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A COMPUTER CODE FOR THE SIMULATION OF NONLINEAR PARTICLE MOTION IN ACCELERATORS

by

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Abstract

RACETRACK is a computer code to simulate transverse nonlinear particle motion in accelerators. Transverse magnetic fields of higher order are treated in thin magnet approximation. Multipoles up to 20 poles are included. Energy oscillations due to the nonlinear synchrotron motion are taken into account. Several additional features, as linear optics calculations, chromaticity adjustment, tune variation, orbit adjustment and others are available to guarantee a fast treatment of nonlinear dynamical problems.

1. Introduction

The FORTRAN program RACETRACK was originally developed to get a tool for investigating the influence of multipole errors in the superconducting dipoles on particle motion in HERA.[1, 2, 3)]
Nonlinear elements are treated in thin magnet approximation. Normal and skew multipoles up to 20-poles are included. Each multipole strength is defined by a constant mean value and a random varying part. Systematic and/or random displacement errors of the multipoles can be introduced.
Special attention has been directed to simplify the input procedure to avoid time waisting error detection. So the tracking program was supplemented by a optics calculating part, which makes the detection of structure input errors very easy.

In order to reduce the revolution time, the single element structure is composed into a block structure consisting of a minimum number of different blocks, where each block is represented by its transformation matrix only.
Special features have been introduced for the performance of often used operations. The chromaticity can automatically be corrected or adjusted to desired values by using two sextupole families. The fractional part of tune can be varied by changing the strengths of two quadrupole families. Systematic or random dipole errors can be scaled to give desired rms errors of orbit deviations at monitor positions which can be defined.

The initial coordinates of an ensemble of particles can be explicitly introduced or arranged according to a Gaussian or a rectangular beam.
An ensemble of particles is found to be stable, if all particles over all revolutions remain whithin the physical aperture. The aperture is defined by aperture limiting insertions (either rectangular or elliptical) which can be placed at any position and may also have different values. Thus the actual gometrically varying aperture can be introduced.
Tracking can be performed for constant energy deviation or by varying the energy according to the actual nonlinear synchrotron oscillations. After each energy change due to synchrotron oscillations, the calculation of the energy dependent single element matrices and the composition into blocks is repeated.

An expansion of the presented version of RACETRACK by additional features is in the test phase and will be published in the next months. There resonace driving terms and resonace widths may be calculated. A compensation scheme for 3rd integer driving terms is introduced. A Fast Fourier transformation for the transverse motion is added and different orbit correction modes are implemented.

2. Analytical Description

Including general fields, the transverse motion of a particle in the nonlinear lattice can be expressed by

$$\frac{d^2x}{ds^2} + K_x(s)\cdot x = \frac{e}{p_o} B_z(z,x,s)$$
$$\frac{d^2z}{ds^2} + K_z(s)\cdot z = -\frac{e}{p_o} B_x(z,x,s) \qquad (1)$$

x, z, s	horizontal, vertical and longitudinal coordinates in a right handed (z, x, s) coordinate system
k_x, k_z	focusing strengths
p_o	momentum of the particle
B_x, B_z	transverse components of the additional magnetic field
e	elementary charge

Since there exists in general no analytical solution for the equation of motion anymore, a computer simulation must be performed to investigate the particle dynamic in the presence of arbitrary field distortions.
Doing this, the equations of motions are solved piecewise for each element and an ensemble of particles with different initial coordinates is transformed through the single element structure.

For linear elements with constant focusing strength and radius of curvature, the homogeneous part of equation (1) leads to a simple linear transformation of the trajectory coordinates.
To make the nonlinear equation solvable a thin magnet approximation is used, that means the integrated effect is concentrated in a magnet element with zero length:

$$\frac{d^2x}{ds^2} = \frac{e}{p_0}\,\delta(s)\int_{-l/2}^{l/2} B_z(z,x,s)\,ds$$
$$\frac{d^2z}{ds^2} = -\frac{e}{p_0}\,\delta(s)\int_{-l/2}^{l/2} B_x(z,x,s)\,ds \qquad (2)$$

l magnet length

Thus the thin magnet transformation merely changes the direction of the particle trajectory according to

$$\delta_{z'} = \frac{\bar{B}_z\, l}{B_0\, \rho}$$
$$\delta_{x'} = -\frac{\bar{B}_z\, l}{B_0\, \rho} \qquad (3)$$

It is practical to use a multipole expansion for the analytical description of the additional magnetic field:

$$\bar{B}_z + i\,\bar{B}_x = B_0 \sum_{n=1} (b_n + i a_n)(x + i z)^{n-1} \qquad (4)$$

b_n, a_n normal and skew multipole coefficients
n = 1 dipole
2 quadrupole
.
.
etc

Substituting (3) in equation (4), we get for the horizontal and vertical deflection of the trajectory coordinates due to multipoles

$$\delta_{x'} = \frac{l}{\rho} \mathrm{Re} \left\{ \sum_n (b_n + i a_n)(x + iz)^{n-1} \right\}$$
$$\delta_{z'} = -\frac{l}{\rho} \mathrm{Im} \left\{ \sum_n (b_n + i a_n)(x + iz)^{n-1} \right\} \qquad (5)$$

