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2D TRACKING CODE FOR DRIFT TUBE LINAC

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Abstract

A 2D tracking code has been developed for Alternating-Phase-Focusing drift tube linacs (APF-DTL). This code can design DTLs with a 2D electric field simulation and particle tracking by approximate equations. In this paper, we describe an outline of the 2D tracking code and a comparison of 2D tracking results and 3D simulation.

INTRODUCTION

Ion linacs are being applied to Boron Neutron Capture Therapy (BNCT), International Fusion Materials Irradiation Facility (IFMIF), carbon cancer therapy facility [1-2] and so on. In general, ion linac systems consist ion source and radio frequency quadrupole (RFQ) and DTL. Basically, DTL doesn't have transverse RF focusing power. In order to apply the transverse focusing power, there are several approaches. For example, the DTL shall consists of quadrupole magnets into the drift tubes [3], quadrupole magnets into the DTL vacuum chamber [4-5], APF-DTL [1-3] and so on.

To design the APF-DTLs, there is no commercial design code. So, we usually design APF-DTLs using 3D simulations. First, we determine cell parameters by a synchronous phase pattern. Next, we calculate the 3D electric field according to a structure obtained by the cell parameters. Figures of ridges, tubes and a tank are optimized to uniform the electric field of a beam axis by parameter search. Third, we confirm a particle behaviour in the 3D electric field by a 3D particle tracking code. If a particle transmission is low, we need to change synchronous phase pattern. So it is necessary to re-optimize the 3D electric field. It takes long time to design the APF-DTL.

Therefore, we developed a 2D tracking code for DTLs applying 2D electric field simulation and approximate equation for the particle tracking. In order to verify the accuracy of 2D tracking code, we compare with 2D tracking results to 3D results.

2D TRACKING CODE

Figure 1 shows the flow chart of the 2D tracking code. The code consists of 4 steps. A feature of this code is 2nd step b). For accuracy of tracking, a T/S factor [6-8] is calculated by 2D electric field of each cell. Maximum surface fields of the tubes are evaluated, too.

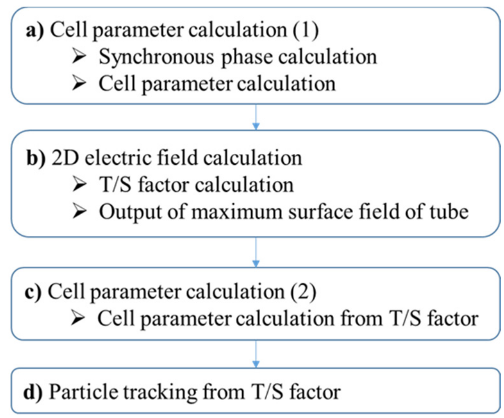

Figure 1:Flow chart of 2D tracking code.

a) Cell parameter calculation (1)
The cell parameters are calculated using input parameters which are synchronous phases, an injection energy, a bore radius, the electric field of each cell and a ratio of a gap length to a cell length. The synchronous phase of each cell could be input as a fixed value or variable values or a function. An energy gain of the cell and the cell length are converged to match the synchronous phases by iteration. The electric fields are input as the average electric field of the cell. For example, the electric field distribution from 2D or 3D simulation was averaged in each cell. Fixed value is available too. In the 1st step a), a transit time factor T is approximately calculated by Eq. (1).

$$T = \frac{1}{I_0(k_r a)} \frac{\sin\left(\frac{kg}{2}\right)}{\frac{kg}{2}}, \quad (1)$$

where k = 2π/βλ, kr = $k * \sqrt{(1-\beta^2)}$, g is a gap length, a is a bore radius. β is a velocity and λ is a wave length at the middle of the gap. I_0 is the modified Bessel function of 0-th order. The velocity and the cell length were converged by iteration.

b) 2D electric fields calculation
The 2D electric field of each cell is calculated by Poisson code. It is normalized to agree with the input average electric field at the step a). The T/S factor is calculated using the 2D electric fields. The T/S factor of a first part, which is from a cell entrance to the middle of the gap, are described in Eq. (2) and (3).

