic approximation (Poisson equation, finite difference method) using DAISI code [4]-[8].

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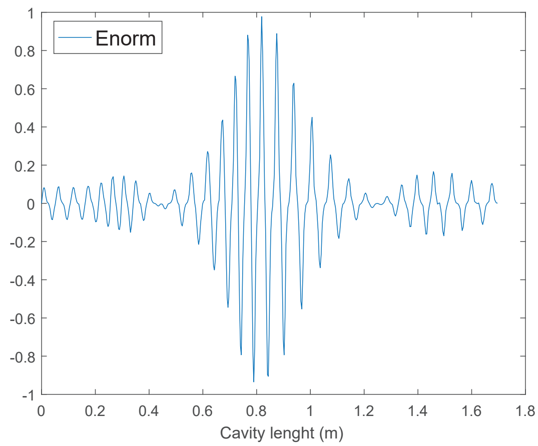

Figure 6: a) Electric field distribution, gap length = 0.01m for every period, resonant frequency 429 MHz.

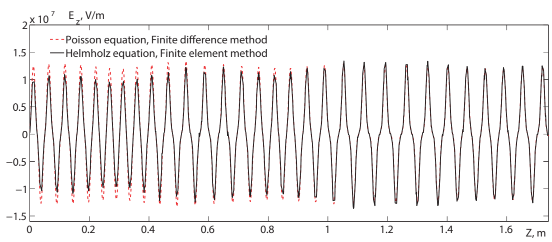

Figure 7: b) Electric field distribution, gap length chosen by the algorithm, resonant frequency 434.6 MHz. Consistent with calculation in electrostatic approximation.

With the use of the algorithm, axial distribution of the field is close to uniform which is a promising environment to gain good acceleration. Moreover, the resonant frequency of the structure (434.6 MHz) is closer to the target frequency (433 MHz) then in case of constant values (429 MHz). After assembling the cavity, a resonant frequency of a several hundred megahertz is typically within about a few megahertz of the target value [9].

CONCLUSION

The research was conducted in the area of linac resonant cavity design. The study indicated that resonant frequency increases, when periods length and gap coefficient increase. It is inversely proportional to drift tube outer radius. Based on these observations we can adjust parameters of each period so that its resonant frequency is close to the target frequency. This tuning makes electric field distribution much more uniform, which is considered to prove the effectiveness of the approach.

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