For the definition of the initial trajectory coordinates the linear beam size, i.e. the twiss parameters α and β at the starting point must be calculated. Therefore first the closed orbit must be found in the presence of all non-linear elements. It is done in an iterative way with help of the linear transformation matrix M at the design orbit. The best initial guess of the closed orbit is taken as

$$\vec{y}_0 = \frac{\Delta p}{p} \vec{D} \qquad (6)$$

and the deviation from this orbit is then given with help of the equations

$$\vec{y}_0 + \Delta\vec{y}_0 = \mathbb{M}(\vec{y}_0 + \Delta\vec{y}_0)$$

$$\vec{y}_1 = \mathbb{M}\vec{y}_0$$

as

$$\Delta\vec{y}_0 = [\mathbb{M} - \mathbb{1}]^{-1}(\vec{y}_0 - \vec{y}_1) \qquad (7)$$

for one iteration step ($\vec{y}_1$ is calculated by transforming the initial vector $\vec{y}_0$ through the nonlinear structure).
Once the closed orbit is found, the optics with linearized fields along this orbit must be calculated. The expansions of equations (5) for quadrupole contributions along the closed orbit (x_o, z_o) are given by

$$\delta_{x'}(x_o + x) = \delta_{x'}(x_o) + \left.\frac{\partial \delta_{x'}}{\partial x}\right|_{x_o} \cdot x$$
$$\delta_{z'}(z_o + z) = \delta_{z'}(z_o) + \left.\frac{\partial \delta_{z'}}{\partial z}\right|_{z_o} z \qquad (8)$$

By solving the eigenwert equations of the revolution matrix along the closed orbit the twiss parameters α and β and the fractional parts of tunes are found.
The initial trajectory coordinates can then be defined for constant betatron amplitude and distributed uniformally on the phase ellipses of both planes.

$$x_i = x_o + A_x \cos\varphi_{xi}$$
$$x_i' = x_o' - \frac{A_x}{\beta_x}(\sin\varphi_{xi} + \alpha_x \cos\varphi_{xi}) \qquad (9)$$
$$z_i = z_o + A_z \cos\varphi_{zi}$$
$$z_i' = z_o' - \frac{A_z}{\beta_z}(\sin\varphi_{zi} + \alpha_z \cos\varphi_{zi})$$

with the starting point parameters

x_o, x_o', z_o, z_o'	closed orbit
β_x, α_x, β_z, α_z	twiss parameters
A_x, A_z	betatron amplitudes
φ_{xi}, φ_{zi}	distribution parameters
x_i, x_i', z_i, z_i'	initial coordinates

Regarding the initial coupling between horizontal and vertical motion, described by the emittance ratio

$$K = \frac{\varepsilon_{z0}}{\varepsilon_{x0}} \qquad A_{x0}^2 = \varepsilon_{x0}\beta_x$$
$$A_{z0}^2 = \varepsilon_{z0}\beta_z \tag{10}$$

the situation is different in the electron case as compared to protons.
For electrons: the equilibrium between quantum excitation and damping gives a Gaussian particle distribution. With respect to the transverse coordinates x, z and their derivatives x', z' we have a four dimensional Gaussian distribution. Scraping this distribution along hyperpheres with constant particle density gives the same reduction in lifetime and therefore the maximum stable hypersphere in the Gaussian distribution should be found by tracking. The actual shape of the stability boundary is of minor interest.

Thus we are looking for the maximum stable horizontal emittance ε_{xo} for amplitudes chosen by the following relations:

$$A_{xj} = \varepsilon_{x0}\beta_x \cos\psi_j \;,\; A_{zj} = K\varepsilon_{x0}\beta_z \sin\psi_j \tag{11}$$

ψ_j distribution parameter

For each amplitude pair the trajectory coordinates are selected according to equations (9).
In terms of oscillation amplitudes the distribution is quadratic

$$\frac{A_{xj}^2}{\beta_x} + \frac{A_{zj}^2}{K\beta_z} = \varepsilon_{x0} \tag{12}$$

and we call it an <u>elliptical distribution</u>.

In proton accelerators the emittance ratio is usually defined by the injection procedure and in principle one can fill the entire stable acceptance with particles. But since the calculation of the entire boundary shape is very time consuming one usually prefers to calculate the maximum stable amplitude A_x (or emittance $\varepsilon_{x\beta}$) for constant emittance ratio, or

$$A_z = A_x \sqrt{K \frac{\beta_z}{\beta_x}} \tag{13}$$

corresponding to the diagonal of linear beam size rectangular in amplitude plane.
We call this a rectangular distribution.

