The application package DeCA for calculating cyclic accelerators.

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Abstract.

The application package DeCA (Design Cyclic Accelerator) is offered to solve a set of problem which arise on designing electron storage ring. The package is based on the block principle. This makes it extremely flexible in designing storage rings and investigating beam dynamics in them. The package is intended for a user not familiar with programming languages, it is arranged so that the user familiar with FORTRAN-77 can easily extend the package functions. This is of particular interest, when the input data are the storage ring or electron bunch parameters. The code allows operation in both the batch and interactive modes. The programming language is FORTRAN-77. The capacity of the total package is 40 000 code lines. The necessary main storage capacity for the total version is 4 Mbytes.

1.INTRODUCTION

In recent years the application package DeCA [1,2] is in wide use in Kharkov Institute of Physics and Technology for design and modernization of storage rings and numerical experiments. The package was used for elaboration of such projects as: electron pulse stretcher ring PSR-2000 [3] with an operating energy 3 GeV, the source of synchrotron radiation ISI-800 [4] with an operating energy 0.8 GeV, the source of synchrotron radiation with an operating energy 2.5 GeV for the Nuclear Research Center in Karlsruhe, Germany. Calculations for the Amsterdam Pulse Stretcher Ring (AmPS) also have been carried out. The computer simulation of the chromatic beam extraction was performed for the PSR-2000 lattice using DeCA [5]. The package includes the following accelerator physics features: calculations of lattice functions and integral characteristics of the beam taking into account the installation errors and energy loss due to synchrotron radiation, reference orbit correction, Hamiltonian formalism for investigation of resonance effects, optimization of lattice parameters, investigation of dynamic aperture by both an analytical and numerical methods taking into account the high order components of magnetic field, numerical simulation of particles motion in 6-dimensional phase space, investigation of spin-orbit motion. The package has rich possibilities for information reflections. The organization of the DeCA code allows to carry out calculations with several input lattice and command files simultaneously. The last version of the DeCA code is realized at the IBM 360/370 like computer and may be accommodate at VAX VMS system and personal computer.

2. PACKAGE STRUCTURE

All program modules of the DeCA package (except the main and standard modules) are unified by the functional principle into several blocks. According to their assignment, these blocks are subdivided into system units (which provide all service functions) and functional units (which directly implement the code functions). Among the system units we mention the following: DIAG - printing of diagnostic messages of the code, FILES - data file handling, COMM - code control (commands block), REFLI - digital and graphic display of information, data display in the plotter.

The functional units of code version 3.3 include: IMOS - description of lattice elements and structures, GAC - calculation and mapping of the geometry of the machine, BEAM - assignment of initial beam parameters, REFTL - calculation of machine functions and parameters, SR - calculation and mapping of synchrotron radiation parameters, MDP - simulation of beam dynamics with nonlinear elements, SOM - simulation of spin-orbital motion of the beam.

All functional blocks and the system part of the package may be combined in various versions of the package depending on user requirements.

3. INPUT DATA

All data files used in the DeCA package are described in the table arranged in the file of the FIDEF (FIle DEFine) type in the fixed format [6]. Files of following types are necessary described in this table: CODEF - file containing the definitions of all control commands in the text form, COMM - control commands specifying instruction for action, COMMT - control commands introduced from a terminal in the interactive mode, ELDEF - file containing the definition of lattice elements, EDEF - file containing the definition of graphic pictures of lattice elements, MOS - file containing the description of the lattice, IBEAM - file containing the initial particle coordinates.

4. DESCRIPTION OF THE STORAGE-RING LATTICE

All lattice elements are assumed to be located along the reference orbit: the orbit of the particle with energy E_0 in ideal field in all magnet elements. The geometric axis of magnet elements is coincident with this orbit. The reference orbit consists of a number of straight sections and arcs formed by bending magnets. The moving set of three vectors forms the right-hand frame of coordinates X,Z,S. The instantaneous direction of the axis S is coincident with the direction of the tangent to the reference orbit, the axes X and Z lie in the radial and vertical planes, respectively.

