IMPACT OF THE BEAM DYNAMICS SIMULATION FOR THE CONCEPT OF IFMIF ACCELERATOR

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Abstract

The control of the beam loss during the acceleration is a major concern about the deuteron linac design for the International Fusion Materials Irradiation Facility (IFMIF). The baseline design for an accelerator module employs the 175 MHz cw RFQ with 8-MeV, 125-mA output beam, and eight 175 MHz separated DTL tanks to provide 32-, 36-, and 40-MeV beams. A newly developed beam dynamics simulation code for high current linac based on the PIC method can be applied to confirm the accuracy of the design codes such as PARMTEQ, especially in the end regions of the RFQ. The effect of the fluctuation of the incident conditions and the RF control error to the final beam loss and the resulting loss of availability are also discussed.

1 INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based intense neutron source to develop the fusion reactor materials. A conceptual design activity (CDA) of the IFMIF [1] has been carried out under the IEA collaboration and the conceptual design was reported in 1996 [2]. Through the CDA and the following CDE (conceptual design evaluation) phase 1997-1998, the accelerator group has discussed about the basic problems to establish the baseline parameters, e.g. the accelerator type and the frequency, to achieve the users requirements on the irradiation neutron field [3]. The derived top-level performance required for the IFMIF accelerator is summarized in Table 1.

Table 1: Requirement list for IFMIF Accelerator.

Requirement	Specification
Particle type	D^{+} (H_2^{+} for testing)
Accelerator type	rf linac
No. of accelerators	2
Output current	250 mA
Beam distribution	rectangular flat top
Output energy	32, 36, or 40 MeV
& dispersion	± 0.5 MeV FWHM
Duty factor	CW
Availability &	≥88%
Maintainability	hands on
Design lifetime	40 years

The design choices based on the requirements are shown in Fig. 1. The total output current is provided by two identical 125-mA rf linac modules in parallel operation. This reduces the engineering risk to develop the high current machine and helps to continue the irradiation tests even when one of the two accelerator modules is failed.

In the following sections, the beam dynamics issues related to the design concept are overviewed and the new code developed for confirming the accuracy of the conventional design codes, like PARMTEQ, is introduced.

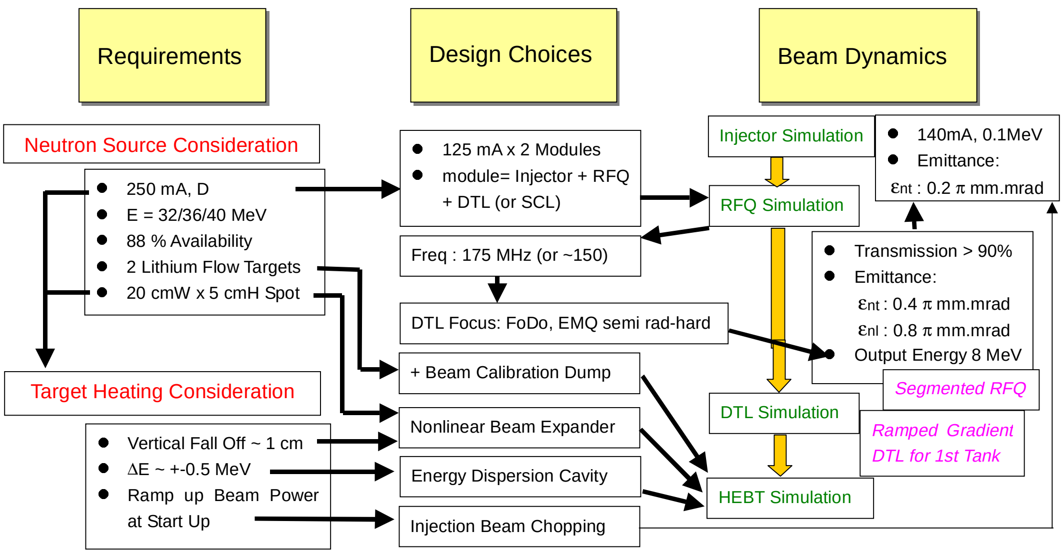

Figure 1: Design parameters of IFMIF accelerator and the related beam dynamics issues.