For exploring the stability range in the tune diagram around an suitable working point, in RACETRACK the fractional part of tune may be automatically adjusted to desired values. The task is activated by introducing an additional data block in the input stream.
For two quadrupole families the sensitivity matrix is calculated

$$\mathbb{M}_Q = \begin{bmatrix} \frac{\partial Q_x}{\partial k_1} & \frac{\partial Q_x}{\partial k_2} \\ \frac{\partial Q_z}{\partial k_1} & \frac{\partial Q_z}{\partial k_2} \end{bmatrix} \tag{14}$$

and the correction is performed in an iterative way corresponding to

$$\begin{bmatrix} \Delta k_1 \\ \Delta k_2 \end{bmatrix} = \mathbb{M}_Q^{-1} \begin{bmatrix} \Delta Q_x \\ \Delta Q_z \end{bmatrix} \tag{15}$$

$\Delta k_{1,2}$ increments in quadrupole strengths
$\Delta Q_{x,z}$ desired change in tune.

Similarly the chromaticity may be adjusted to desired values by using two sextupole families. The derivative of the tunes with respect to the relative energy deviation is obtained by calculating the tunes for zero and small $\pm$ $\Delta p/p$ momentum deviations.

For both procedures adjustment is repeated until the difference to the desired values is below the accuracy parameter. Instead of single type families also combinations of quadrupole and sextupole families may be used for the optimization procedure.

Another possible feature of RACETRACK is the introduction of energy variations according to the actual synchrotron oscillation. For this operation mode cavities must be introduced in the structure.
Synchrotron phase ϕ and energy E are varied according to the equations

Cavity:
$$E_{n+1} = E_n + e\frac{U_o}{n_c}\left[\sin(\Psi+\phi_n) - \sin\Psi\right]$$
$$\phi_{n+1} = \phi_n \qquad (16)$$

Arc:
$$E_{n+2} = E_{n+1}$$
$$\phi_{n+2} = \phi_{n+1} - 2\pi q C_\theta \frac{E_{n+1}-E_o}{E_o} \qquad (17)$$

with U_o total voltage
n_c No. of cavities per circumference
Ψ synchronous phase
q harmonic number
E_o equilibrium energy
e elementary charge

and

$$C_\theta = \oint \frac{D(s)}{\rho_o(s)}\frac{ds}{L_o} = \alpha_c/n_c$$ for superperiodic arrangement of cavities

α_c momentum compaction
ρ_o bending radius

After each energy change according to equation (16), the linear transformations are recalculated and the composition into structure blocks is repeated.

3. Data Structure

The code is executed by a set of data blocks according to the tasks to be performed. Each of the blocks has a command which identifies the task, followed by data specific for the block. At the end of each data block the command "NEXT" is expected.
The minimum program input consits of the "SINGLE ELEMENTS" list, the "BLOCK DEFINITION" i.e. the composition of single elements into groups, and the "STRUCTURE INPUT" of the ring.
Beside these structure definitions, operational blocks are introduced in the input stream for initating special calculations.

In the following a detailed definition of all data blocks is given. A complete input and output example of the program is given in Appendices 1 and 2. The end of the data input is assigned by the command "ENDE" in format (A4).

3.1 Program Versions

Since flexibility and speed of a tracking program are contradicting requirements, two versions of the program, either matched for speed or flexibility are available. Setting the first data card either

to SPEED
or FLEXIBILITY

the corresponding mode is seclected (default = SPEED). The input data of "SPEED" are compatible with the program mode "FLEXIBILITY", but not vice versa.
In the more general version single multipoles from dipoles up to 20 poles, normal and skew can be introduced. In addition a nonlinear insertion including all these multipoles in one element is available. Displacement errors of the thin magnet elements can be introduced. The aperture limitation may either be chosen as rectangular or elliptical and combined with each thin element insertion.

Monitor positions may be explicitly introduced or combined with other thin magnet elements. The actual nonlinear synchrotron motion may be included.
In the speed optimized version, only the normal sextupole for chromaticity-correction and the combined multipole insertions are included. The closed orbit displacement measurements and aperture limitations are combined with the normal sextupoles. Only constant energy tracking can be performed.
The remaining columns (after A4, 8x) may be used for the heading.

