INTEGRATION OF FRINGE FIELD ALPHA MAGNETS INTO THE V-CODE BEAM DYNAMICS SIMULATION TOOL*

Sylvain Franke**, Wolfgang Ackermann, Bastian Steiner, Thomas Weiland,
Technische Universität Darmstadt, Institut für Theorie Elektromagnetischer Felder,
Schlossgartenstraße 8, 64289 Darmstadt, Germany,

Joachim Enders, Christoph Heßler, Yuliya Poltoratska,
Technische Universität Darmstadt, Institut für Kernphysik,
Schlossgartenstraße 9, 64289 Darmstadt, Germany

Abstract

The design process and the operation of particle accelerator machines can advantageously be assisted by fast online beam dynamics simulations because of its flexible parameter variation combined with nearly simultaneous solution responses providing a detailed insight into the actual machine status. Based on the moment approach a fast tracking code named V-Code has been implemented at TEMF. At the Superconducting DArmstädter LINear ACcelerator S-DALINAC the V-Code is used during the design process of the injector for the new 100 keV polarized electron source but is also supposed to be employed at the control system. For these purposes an implementation of fringe field alpha magnets is mandatory. In this paper a summary of issues regarding the implementation complemented with simulation results will be provided.

INTRODUCTION

At the Superconducting DArmstädter LINear ACcelerator (S-DALINAC) a new 100 keV polarized electron source is currently being installed. Therefore, a new low energy injection concept has to be designed. The most important components of the injector are a polarized electron source, an alpha magnet and a Wien filter used for spin rotation together with various beam forming elements. The polarized electrons extracted vertically from a photo cathode are bent into the horizontal injector beam line with the help of an alpha magnet. Unlike a classical alpha magnet designed as a half quadrupole given for example in [1], the hyperbolic poles of the installed alpha magnet are supplemented by a dipole like extension in order to achieve a $90°$ bending angle. In Fig. 1 a schematic computational model of the realized alpha magnet is visualized. Within the V-Code simulation tool the beam line is represented as a consecutive alignment of separate independent beam line elements. This procedure allows to simulate even a very long beam line with minimum requirements to the computer memory. In order to be able to simulate the hole injector an implementation of alpha magnets was missing so far.

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** franke@temf.tu-darmstadt.de

NUMERICAL MODEL

The V-Code simulation tool is based on the moment approach to beam dynamics. Instead of using the particle distribution itself this method applies a discrete set of moments of the particle distribution. The time evolution of each moment can be deduced from the VLASOV equation when suitable initial conditions are given and all essential external forces are known. These forces are given by the LORENTZ equation in combination with the distribution of electric and magnetic fields obtained during a preprocessing step.

The required three-dimensional field distribution in the immediate vicinity of the particle trajectory can be reconstructed from extracted one-dimensional field components by means of a TAYLOR series expansion. This allows to considerably reduce the size of the required field data inside a specific beam line element.

A precise description of the numerical model is given in [2]. Details about its implementation in V-Code are published for example in [3] and [4].

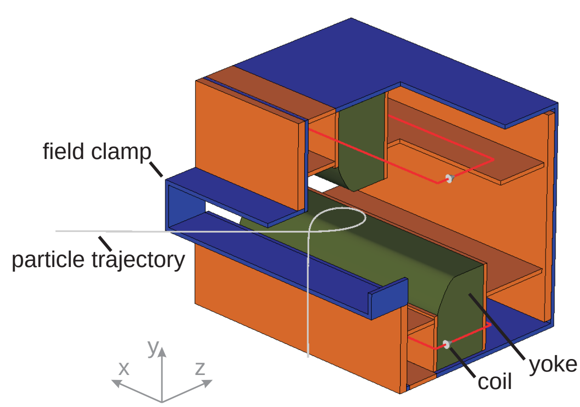

Figure 1: Schematic computational model of an α-magnet including the excitation coils and the high permeable yoke. For visualization reasons the upper corner of the housing and the yoke have been cut away. Additionally, a typical particle trajectory is specified as a reference path.

Magnetic Field Calculation

The particle tracking in external magnetic fields requires the detailed knowledge of the local field distribution which can be determined for example with the magnetostatic solver included in the CST Design Environment. From the precise field data one can extract the necessary multipole components and provide those information in a very efficient manner for further usage. In V-Code the full field can be reconstructed and evaluated particularly in the vicinity of the bunch trajectory. Due to the layout of the magnet it is sufficient to evaluate the field along the longitudinal axis z while it is assumed to be constant in transversal direction. In Fig. 3 the important vertical component of the magnetic flux density is displayed.

Multipole Expansion

In order to determine the components which have to be considered in the multipole expansion, one can analyze the tangential field component on concentric circles of different radii along the longitudinal axis of the alpha magnet. In Fig. 2 the calculated multipole coefficients are shown in logarithmic scale. From the plot one can see that the sextupole part forms the most eminent disturbance to the dipole field. Since the magnitudes of all higher order multipoles are at least two orders of magnitude smaller than the dominant dipole component even for the pessimistic evaluation radius $r = 6$ mm we neglect all multipole parts except the dipole field in the following.