2 IMPORTANCE OF BEAM DYNAMICS SIMULATION IN IFMIF ACCELERATOR

Since the IFMIF accelerator handles the high current deuteron beam, the suppression of the beam loss from the ion source to the target stations is the most important issue to use as an irradiation test facility continuously. In the low energy part the situation is the same but the induced radiation and activities are different. There are two contributions for such beam loss: (1) transient component due to the changes or fluctuations of the parameters, and (2) stationary component due to the beam halo. Both components should be taken into account in the actual operation time and they are minimized for achieving the hands-on maintenance. It is possible to use a local shield where the undesirable beam component is intentionally lost using such as halo scraper. These procedures require the detailed information of the particle trajectory for every point and every operating condition, so the accurate beam dynamics simulation is necessary. The question is that "What extent the conventional design codes can predict the beam behavior accurately?" For the problems for which analytical solutions are obtained, it is easy to estimate the accuracy, however, in the general case the most reliable numerical calculation method is necessary as the reference. These calculations are needed to compare with the precise measurements finally. As the last step, it is necessary to compare with the conventional design codes and make an improvement because such fast and easy-to-use code is useful to survey the parameter space.

In the IFMIF accelerator case, the stationary beam loss is occurred around the injector and RFQ. Also the transient beam loss is critical at the higher energy region, DTL and HEBT. The usual code does not detect any beam loss in the steady state operation, however the margin is necessary to avoid the beam loss due to the transient phenomena. In this context, the superconducting linac technology considered as the alternative of the reference design should be continued to enhance the ratio of bore to beam radius and the finer rf control.

3 SIMULATION CODE

As described above, the beam dynamics simulation with an enough precision is required in the many sections of the IFMIF accelerator. The newly developed code is based on the 3-dimensional Particle-in-cell (PIC) method and solves the Maxwell equation in the time domain by using the finite difference method. The integration scheme is a conventional leap-frog method and the particle weight is distributed over the grid points adjacent to the particle position. Thus, the internal field is solved self consistently within the precision of space grid size. The flow diagram of the time integration is shown in Fig. 2. The External field is prepared separately and added when the motion of equations is integrated.

The beam consists of several kinds of species of ions and neutrals (e.g. D^+, D_2^+, D_3^+ and D^0). All particles are tracked in the region of interest where the self field is calculated. There is an option to restrict the space where the force is applied to each particle. This is necessary to set up the internal field before the first particle enters into the interaction region.

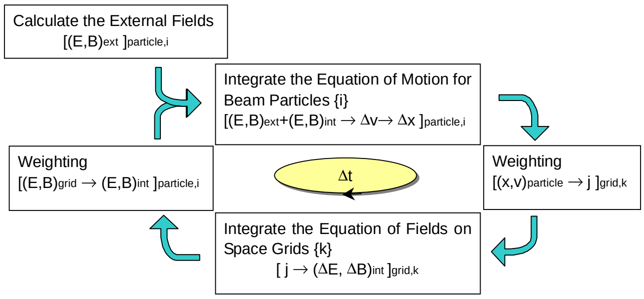

Figure 2: Flow diagram of particle tracking in electromagnetic fields.

The main part is written in Fortran 77 and ported to Sun SPARC WS, DEC Alpha WS, and Windows NT WS. The front-ends of the data process, such as the initial phase space coordinates and the space mesh generators, are written in JAVA.

4 CALCULATION RESULTS

As the primary step to check the simulation code, the simplified model of the segmented RFQ [4] is considered as shown in Fig. 3. The rectangular region of interest is bounded by the conductor surfaces and four vanes are placed with a small gap between the modules. When no external electromagnetic field is applied, only the internal self-field of space charge and image charge are encountered in the particle motion. The time integration starts from the first particle entering the region, however, the momentum is updated only in the central region of length $\beta\lambda$ including the segment module gap.

In this example calculation, the cold beam, i.e. no momentum spread, is assumed as the initial condition. After a $\beta\lambda$ passage, the cold beam has warmed up due to the self field. The typical example is shown in Fig. 4, the variation of the radial momentum is found with 90° period corresponding to vane positions. This cannot be removed using a linear focusing field and may produce the later emittance growth. The dependence of the parameters, such as vane gap size, module gap size, etc., are surveyed and the results are always interpreted by the change of the self field intensity.

As the another comparison with the semi-analytical solution for the uniform ellipsoidal bunched beam in the pure drift space [5]. As shown in Fig. 5, the semi-analytical solution gives the linear phase space plots in e.g. x' vs. x phase plane. The parameters for the final beam size can well describe the particle tracking simulation.