All lattice elements that have been realized in DeCA code are described in the file of the ELDEF type, where the

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formats of the element definition in the lattice are fixed. The following lattice elements are realized in the code version 3.3:

NULL - empty element,
DS - drift space,
PICK - pick-up station,
BM - bending magnet,
BMR - bending rectangular magnet,
PFR - pole face rotation,
KICX - kicker magnet in XS plane,
KICZ - kicker magnet in ZS plane,
COR - correction magnet,
QL - quadrupole magnet,
QLP - pulse quadrupole magnet,
SOL - solenoid,
ROT - rotation of coordinate frame around axis "S"
RFC - thin RF-cavity;
RFCN - RF-cavity;
SL - sextupole magnet,
SLP - pulse sextupole magnet,
OL - octupole magnet,
OLP - pulse octupole magnet,
MLP - multipole magnet,
INJ - injection point,
ESX - electrostatic X-septum,
ESZ - electrostatic Z-septum,
MSX - magnetic X-septum,
MSZ - magnetic Z-septum,
APRL - local rectangular aperture,
APEL - local elliptic aperture,
APRG - global rectangular aperture
APEG - global elliptic aperture,
INCR - increment/decrement.

To describe the machine lattice, we use the input files of MOS type (Magnetic Optical Structure). The description is the sequence of sentences, each specifying one element or a group of elements in the particular place of the lattice. Sentences of the following types are used at the language of lattice description:

- explicit assignment of the lattice element;
- a copying of a previously defined element;
- explicit assignment of the substructure (group of elements);
- direct or inverse copying of a previously defined substructure.

For example a description of the element in the lattice of the source of synchrotron radiation for Karlsruhe Nuclear Research Center are presented below:

```
SUP(1): LINE;
  DS1: DS  L=1.45548;
  QF1: QL  L=0.30  K1=1.87;
  DS2: DS  L=0.30;
  QD1: QL  L=0.30 K1=-1.25;
***  FIRST BEND
  CELL(1): LINE;
    B(1): BMR L=1.468 ANG=15. K1=-0.09541;
    DS3(1): DS  L=0.35;
    DS3(2): ;
    B(2): ;
    DS4: DS  L=0.60;
    QF2: QL  L=0.30  K1=2.35758;
    DS5: DS  L=0.80;
    B(3): ;
    DS5:  DS  L=0.25;
  CELL(1): ENDLINE;
  -CELL(2): ;
SUP(1): ENDLINE;
SUP(2):; SUP(3):; SUP(4): ;
```

Commands of the package control are defined in the file of the CODEF type where the command formats are determined [6]. The code can work both in the interactive and in the batch calculation modes. The file of the COMM type is formed to work in batch mode. Then the control of the code is passed to this file.

About 70 commands are realized in the DeCA code. These commands provide the execution of all necessary functions.

For example we present the fragment of the COMM file:

```
IMOS DECKRL3;  ENER E=2.5;
TOLS X=0.0001 Z=0.0001 S=0.0001;
IRL LONG; MTEL CYC;
FFSL ICH CHR;
GRFL BETX BETZ PSIX EL1=QF1; PRFL;
DAP SL PRX PRC Z=0.0 AZIM=QF1;
```

4. FUNCTIONAL POSSIBILITIES OF THE PACKAGE.

The package DeCA uses 5x5 matrix (matrix elements that describe the perturbations of the magnetic field due to errors in the installation of lattice elements and their imperfections are recognized in fifth column of the matrix) and the coordinate vector (x,x',z,z',l) for description of particle motion without taking into account the energy spread in the beam ($p=p_0=const$); 7x7 matrix and the coordinate vector $(x,x',z,z',l,s,\Delta E/E)$ are used for description of particle motion taking into account the energy spread in the beam ($p=p_0+\Delta p$) (following A.W.Chao [7], we included elements that describe the energy losses due to synchrotron radiation into fifth column of the bending magnet matrix); 8x8 matrix and the coordinate vector $(x,x',z,z',s,\Delta E/E,\alpha,\beta)$ for description of spin-orbit motion of particles and 3x3 matrix and coordinate vector (S_x,S_z,S_s) for description of spin motion of particles. The numerical simulation taking into account the influence of nonlinear magnetic fields on particle motion is carried out in the 6 dimensional phase space $(x,x',z,z',s,\Delta E/E)$.

4.1 Lattice functions and integrals characteristics of the beam.

The algorithms for calculations of lattice functions, integral characteristics of the beam, analytical treatment of the dynamic aperture are based on the following model of the ring lattice. The orbit in the storage ring is assumed to be plane, i.e., there is no pitch to the vertical plane, the vertical

dispersion is zero, no twisting occurs. The curvature radius ρ and the field index n are regarded to be constant inside the bending magnet. The magnetic field boundaries in the magnets are assumed to be sharp.

