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*JACoW Paper

SYMPLECTIC TRACKING AND COMPENSATION OF DYNAMIC FIELD INTEGRALS IN COMPLEX UNDULATOR STRUCTURES

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Abstract
This presentation covers analytical models that describe the interaction of a relativistic particle beam with the magnetic field of undulators. Analytic approximations to the Hamilton-Jacobi equation yield generating functions useful for particle tracking and, therefore, efficient simulation. Analytic expressions for kick maps of APPLE II undulators are presented as well. Passive and active shimming schemes including magic fingers and current sheets are also modelled. Applications at BESSY II are discussed which ensure efficient injection during top-up to satisfy machine protection and radiation safety requirements.

TRACKING WITH GENERATING FUNCTIONS

In synchrotron radiation sources, like storage rings, a large fraction of the circumference is covered by insertion devices and thousands of passages through the IDs are required in tracking simulation, to decide on beam stability. A fast and symplectic tracking code to simulate the ID effects is required for an effective scanning of a large parameter space. The method of GF offers this possibility. For Cartesian coordinates (x, p_x, y, p_y) this is described in [1]. The GF is derived by starting with a special Hamiltonian function, given by the longitudinal particle momentum p_z,

$$H = -p_z = -1 + (p_x - A_x)^2/2 + (p_y - A_y)^2/2 - A_z$$

All vector potential terms $\vec{\tilde{A}} = (\tilde{A}_x, \tilde{A}_y, \tilde{A}_z)$ are normalized by the magnetic particle stiffness eBρ, yielding $\vec{A} = (A_x, A_y, A_z) = (\tilde{A}_x/eB\rho, \tilde{A}_y/eB\rho, \tilde{A}_z/eB\rho)$.
Similarly, all momenta $\vec{\tilde{p}} = (\tilde{p}_x, \tilde{p}_y, \tilde{p}_z)$ are normalized by the particle momentum p_0,
$\vec{p} = (p_x, p_y, p_z) = (\tilde{p}_x/p_0, \tilde{p}_y/p_0, \tilde{p}_z/p_0)$.
This Hamiltonian is applied to solve the Hamilton-Jacobian equation $\partial F_3/\partial z + H = 0$ by an iterative procedure [1] with increasing accuracy. As a result, F_3 is solved by a series expansion, the leading terms are given by

$$F_3 = z_f - (p_{xf}x + p_{yf}y) - (p_{xf}^2 + p_{yf}^2)z_f/2 + f_{101}p_{xf} + f_{011}p_{yf} + f_{003} + f_{002} + f_{001}$$

with the coefficients

$$f_{001} = 0, \quad f_{101} = \int A_x dz, \quad f_{011} = \int A_y dz,$$

$$f_{002} = -(1/2)\int (A_x^2 + A_y^2)dz,$$

$$f_{003} = \frac{1}{2}\int\left(\frac{\partial}{\partial y}\left(\int (A_x^2 + A_y^2)dz\right)\right)A_y dz' + \frac{1}{2}\int\left(\frac{\partial}{\partial x}\left(\int (A_x^2 + A_y^2)dz\right)\right)A_x dz'$$

This GF expansion for arbitrary, 3-dimensional magnetic fields converges well, if the components of normalized vector potential and the transverse momenta are small. The GF depends on integration step length z_f, the initial particle coordinates (x, y) and on the final momenta (p_{xf}, p_{yf}). The conjugated coordinates are derived from relations

$$p_x = -\partial F_3/\partial x, \quad p_y = -\partial F_3/\partial y$$
$$x_f = -\partial F_3/\partial p_{xf}, \quad y_f = -\partial F_3/\partial p_{yf}.$$

The resulting transformation is formed into an explicit function, depending on the initial particle coordinate variables and yielding the final particle coordinate variables. The tracking routine is solved for arbitrary magnetic fields, and can be applied to a specified field, if the components of the vector potential can be expressed by functions which can be integrated and differentiated as required, like terms of a Fourier series. The step length z_f depends on the smallness of the scaled vector potential terms (A_x, A_y, A_z), but normally the steps are much longer than comparable integration steps, increasing the speed of the transformation enormously. This method becomes especially fast for fast oscillating fields, where many oscillations can be tracked in a single step, whereas an integration methods requires steps much shorter than the shortest oscillation period. If the vector potential is derived from a Fourier series, the required f_{ijk} coefficients become very simple, because many terms cancel.

MAGNETIC FIELD MODELS OF UNDULATORS

If possible it is extremely useful to develop analytic models of the magnet structures to be studied. Assuming a permeability of one (only for pure permanent magnet devices) the field can be composed with a linear superposition of the fields of individual undulator sub-arrays. Often, the complete system can be described in all modes of operation (energy and polarization, i.e. magnetic gap and magnet row phase) by only a small set of parameters. Many undulator structures can be composed of a combination of several longitudinally extended magnet arrays and, usually, several rows can be described with the same set of coefficients. A few more parameters describe the transverse and longitudinal row