3.2 SINGLE ELEMENTS

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
SINGLE ELEMENTS-----------------------------------------------------
QV1    2  .0           .0347128   5.0
QH1    2  .0          -.03417102  3.6
QI1    2  .0           .01389337  1.8
QI2    2  .0           .0470378   1.8
QF     2  .0          -.03493976  1.8
QD     2  .0           .03440086  1.8
BI1    1  .0016783     .0         6.0
BI2    1  .0016783     .0         3.0
BV1    4 -.00096666    .0         6.0
BV2    4  .00096666    .0         6.0
DINT   0                         10.0
DB1    0                          7.9
DB2    0                          0.5
DB3    0                          1.384
MPM   10
SPH    3  -.20962
SPV    3   -.01591
OC1    4   .01000                          0     1.5    0.     1.5
OC2    4  -.01000                          0.    1.5    0.     1.5
NEXT----------------------------------------------------------------
```

Linear and nonlinear single elements may be introduced in arbitrary order. A maximum number of 100 elements is allowed.

3.2.1 Linear Single Element

Each linear single element is defined by the name, label, inverse bending radius, focusing strength and length.

NAME, LABEL, $1/\rho$ [m^{-1}], k[m^{-2}], l[m]

Format (A4, I4, 3D12)

The following magnet types assigned by the label can be used:

label	
0	drift space
1	horizontal bending, wedge- or combined function magnet horizontal
2	quadrupole
3	vertical bending, wedge- or combined function magnet vertical
4	horizontal bending, sector
5	vertical bending, sector
6	edge focusing

$1/\rho > 0$ in the horizontal plane is used for the deflection of the normal bending magnets. In the vertical plane the positive sign indicates a deflection in the upwards direction

$k < 0$ corresponds to a horizontal focusing quadrupole

The edge focusing element with label 6 is necessarily used if a rectangular magnet is split to introduce nonlinear insertions in between. It is horizontally defocusing corresponding to a horizontal rectangular magnet. Inverse bending radius and length for this element are the values of the complete, non split bending magnet.
Introducing a negative length at this position, a horizontal focusing element is produced corresponding to a vertically deflecting wedge magnet.

3.2.2 Nonlinear Single Element

The nonlinear single element is characterized by its name, a label defining the type, the mean value of the strength, the rms value of the random fluctuating part of the strength and the length "zero", which distinguishes the nonlinear insertion from the linear element. In addition horizontal or vertical displacements of nonlinear elements, either systematic or statistically fluctuating, can be introduced (x, x-rms, z, z-rms).
The input has the following form:

NAME, LABEL, STRENGTH [in m^{-n+1} for a 2n-pole],
STRENGTH-rms [m^{-n+1}], LENGTH-0, x[mm], x-rms [mm], z [mm], z-rms [mm]

Format (A4, I4, 3D12, 4F7).

Positive labels from 1 to 10 are used for horizontal dipoles, normal quadrupoles and normal multipoles up to 20-poles, i.e.

label "+ n" corresponds to a normal 2n-pole "B_n"

Correspondingly negative labels from - 1 to - 10 are used for vertical dipoles, skew quadrupoles and skew multipoles up to 20-poles

label "- n" corresponds to a skew 2n-pole "A_n"

Label 11 is used for a thin magnet element containing all normal and skew multipoles up to 20-poles at the same position. Using this element type, the additional data block "MULTIPOLE COEFFICIENTS" is necessary.
In Appendix 3 all nonlinear transformations are collected.

The input multipole strengths A_n on B_n in [meter^{-n+1}] are related to the multipole coefficients of equation (1) by

$$A_n = \delta_o \, a_n$$
$$B_n = \delta_o \, b_n$$

δ_o deflection of the normal bending magnet
a_n, b_n multipole coefficients as defined in equation (4)

SPEED-mode: Only the combined multipole insertion and normal sextupoles without displacement and field errors are allowed.

3.3 BLOCK DEFINITIONS

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
BLOCK DEFINITIONS-------------------------------------------------------
  4   1   1   1   1
BL1   DINT QV1   QH1   BI1   QI1   DB2   BV1   QI2   QI3   QI4
      DB1  BI2   DB2   BI2   QI5   DB3   BI2   DV1   BV2   QI6
BL2   DB4  BI2   DB5   BI2   QI7
BL3   DB6  BI2   QI8
BL4   DB   B/6
BL5   B/3
BLA   B/6  QB3
BLB   B/6  QB1
BLC   B/6  QJ6
BLD   DV3  BV2   QJ5   QJ4   QJ3   QJ2   DV2   BV1   QJ1   BJ1
      QH2  QV2   DINT
NEXT--------------------------------------------------------------------
```

To reduce computation time, structure parts which are identical are composed into blocks, where during computation each block is represented by its transformation matrix only. A block is defined by its name and the single element structure in the following form:

BLOCK NAME, ELEMENT NAME, ELEMENT NAME, ...

Format (5x, 11(A4, 1x))

The number of elements introduced by one line is less or equal to 10. If more than 10 elements shall be composed into one block, an arbitrary number of continuation cards must be used in the following form:

ELEMENT NAME, ELEMENT NAME, ...

Format (10x, 10(A4, 1x))

The element name corresponds to the name defined in the data block "SINGLE ELEMENTS"

3.4 STRUCTURE INPUT

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
STRUCTURE INPUT---------------------------------------------------------
          BL1   BL2A SP0   BL2B SP0   BL2C BL3A SP0   BL3B
          BL4   SPH  PS    BL5  PS    BL5  PS   SPV   BL9
     18*(BL4   SPV  PS    BL5  PS    BL5  PS   SPH   BL10 APT
          BL4   SPH  PS    BL5  PS    BL5  PS   SPV   BL11 APT
        )
          BL4   SPV  PS    BL5  PS    BL5  PS   SPH   BL10
          BL4   SPH  MPM   BL5  MPM   BL5  MPM  SPV   BL20
          BL21
NEXT--------------------------------------------------------------------
```

The structure blocks defined above and the nonlinear single elements are arranged corresponding to the magnet structure. The total number of blocks + nonlinear insertions may not exceed 5000. The structure input is given by cards with maximum 10 block elements in the following form:

BLOCK, BLOCK, NONLINEAR INSERTION, BLOCK ...

Format (10x, 10(A4, 1x))

Repetitions of structure parts are introduced by brackets and a multiplying factor in front of the expression:

```
     N * (BL1, BL2, BL3, SPH
          BL4, BL5, BL6, BL7, SPV
          BL8, BL9
         )
Format   (4x, I3, 1x, A1, 1x, 10(A4, 1x)
         10x, 10(A4, 1x)
          8x, A1
         )
```

By this input the block structure in between the brackets will be repeated N times.

3.5 MULTIPOLE COEFFICIENTS

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
MULTIPOLE COEFFICIENTS-------------------------------------------------
          25.0    10.06921
      0.          0.0001544 0.          0.0000635
      0.          0.0000833 0.          0.0000833
      0.0030      0.000300  0.          0.00007
      0.          0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
     -0.00029     0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
     -0.00048     0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
NEXT-------------------------------------------------------------------
```

As already mentioned above, the nonlinear insertion assigned by label 11 in data block "SINGLE ELEMENTS" introduces nonlinear fields with normal and skew multipoles up to 20-poles. This data block is used for defining the multipole strengths of an element with label 11.

The input is given by

RO [mm], DO [mrad]	Format (10x, 2F10,
B_1, B_1-rms, A_1, A_1-rms	10x, 4F10
. .	
. .	
. .	
B_{10}, B_{10}-rms, A_{10}, A_{10}-rms	10x, 4F10)

With B_n and A_n the systematic normal and skew multipole strengths and B_n-rms and A_n-rms the randomly varying part.
Since the relevant multipoles are normally the result of an integrated field measurement at radius RO in the bending magnet, the input strengths are defined as relative deflection strengths at RO, i.e.

$$B_n, A_n = \frac{\delta_n/\delta_o}{(R/R_o)^{n-1}}\bigg|_{R=R_o} = \delta_n/\delta_o$$

With δ_o nominal deflection of the bending magnet
δ_n deflection due to multipole 2n

For a nonrelative form of input strengths, DO must be set to 1000. and RO must be expressed by the unit of the multipole strength in mm.

Example:

Multipole expressed in	for DO	RO
$[inch^{-n+1}]$	1000.	25.4
$[meter^{-n+1}]$	1000.	1000

3.6 RANDOM FLUCTUATION STARTING NUMBER

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
RANDOM FLUCTUATION STARTING NUMBER-----------------------------------
        00000000000011822903
NEXT----------------------------------------------------------------
```

For the statistical fluctuation of multipole strengths and multipole displacements a Gaussian random distribution is used. This data block may be used to set the initial value of the random sequence. It has one data card of the form:

RNO Format (10x, I20)

If the data block is missing, the initial value will internally be produced and listed in the output.

3.7 PRINTOUT SELECTION

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
PRINTOUT SELECTION--------------------------------------------------
NEXT----------------------------------------------------------------
```

Using this data block, the input data will appear in the output list.

The string "PLOT" introduced in the structure defined in data block "STRUCTURE INPUT" will produce an output with phase space diagrams of the particle motion at that position.

SPEED-mode: No phase space diagrams are available.

3.8 LINEAR OPTICS CALCULATION

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
LINEAR OPTICS CALCULATION-------------------------------------------
ELEMENT          13
NEXT----------------------------------------------------------------
```

Calculation and printout of linear optics is initiated by this data block. The input data have the form:

CALCULATION MODE, NO. OF BLOCKS

Format (A4, 6x, I10)

The first parameters defining the output mode can either be the string "BLOCK" or "ELEMENT", performing calculation and output for the block structure or the single element structure. The printout of the optical parameters is given at the end of each block or single element. The second parameter defines the number of blocks for which the calculation of linear optics should be performed. The complete structure is calculated for zero or blank at this position.

3.9 TUNE VARIATION

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
TUNE VARIATION-----------------------------------------------------
QF        0.15
QD        0.179
NEXT----------------------------------------------------------------
```

For the investigation of optical structures the tunes must be varied to avoid influences of nearby resonances on stable acceptance. As outlined in chapter 2, this data block can be used for varying the fractional tunes by two quadrupole families.

The input has the form:

NAME QUADRUPOLE-1, DELTA-QH
NAME QUADRUPOLE-2, DELTA-QV

Format (A4, 6x, F10,
A4, 6x, F10)

By changing the selected quadrupole families the fractional tunes are set to the required values DELTA-QH and DELTA-QV.

Since there is an ambiguity in the fractional tune calculation, only the range between - 0.5 and + 0.5 can be adjusted by this data block in one step. For variations beyond these limits the quadrupole strength must slightly be changed to skip these limits. The output of the fractional tune corresponds to the deviation from the integer part in the range "integer $\pm$ 0.5".