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$$\mathrm{T1} = \int_{-(\frac{g}{2}+L1)}^{0} \mathrm{E}_z(z, r=0) * \cos(kz)\, dz / V_0 \quad , (2)$$

$$\mathrm{S1} = \int_{-(\frac{g}{2}+L1)}^{0} \mathrm{E}_z(z, r=0) * \sin(kz)\, dz / V_0 \; , (3)$$

where g is the gap length, L1 is the length from the cell entrance to the gap entrance, V_0 is the integrated electric field along the beam axis from the cell entrance to the middle of the gap. The T/S factor of a second part is integrated from the middle of the gap to a cell exit, too. In addition, maximum surface fields of the tubes are evaluated in this step.

c) Cell parameter calculation (2)
The cell parameters are recalculated using the T/S factor which are deduced in b).

d) Particle tracing from T/S factor
A particle tracking using the T/S factor from b) and the cell parameters from c) is calculated. We could obtain a transmission, twiss parameters and graphical outputs.

2D DESIGN FOR APF-DTL

We designed a sample of APF-DTL using the 2D tracking code. An accelerating frequency, a charge to mass ratio of ion and an injection energy are 200MHz, 1/3 and 0.6MeV/u, respectively.

The synchronous phase pattern which we optimized by the 2D tracking code is shown in Fig. 2. The input average electric field is shown in Fig. 3. In this sample, 3D electric field distribution was used for comparison with 3D tracking. We evaluated the average electric field of each cell using the electric field distribution from the 3D electromagnetic simulation by using CST Microwave Studio (MWS) which the model has roughly optimized figures of ridges and tubes. The maximum surface field was evaluated 24 MV/m at the outer diameter 15 mm and the inner diameter 8 mm of the drift tube.

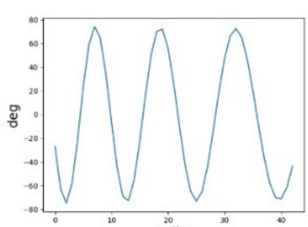

Figure 2: Synchronous phase of each cell.

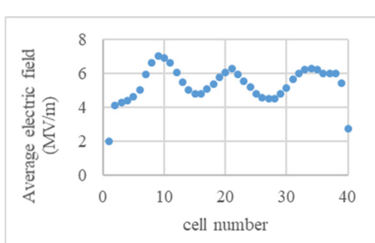

Figure 3: Electric field distribution from 3D simulation.

Figure 4 is shown in the results of the 2D tracking. The number of particles was about 1000, the calculation time including output of graphical plots was about 7 minutes with a laptop computer. The δW, the δϕ and the δr are oscillated along the beam axis according to the synchronous phase oscillation without the beam divergence. The input and output beam plot are shown in Fig. 5. The beam of the r-r' and the φ-W plane are focal. The beam transmission was 95.1 %.

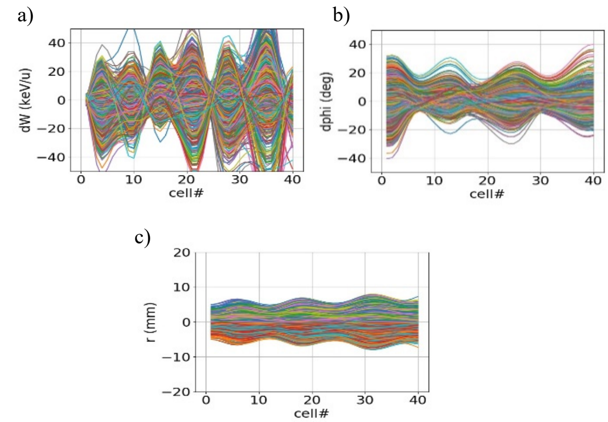

Figure 4: Results of beam tracking by 2D tracking code. a): δW, b): δϕ, c): δr versus cell number, respectively.