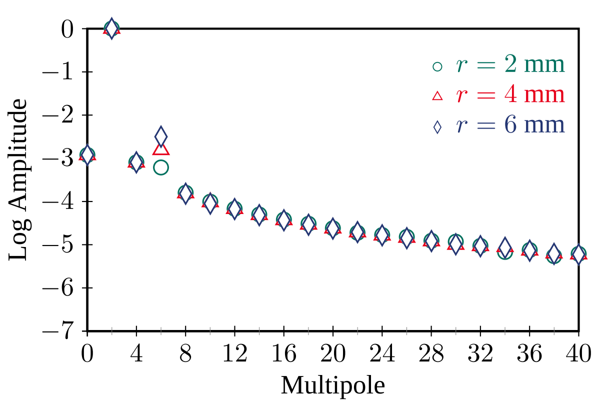

Figure 2: Normalized multipole moments of the magnetic flux density evaluated on concentric circles of different radii in the center of the α-magnet.

Reference Path

Within the V-Code simulation tool the entire beam line is represented as a straight line directed along the z axis. This requires for a beam line element like the alpha magnet the definition of a curved reference path, determining the nominal length inside the beam line. A suitable reference path can be attained for example by tracking a single particle with proper initial conditions in the provided magnetic field.

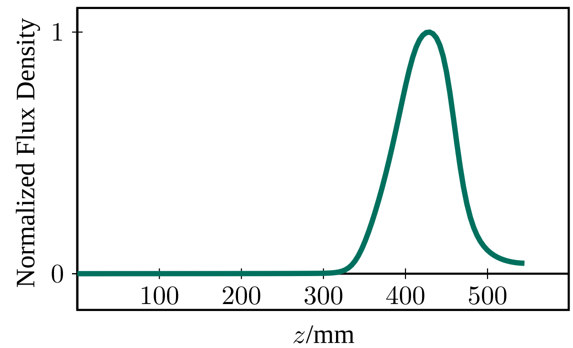

Figure 3: Vertical component of the magnetic flux density inside the α-magnet normalized to the absolute maximum. Geometric details are specified in Fig. 1.

IMPLEMENTATION

For accuracy reasons it is not advisable to calculate and visualize the bunch evolution in the same successively rotated coordinate system. A more accurate proceeding avoiding the accumulation of errors due to rotation is illustrated in Fig 4. At the beginning a coordinate transformation is performed to align the global primed coordinate system with the unprimed system in which the field components are reconstructed and the bunch evolution is calculated. The simulated bunch parameters are plotted in the visualization pane relative to the reference path using the double primed coordinate system. For this purpose the normal projection from the actual bunch position (z_1, x_1) onto the reference path (z_s, x_s) and a local coordinate transformation for the first and second order moments is performed. At the end a final transformation from the unprimed to the triple primed coordinate system is necessary in order to orient the global system along the subsequent beam line.

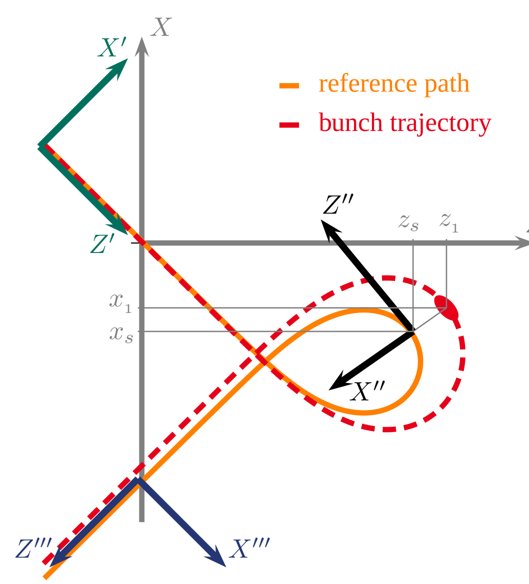

Figure 4: Typical projected bunch trajectory together with the predefined reference path for the α-magnet setup specified in Fig. 1.

SIMULATION

In order to study the applicability of the preprocessing steps and the implementation of the proposed scheme the simulation results from V-Code are compared to simulation results obtained with a reference tracking code based on the so called Boris algorithm [6] as well as results extracted from the particle tracker integrated in the CST Design Environment.

In Fig. 5 and Fig. 6 the evolution of the center of mass of a nearly point-like bunch equipped with a vertical offset of 1 mm from the reference path is tracked with V-Code and is compared to trajectories of individual particles calculated with the Boris algorithm and with the CST particle tracker.

