A PROGRAM PACKAGE FOR BEAM DYNAMICS STUDY

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Abstract

A program package designed for charged particle dynamics simulation in circular accelerators, storage rings, and beam lines is described in the paper.

The package consists of a set of programs. The first-order program can fit selected elements of transfer matrices, beam envelopes in a beam line, and betatron tunes and Twiss functions in a periodic lattice. Nonlinear beam dynamics calculations are based on aberration theory. The programs enable to compute nonlinear phase space ellipse distortions in beam lines as well as nonlinear distortions of closed orbits, Twiss functions and betatron tunes in circular machines. Multipole corrections to eliminate nonlinear distortions can be calculated using the programs.

BETRAMF

BETRAMF [1] is a first-order program. It employs algorithms based on calculation of phase-space coordinate transfer matrices of optical elements. As an element of an optical system bending magnets (with uniform and non-uniform magnetic field) and quadrupoles may be used with drift spaces between them. Sextupole and octupole lenses are treated by the program as drift spaces. Hard-edge fringe field of bending magnet as well as pre-calculated transfer matrices may be used as a separate element of an optical system.

BETRAMF may be used to solve the following problems:

1. Computation of a six-dimensional phase-space coordinate transfer matrix through the total magnetic system as well as through any part of it.
2. Beam envelopes calculation.
3. Calculation of periodic functions (Twiss functions and dispersion function) in circular accelerators, betatron oscillation tunes and phase advance of oscillations at each element of the lattice. All these parameters may be calculated for matched insertions and beam transport systems.
4. Optimization and fitting of magnetic system parameters to meet certain requirements on beam dynamics. There are two optimizing algorithms implemented into the program, one of them based on Davidon-Fletcher-Powell method and the other based on random search method.
5. All optical characteristics of the system may be calculated with step-by-step variation of parameters of magnetic elements.

TOREX

TOREX [2] is a ray-tracing program. It was written to calculate second- and third-order aberration coefficients of phase-space variables transformation by magnetic systems. It is also possible to calculate some other properties of nonlinear beam dynamics.

The program uses the same magnetic elements as BETRAMF. Sextupole and octupole field components may be introduced in the elements. Matrix transformation of phase space variables used as an element of a magnetic system may be extended up to the third-order.

All nonlinear terms in equations of motion are subdivided into three groups. The first group is a group of intrinsic kinematic nonlinear terms due to curvature of a particle trajectory. The second and the third group contain the terms driven by the sextupole and the octupole magnetic field components respectively. The program may treat the terms of these groups separately or in arbitrary combinations.

The method of calculation of aberration coefficients is based on ray-tracing with a special set of initial values of phase-space variables. After tracing high-order accuracy differential operators are used so that no errors of fourth-order are introduced in aberration coefficients.

The main result of TOREX is a matrix of aberration coefficients, i.e. the coefficients in the six-fold Taylor expansion of phase-space variables using their initial boundary values.

Some other optional results of non-linear beam dynamics may be obtained by use of TOREX. In transport channels beam envelopes distorted by chromatic aberrations can be calculated for arbitrary spectrum of fractional momentum errors. For magnetic lattices of circular accelerators non-linear corrections to betatron tunes, Twiss and dispersion functions as well as parameters of longitudinal motion can be computed. The method of calculation of these corrections in terms of aberration coefficients is given in [3,4]. TOREX can also check up symplecticity of Jacobi matrix of phase-space transformation and produce a power expansion of the Jacobian. The coefficients in the expansion manifest the degree of accuracy of calculations based on aberration expansions [5].

MARTLET

MARTLET is the third program of the package. It was developed for the computer simulation of the influence of second- order aberrations on the beam phase-space volume shape and size and for optimization of magnetic systems so as to reduce second-order distortions of the beam.

The influence of aberrations on beam parameters is studied on the base of analysis of deformation of the surface which encloses a region of phase space occupied by the particles of the beam. To solve this problem some methods of differential geometry were used [6].

Other Programs

The package of programs contains some other more specialized modules. The most often used of them are MAP and LEASQ.

MAP module is used for one- and two-dimensional plotting of distorted by nonlinear effects phase-space particle distribution.

LEASQ module is used for a system of linear algebraic equations solving by means of a regularized least square method. Such a problem often arises in calculation of correction of nonlinear effects in magnetic systems.

General Outlook

All programs of the package are composed of a set of logically closed modules. The execution order of the modules is relatively independent. Such a structure of the programs increases their flexibility. It is possible to incorporate some new modules if a new problem arises.

The programs are supplied with user-friendly interfaces based on a special symbolic meta-language. The main syntactic units of the language are control operators which call out the certain modules of a program. All required data are specified in symbolic or format-free form. There is no need for user to know peculiarities of algorithms.

Long-time experience of extensive calculations proved reliability of methods and practical convenience of the package.

References

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