3.10 CHROMATICITY ADJUSTMENT

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
CHROMATICITY CORRECTION-----------------------------------------------
SPH       1.5
SPV       1.5
NEXT------------------------------------------------------------------
```

Two sextupole families can be used to compensate the chromaticity or to adjust it to desired values.

The data input has the form:

NAME, SEXTUPOLE-1, CHROMATICITY-H
NAME, SEXTUPOLE-2, CHROMATICITY-V

Format (A4, 6x, F10,
A4, 6x, F10)

with the sextupole names corresponding to the single element list and the horizontal and vertical chromaticities which should be adjusted.

3.11 COMBINATIONS OF ELEMENTS

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
COMBINATION OF ELEMENTS-------------------------------------------------
QF         - 0.5     QF1
QD           1.234   QD1   -0.233    QD2
SPH          0.8     SPHA
SPV         -0.75    SPVA
NEXT--------------------------------------------------------------------
```

For the tune variation it is sometimes desirable, instead of varying two families, to use combinations of quadrupole families to guarantee for instance an orthogonal variation of horizontal and vertical tune. Similar for the chromaticity correction it might be useful to keep the ratio of sextupole strengths constant which are optimized for instance for resonance compensation.
With the data block under consideration the quadrupole types used in "TUNE VARIATION" or sextupole types used in "CHROMATICITY ADJUSTMENT" may be related by a fixed ratio to other elements.

Input data:

ELEMENT-0, RATIO-1, ELEMENT-1, RATIO-2, ELEMENT-2, ...

.
.
.
.

4 lines maximum

Format (A4, 6x, 4(F10, A4, 1x))

ELEMENT-0 is one of the elements used in data blocks "TUNE VARIATION" or "CHROMATICYTY ADJUSTMENT". For the optimization procedures indicated by these blocks the ratio to all following elements in the data line (maximum = 4 elements) is kept constant according to

$$\text{RATIO-i} = \frac{\text{STRENGTH (ELEMENT-i)}}{\text{STRENGTH (ELEMENT-0)}}$$

For each of the elements used in the data blocks mentioned, combinations with other elements may be established.

3.12 ORBIT ADJUSTMENT

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
ORBIT ADJUSTMENT-----------------------------------------------------
  1.5      1.5
MON=SPH
MON=SPV
NEXT-----------------------------------------------------------------
```

Dipole errors assigned by label 1 and -1 in the single element list or included in the combined multipole insertion with label 11 can be adjusted to give desired orbit rms values. The positions of orbit measurement are either introduced explicitly by the symbol MON in the block "STRUCTURE INPUT", or given by mapping of the orbit displacement measurement on another insertion as explained below.
The random and systematic dipole errors will be scaled to give the required orbit displacements.

Data input:

X-RMS [mm], Z-RMS [mm]
MON = NAME-1
MON = NAME-2
.
.
Format (2F10/A4, 1x, A4)

The first line includes the horizontal and vertical orbit rms values as desired.
In the second line, and an arbitrary number of following lines the positions of orbit displacements monitors are defined. Nonlinear insertion of type NAME in the single element list will be the position of orbit measurement.

SPEED-mode: Only dipole errors in the combined multipole insertion are scaled and no explicit introduction of orbit measurement by the symbol "MON" is allowed. The orbit measurement is performed at the positions of normal sextupoles.

3.13 INITIAL COORDINATES

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
INITIAL COORDINATES-----------------------------------------------------
TRAJ       10.6       0.0        5.3        0.0
         -15.0        1.0        6.7       -0.7
           4.0        2.0        3.5        1.8
NEXT--------------------------------------------------------------------
```

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
INITIAL COORDINATES-----------------------------------------------------
SET        0.0        0.0        3.0        0.0
           0.0        0.0        0.15       0.0
NEXT--------------------------------------------------------------------
```

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
INITIAL COORDINATES-----------------------------------------------------
         4  15.       90.0       0.5
         4   0.       30.0
NEXT--------------------------------------------------------------------
```

This data block is used to define the number of particles and the initial trajectory coordinates. Three modes may be used. The initial coordinates can either be introduced explicitly, arranged according to a rectangular beam, or according to a Gaussian or elliptical beam.

a) Explicit Initial Coordinates

Up to 100 trajectories can be tracked at the same time. Their initial coordinates can be introduced in the following form:

```
"TRAJ", x1 [mm], x1' [mrad], z1' [mrad], z1' [mrad]
        x2     , x2'       , z2        , z2'
        .
        .
Format (A4, 6x, 4F10)
```

The string "TRAJ" indicates that explicit initial coordinates are following. x_i, z_i are the horizontal and vertical initial displacements and x_i' and z_i' the corresponding derivatives.

Normally, when using the program for particle tracking in circular accelerators, the twiss parameters and the closed orbit at the starting point are calculated by the program. This calculation may be suppressed, if the following parameters are introduced in the data block of consideration.

"SET", CLO-H, CLO'-H, BETA-H, ALFA-H
CLO-V, CLO'-V, BETA-V, ALFA-V

Format (A4, 6x, 4F10/10x, 4F10)

With the following meaning:

CLO-H,V	horizontal and vertical closed orbit deviation at the starting point
CLO'-H,V	derivatives of the closed orbit
BETA-H,V	beta values at the starting point
ALFA-H,V	alfa values at the starting point

This input mode can be used in combination with the following definitions of rectangular and elliptical particle distributions as an alternative way to set the initial coordinates. It will be used if noncircular structures are investigated and is also very helpful for error detection in a new structure input. In combination with the "LINEAR OPTICS CALCULATION", the position of a lattice input error can easily be detected.

b) Rectangular Distribution

Initial coordinates of a rectangular beam can be introduced by the following data structure:

NP, FIO [degree], DFI [degree], K

Format (6x, I4, 3 F10)

That means NP particles are distributed on the horizontal phase ellipse at the starting point according to equation (9). The initial betatron phase of the first particle is FIO. The following particles are spaced by DFI.