The code allows to calculate amplitude and dispersion functions of the lattice, coordinates of the reference orbit, betatron oscillations tunes, integral characteristics of the beam such as: emittance, energy spread, chromaticity of the system, energy losses per turn, momentum compaction factor, equilibrium beam size and divergence etc. The detail description of package possibilities and algorithms used can be find in [8]. Calculations are based on analytical equations. The tune shift and dynamic aperture that have been caused by sextupole and octupole components of magnetic field can be calculated by using the Hamiltonian formalism. The correction of the reference orbit is carried out by the method of Herrevard-Baconierry.

4.2.Numerical simulation.

The block of numerical simulation is organized thus that we can observe practically all single particle effects that are known in accelerator physics. The 10-th pole thin lens is used at the block for simulation of nonlinear effects. The chromatic aberrations are taken into account in this model. Lens parameters may be changed according to some definite low. It allows to simulate the pulse elements. The wide possibilities of input beam parameter setting (the setting of particle distribution on the bunch, the setting of fixed particle coordinates and combination of both these methods) in combination with the convenient displaying output information allows to investigate resonance processes such as, multiturn injection and slow beam extraction.

4.3 Spin-orbit motion and equilibrium degree of polarization.

The SOM block allows to simulate the spin motion of particles and to calculate the equilibrium degree of polarization. The calculations are based on matrix formalism and linear beam dynamics. We use the algorithm which was designed by A.W.Chao [9] and H.Mais [10] and is based on analyzing of the eigenvectors and eigenvalues of the cyclic matrix of spin-orbit motion. Unlike the SLIM code by A.W.Chao, in the DeCA code the thick matrix models of magnet elements for the description of spin-orbit motion are used. The programmed connections between code modules allow to calculate the equilibrium degree of polarization as a function of coordinates of the reference orbit.

4.4 Lattice parameter optimization.

The universal mechanism of the choice and optimization of lattice parameters which allows to optimize any lattice parameter is used in the DeCA package. The code has got the following possibilities:

- setting the space of lattice parameters being varied (any parameters of lattice elements: element lenght, lense strenght etc.). The method of variation for every parameter is set independently;

- setting the list of parameters which are optimize (any characteristics and lattice functions: beta function, dispersion function, emittance etc.). Criteria of optimization has a follow form: $\sum_{i}^{N} w_i p_i \longrightarrow \min$, where p_i - parameters which are optimize, w_i - weight coefficients. ;

- multiple calculation of parameters under optimization and selection of variants which satisfy the given criteria.

5.REFERENCE

[1] P.I.Gladkikh,M.A.Strelkov,A.Yu.Zelinsky. DeCA - code for analyzing and design of cyclic accelerators. Proc. of the Second European Part. Accel. Conf. EPAC-90, Nice 12-16 June, 1990, v.2, pp. 1688-1691.

[2] P.I.Gladkikh,M.A.Strelkov,A.Yu.Zelinsky. New version 3.3 of the DeCA code. Proc. Third European Part. Accel. Conf., EPAC-92, Berlin 24-28 march, 1992, v.1, pp. 685-687.

[3] S.V.Efimov,P.I.Gladkikh,A.Yu.Zelinsky et al. The Pulse Stretcher Ring PSR-2000. Current Status. Proc. Third European Part. Accel. Conf., EPAC-92, Berlin 24-28 march, 1992, v.1, pp. 453-455.

[4] I.Karnaukhov,V.Androsov,E.Bulyak et al. The Synchrotron Light Source for the Ukrainian Research Center. This Proceeding.,PAC-93.

[5] S.V.Efimov,P.I.Gladkikh,I.S.Guk et al. The PSR-2000. Current Status. Proc. XIII Particle Accel. Conference, Dubna 13-15 october, 1992, to be published.

[6] P.I.Gladkikh,M.A.Strelkov,A.Yu.Zelinsky. Application package DeCA. Version 3.3. User,s guide. Part 1. Preprint KhPTI 1993, to be published.

[7] A.W.Chao. Evaluation of beam distribution parameters in an electron storage ring. J.Appl.Phys., v.50(2), February 1979y,pp. 595-598.

[8] P.I.Gladkikh,M.A.Strelkov,A.Yu.Zelinsky. Calculation of integral electron storage ring beam characteristics in the application package DeCA. Version 3.3. A physical model. Preprint KhPTI 1993, to be published.

[9] A.W.Chao. Evaluation of radiative spin polarization in an electron storage ring. Nucl. Instr. & Meth., 180(1981), pp.29-36.

[10] H.Mais, G.Ripken. Theory of spin-orbit motion in electron-positron storage rings. DESY 83-062