5 CONCLUSION

The 3-dim PIC particle tracking code is developed and tested for the module gap region of segmented RFQ employed in IFMIF accelerator design concept. The results are confirmed through the interpretation using the self-field and simple parameter dependency, and also by the semi-analytical model solution.

6 ACKNOWLEDGMENTS

The technical contributions provided by all the participant members of the IFMIF-CDA are gratefully acknowledged.

7 REFERENCES

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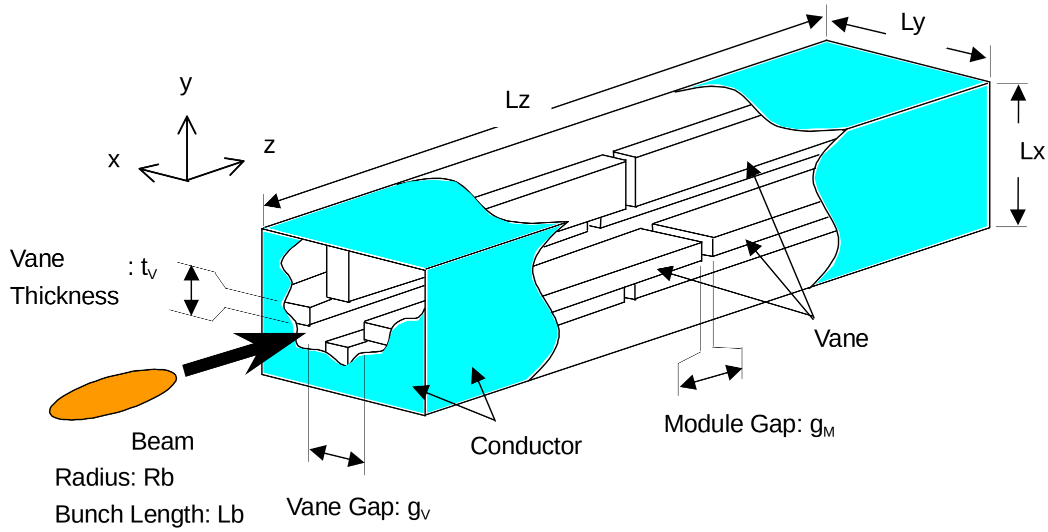

Figure 3: Computational modelof the segmented RFQ (Lz > **βλ**+2 Lb).

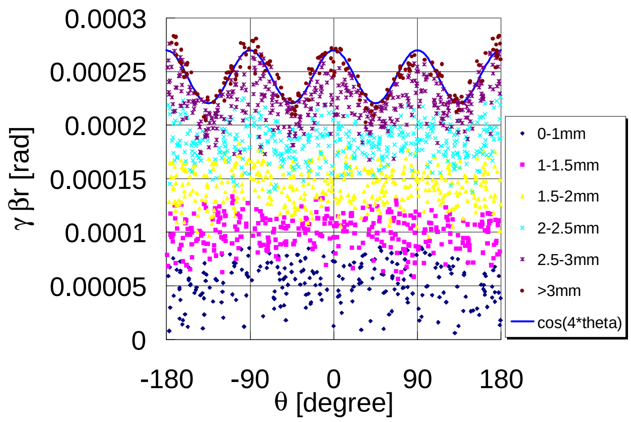

Figure 4: Radial momentum vs. azimuthal angle phase space plot divided to each radial position group. The oscillation of the outermost particles are influenced by the image charge field.

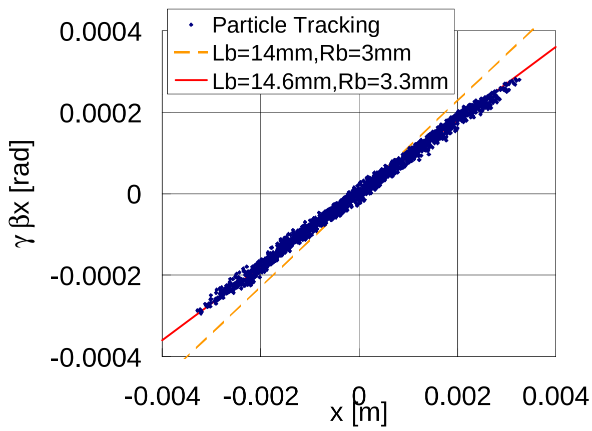

Figure 5: X' vs. X phase space plot for no image charge case, compared with semi-analytical results.