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Magnetic field aberration simulations

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Abstract

We have developed a calculation procedure that integrates the equations of motion of charged particles passing through any magnetic field supplied by the user. This provides more realistic results in beam-transport simulations than the existing programs. Moreover, it reproduces the beam dynamics of any experimental setup whenever a field map is available. The procedure has been incorporated in one of our beam-transport program packages that can calculate space charge effects, too. In this report the method is briefly summarized and applied to a solenoid for which the magnetic field calculations and emittance measurements data exist.

Introduction

The most common charged particle tracking programs, both multiparticles as well as envelope solvers, have the possibility of calculating the dynamics of a particle beam through magnetic elements (quadrupoles, solenoids, dipoles). In order to simplify the calculations the elements are regarded as "ideal" and are characterized by three parameters only: the length, the aperture and the field which is assumed to be constant. This simplification allows to reduce the solution of the motion equations to a matrix multiplication instead of a step-by-step integration [1]. This method gives reasonably accurate and fast results in lots of the cases.

The "real-life" field distribution of any magnetic element is often far from the ideal one and this reflects in measured beam profiles and emittances quite distorted with respect to the ideal case. A need was felt for a procedure that could properly calculate the particle motion in any field. Recently it has been implemented and it takes field information coming either from calculations or measurements and integrates the equations of motion along the desired magnetic region.

The procedure, incorporated in the program package PATH [2,3], has been tested against the South-Hall two-solenoid low energy beam transport line [4] for which magnetic field calculations and measurements [5] as well as emittance measurements [4] exist. In this report both the former and the new method and the simulation results are presented.

Former method

This simulation approach is presented via a solenoid example. Figure 1 a, b compares a modulated-winding solenoid field as calculated by POISSON [6] with the ideal field distribution taken into account by beam transport programs like TRACE and PARMILA.

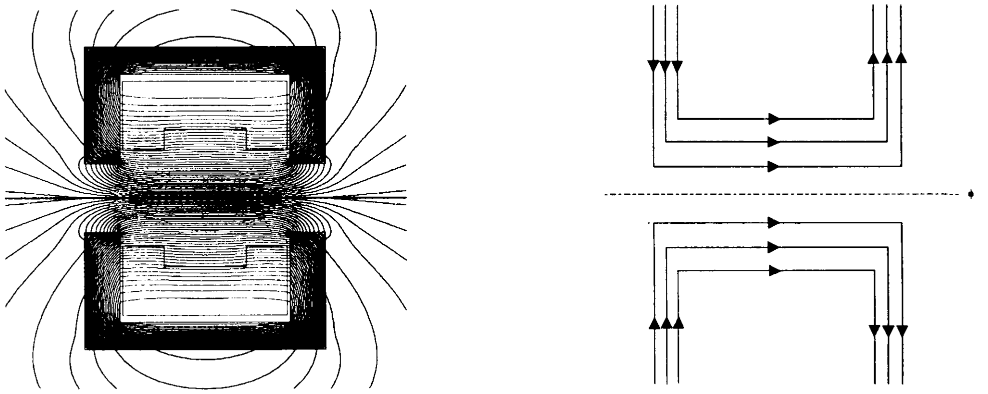


Figure 1 a) Computed magnetic-field distribution b) Assumed magnetic-field distribution

The solenoid, described by its length (L) and field strength (B), is assumed to have constant longitudinal field B inside and sharply rising transverse and longitudinal components at the ends. With this approximation the particle phase-space coordinates at the solenoid output plane depend on the input ones via only matrix transformations, a rotation plus a focalisation.

Recent method

A more general simulation approach is to integrate the equations of motion in magnetic field. Whenever a field map is available the motion of a charged particle through it is computable by numerical integration. The momentum of such a particle changes according to the differential equations of motion:

$$\dot{\mathbf{p}} = q\,(\mathbf{v} \times \mathbf{B})$$

where **p**, **v**, *q* are the particle's impulse, velocity and charge, respectively, and **B** is the magnetic field that may arbitrary depend on the coordinates.

As an example for space dependence, Figure 2 a, b show the radial and longitudinal field variation of the South Hall solenoids. The plots correspond to the field distribution presented in Figure 1,a. The curves on each plot represent different radii.