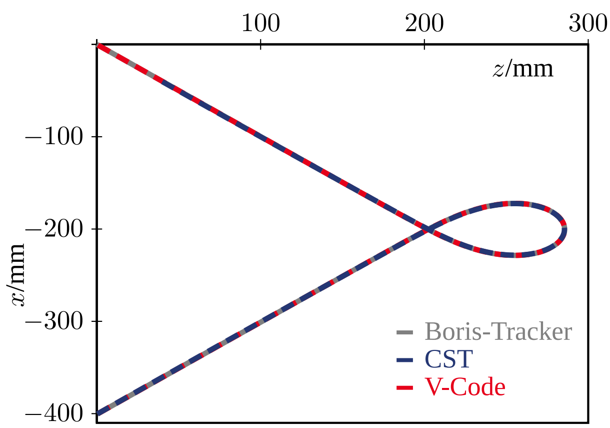

Figure 5: Simulation of the horizontal evolution of two individual particles with 1 mm vertical offset from the symmetry plane within the α-magnet.

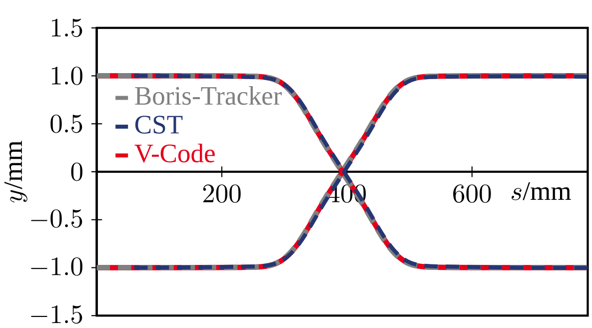

Figure 6: Simulation of the vertical evolution of two single particles with 1 mm vertical offset from the symmetry plane within the α-magnet.

In Fig. 7 and Fig. 8 the focusing behavior inside the alpha magnet is illustrated. From the CST Design Environment the bunch dimensions were obtained by tracking a bunch of particles through the build-in particle monitors placed orthogonal to the reference path inside the alpha magnet. In V-Code the horizontal and vertical bunch dimensions are calculated from the global coordinates by means of coordinate transformations as explained in the previous section. In all tracking routines space charge effects are neglected.

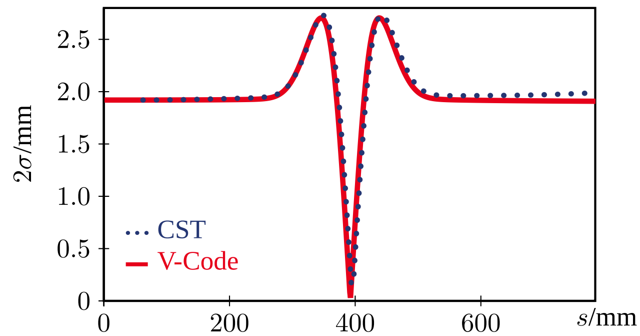

Figure 7: Simulation of the horizontal focusing behavior within the α-magnet.

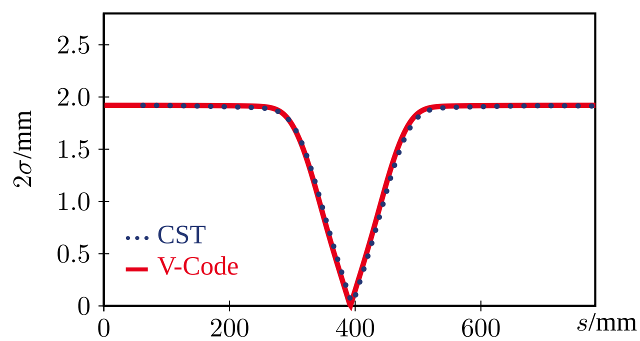

Figure 8: Simulation of the vertical focusing behavior within the α-magnet.

The provided charts show that the center of mass as well as the transversal beam dynamics are precisely modeled in the new beam line element in V-Code.

REFERENCES

[1] M. D. Borland, A High-Brightness Thermionic Microwave Electron Gun, Thesis (PH.D.), SLAC-R-402, Stanford University, 1991.

[2] P. J. Channell, The Moment Approach to Charged Particle Beam Dynamics, *IEEE Trans. Nucl. Sci.* , NS-30, No. 4, Page 2607, 1983.

[3] W. Ackermann, T. Weiland: Data Base Extension for the Ensemble Model using a Flexible Implementation, presented at the 2005 Particle Accelerator Conference (PAC05), Knoxville, Tennessee, USA, May 16-20, 2005, 19.05.2005.

[4] S. Franke, W. Ackermann, B. Steiner, T. Weiland, J. Enders, C. Hessler, Y. Poltoratska: Implementation of Fringe Field Dipole Magnets into the V-Code Beam Dynamics Simulation Tool, Proceedings of the 11th European Particle Accelerator Conference (EPAC 2008), Genoa, Italy, June 23-27, 2008.

[5] CST - Computer Simulation Technology, Bad Nauheimer Str. 19, D-64289 Darmstadt, Germany, http://www.cst.com.

[6] J. Boris, Relativistic Plasma Simulation - Optimization of a Hybrid Code, Proceedings of the 4th Conference on the Numerical Simulation of Plasmas, Washington, D.C., November 2-3, 1970.