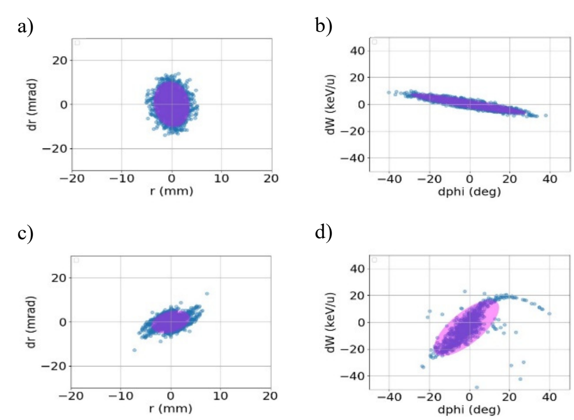

Figure 5: Input and output phase space distributions by 2D tracking code.

a) and b): input beam. c) and d): output.

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3D TRACKING

The 3D tracking using the General Particle Tracer (GPT) code and the MWS code was done for comparison with the results of the 2D tracking. The GPT code and the MWS code are generally used for accelerator designs. Figure 6 shows the results of 3D tracking. The same electric field distribution for the 2D tracking was used. The oscillation pattern of the δW, the δϕ and the δx are similar to the 2D pattern. The input and output beam plots are shown in Fig. 7. The distribution of each plot is similar to the result of 2D tracking.

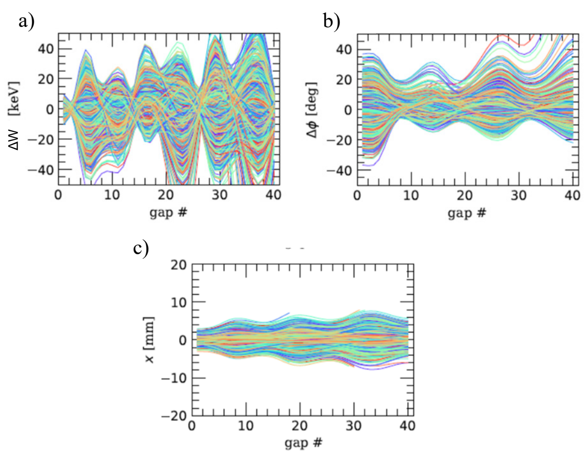

Figure 6: Results of 3D beam tracking by MWS and GPT. a): δW, b): δϕ, c): δx versus cell number, respectively.

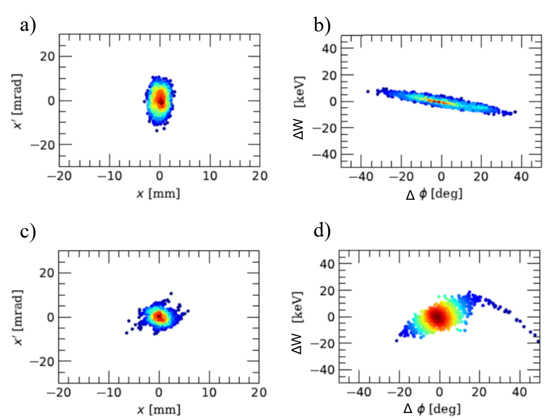

Figure 7: Input and output phase space distributions by MWS and GPT.

a) and b): input beam, c) and d): output beam.

The main parameters of the results of the tracking are listed in Table 1. As the same injection energy, we obtained the same extraction energy and similar length of DTL and the same transmission. We suppose the reason for the difference of the length is difference between 2D and 3D electric field.

Table 1: Design Parameters

Parameter	2D tracking	3D tracking	Unit
Injection energy	0.6	0.6	MeV/u
Extraction energy	2.03	2.03	MeV/u
Length	1.51	1.49	m
Transmission	95	95	%

As a result, we confirmed that the 2D tracking code had enough performance for wide parameter survey to design APF-DTLs quickly.

CONCLUSION

We have developed the 2D tracking code for the design of the DTLs. We have designed the sample of the APF-DTL. Through the optimization for the synchronous phase pattern, the beam divergence has controlled and we have gotten the transmission ratio of 95.1 %. The 3D tracking using the GPT and the MWS code has been done for comparison with the results of the 2D tracking. We have confirmed that the 2D tracking code had enough performance for wide parameter survey to design APF-DTLs quickly. After the rough design is determined by 2D tracking code, we will design the DTL using 3D simulations including tuners and a coupler for high accuracy.

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