SOLENOID FIELD VARIATION EXAMPLE

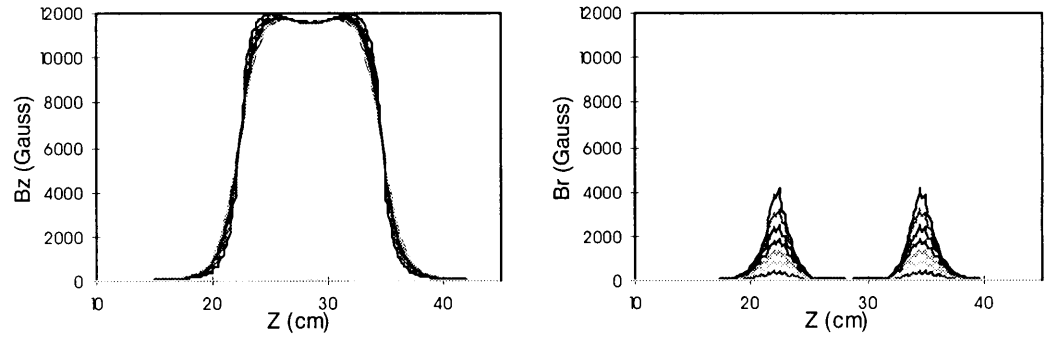


Figure 2 a) Longitudinal field components b) Radial field components

Measurement and simulation results

We have compared the results of the two approaches against the measurement on a 7-KeV, 10-mA proton beam passing through two solenoids of the linac2 type. Space charge calculations were not included in the simulations due to the beam neutralization and the lack of the effective current. Figure 3 a, b, c resumes the results of our comparison:

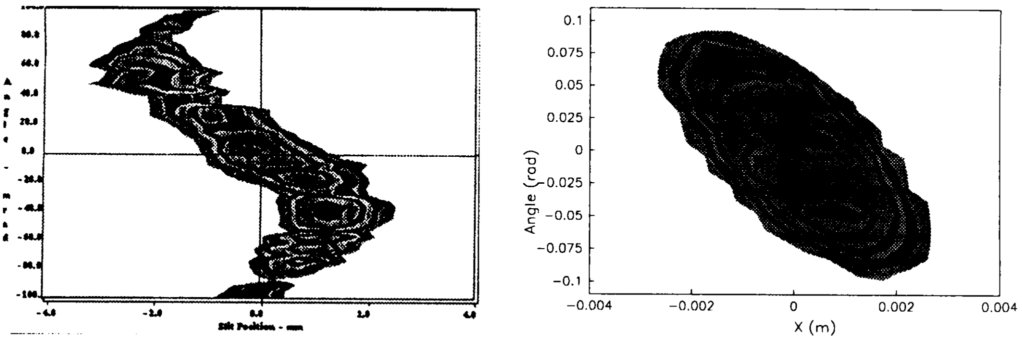
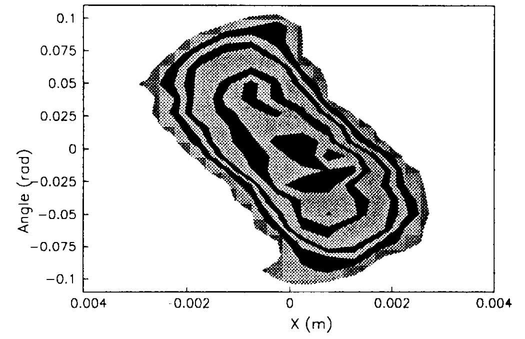


Figure 3 a) x-x' plane from measurement b) x-x' plane from former simulations



c) x-x' plane from field integration

As we can see, the simplified field calculation could well reproduce the general behavior (the ellipse orientation in phase-space), but the distortions visible at the edges of the measured phase-space plot could only be reproduced when correctly taking into account the variation of the magnetic field.

Conclusion

A procedure to integrate the motion equations of charged particles in any magnetic field has been implemented in the multiparticle program PATH[2, 3]. The method has been tested against measurements showing the capability of reproducing the measured distortions in the transverse phase-space.

References

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