The same arrangement is used in the vertical plane and each horizontal coordinate is combined with all vertical coordinates. Thus a total number of NP*NP particles will be introduced in this way.

The amplitude ratio between the vertical and horizontal plane is defined by the coupling constant or emittance ratio K. Using this kind of particle distribution, the initial coupling K is constant for all particles.

c) Elliptical Distribution

If in addition to b) a data line of the following form is introduced:

NPA, PSIO [degree], DPSI [degree]

Format (6x, I4, 2 F10)

the arrangement of initial coordinates is performed corresponding to an elliptical distribution. The amplitude ratio between vertical and horizontal motion is not constant anymore, but varying according to equation (11). For each of the amplitude combinations an arrangement as outlined in b) is produced. Thus the total number of tracked particles is given by the product NPA*NP*NP.

3.14 TRACKING PARAMETERS

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
TRACKING PARAMETERS-------------------------------------------------------
       100
        20 25.0       10.0
         5 -0.01       0.01
NEXT---------------------------------------------------------------------
```

The number of revolutions, the starting amplitude and the relative energy deviation are introduced here in the following way:

NUML	Format (6x, I4/
NAP, ASTART, AMP	6x, I4, 2 F10/
IPM, DP+, DP-	6x, I4, 2 F10)

Where NUML is the number of revolutions for which the tracking should be performed. NAP is the number of variations for the horizontal starting amplitude ASTART at the observation and starting point. The amplitude is varied by halving the range between maximum stable and minimum unstable amplitude. AMP is the initial "stable amplitude" for the variation procedure. Usually its value will be selected to be zero.

If the input value of AMP is negative, an alternative amplitude decrementation procedure will be initiated. The starting amplitude will then be constantly reduced by AMP. The number of steps is given by NAP. DP+ and DP- define the energy range for which the tracking should be performed. IPM is the number of energy points for which the calculation will be performed including the minimum energy DP- und the maximum energy DP+. Default value of the starting point is the initial point given by the structure as defined in data block "STRUCTURE INPUT".

By introducing the string "GO" somewhere in the structure input, this point will be taken as new observation and starting point.

SPEED-mode: Constant amplitude decrementation with negative AMP is not allowed.

3.15 LIMITATION OF APERTURE

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
LIMITATION OF APERTURE-------------------------------------------------
SPH  RE     28.       28.
SPV  RE     28.       28.
APT  EL     40.       20.
NEXT-------------------------------------------------------------------
```

Each type of thin element insertion defined in the "SINGLE ELEMENTS" block may be used as a point of aperture limitation.

Input data:

NAME, LIMIT-TYPE, AP-H [mm], AP-V [mm]

.
.
.
.

(maximum = 20 elements)

Format (A4, 2x, A2, 2x, 2 F10)

The first string is the name of the element also used for aperture control.
LIMIT-TYPE defines the type of aperture limitation.
The string "RE" defines a rectangular aperture limitation corresponding to the inequalities

$$x_i < AP\text{-}H \wedge z_i < AP\text{-}V$$

and "EL" defines an elliptical aperture limitation corresponding to

$$\frac{x_i^2}{(AP\text{-}H)^2} + \frac{z_i^2}{(AP\text{-}V)^2} < 1$$

AP-H and AP-V are the horizontal and vertical half apertures respectively.
The actual shape of the vacuum chamber can be introduced in this way.

SPEED-mode: Only normal sextupoles can be used for aperture limitations in rectangular form.

3.16 SYNCHROTRON OSCILLATIONS

Input example:

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
SYNCHROTRON OSCILLATIONS----------------------------------------------
 3840.     0.0028    100.      15000.    25.       0.
NEXT------------------------------------------------------------------
```

The variation of energy according to the synchrotron motion will be activated by introducing this data block in the input stream.

Data input:

HARM, MOM. COMP, U0 [MV], E0 [MeV], PSI0 [degree], FI0 [degree]

Format (10x, 6F10)

with the meaning:

HARM	harmonic number
MOM. COMP	momentum compaction
U0	accelerating voltage
E0	equilibrium energy
PSI0	synchronous phase
FI0	starting phase of synchrotron oscillation

The energy variation is performed at each cavity position according to equations (16) and (17). The initial relative energy deviation is given by DP+ in the data block "TRACKING PARAMETERS".

Default value of the cavity position is the starting point. If more than one cavity is wanted, the string "CAV" must be introduced at the desired position in the "BLOCK STRUCTURE" input. So far only a supersymmetric arrangement is allowed.

After each energy variation the energy dependent single element matrices are recalculated and the composition into blocks repeated. If too many cavity positions are introduced, the advantage of speed increase due to the block structure may be lost.

SPEED-mode: Does not contain synchrotron oscillations. Only constant energy tracking may be performed.

4. References

/1/ HERA Proposal, ECFA 80/42 and DESY HERA 80/01, March 1980

/2/ A. Wrulich, "Aperture Limitations in the HERA Proton Ring due to Nonlinear Fields", DESY HERA 82/04, April 1982

/3/ A. Wrulich, "Tracking Studies in HERA", DESY HERA 82/07, June 1982

APPENDIX I MULTIPOLE EXPANSION

DEFLECTION: $X = B(N)*R(N)-A(N)*I(N)$

$Z = B(N)*I(N)+A(N)*R(N)$

...DEFLECTION OF NORMAL BENDING MAGNET

B(N)...NORMAL MULTIPOLE COEFFICIENT

A(N)...SKEW MULTIPOLE COEFFICIENT

DIPOLE --> $R1 = 1$

$I1 = 0$

QUADRUPOLE --> $R2 = X$

$I2 = Z$

SEXTUPOLE --> $R3 = X^2 - Z^2$

$I3 = 2ZX$

OCTUPOLE --> $R4 = X^3 - 3ZX$

$I4 = 3ZX^2 - Z^3$

DECAPOLE --> $R5 = X^4 - 6Z^2X^2 + Z^4$

$I5 = 4ZX^3 - 4Z^3X$

DODECAPOLE --> $R6 = X^5 - 10Z^2X^3 + 5Z^4X$

$I6 = 5ZX^4 - 10Z^3X^2 + Z^5$

14-POLE --> $R7 = X^6 - 15Z^2X^4 + 15Z^4X^2 - Z^6$

$I7 = 6ZX^5 - 20Z^3X^3 + 6Z^5X$

16-POLE --> $R8 = X^7 - 21Z^2X^5 + 35Z^4X^3 - 7Z^6X$

$I8 = 7ZX^6 - 35Z^3X^4 + 21Z^5X^2 - Z^7$

18-POLE --> $R9 = X^8 - 28Z^2X^6 + 70Z^4X^4 - 28Z^6X^2 + Z^8$

$I9 = 8ZX^7 - 56Z^3X^5 + 56Z^5X^3 - 8Z^7X$

20-POLE --> $R10 = X^9 - 36Z^2X^7 + 126Z^4X^5 - 84Z^6X^3 + 9Z^8X$

$I10 = 9ZX^8 - 84Z^3X^6 + 126Z^5X^4 - 36Z^7X^2$

COMBINED ELEMENT (LABEL = 11) WITH MULTIPOLES FROM DIPOLES UP TO 20-POLES --> B[N]*R[N] =

$$B_1+X[B_2+X[B_3+X[B_4+X[B_5+X[B_6+X[B_7+X[B_8+X[B_9+X[B_{10}]]]]]]]]]$$
$$-Z^2[B_3+X[3B_4+X[6B_5+X[10B_6+X[15B_7+X[21B_8+X[28B_9+X[36B_{10}]]]]]]]]$$
$$+Z^4[B_5+X[5B_6+X[15B_7+X[35B_8+X[70B_9+X[126B_{10}]]]]]]$$
$$-Z^6[B_7+X[7B_8+X[28B_9+X[84B_{10}]]]]$$
$$+Z^8[B_9+X[9B_{10}]$$

A[N]*I[N] =

$$+Z[A_2+X[2A_3+X[3A_4+X[4A_5+X[5A_6+X[6A_7+X[7A_8+X[8A_9+X[9A_{10}]]]]]]]]]$$
$$-Z^3[A_4+X[4A_5+X[10A_6+X[20A_7+X[35A_8+X[56A_9+X[84A_{10}]]]]]]]$$
$$+Z^5[A_6+X[6A_7+X[21A_8+X[56A_9+X[126A_{10}]]]]]$$
$$-Z^7[A_8+X[8A_9+X[36A_{10}]]]$$
$$+Z^9[A_{10}]$$

APPENDIX II RACETRACK - INPUT EXAMPLE

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7-
SPEED      'HERA ELECTRON OPTICS 60 DEG CELL PHASE ADVANCE'
SINGLE ELEMENTS------------------------------------------------------------
QV1    2                .0347128    5.0
QH1    2               -.03417102   3.6
QF     2               -.11454313   0.76
QD     2                .11421771   0.76
QF2    2               -.11454313   0.38
QD2    2                .11421771   0.38
B      1   .0015555Ø                9.709
L      Ø                            0.65
Q2D    2                .086492384  0.38
Q1F    2               -.026962391  0.76
ROQ6   2               -.085059812  1.0
ROQ5   2                .1234139    1.0
ROQ4   2               -.057783393  1.0
ROQ3   2                .054818607  1.0
ROQ2   2               -.13974582   1.0
ROQ1   2                .10756499   1.0
HQ12   2                .000988913  1.0
HQ11   2    1.00       -.0849526Ø3  1.0
HFQ2   2    1.00        .14771194   1.0
HFQ1   2    1.00        .015175759  1.0
HFQF   2    1.00       -.15737296   1.0
HFQD   2    1.00        .16362770   1.0
IPQ2   2    1.00       -.060778143  1.0
IPQ1   2    1.00        .10050153   1.0
B1     1    6.473       .0015556    6.473
ROVD   4    4.664      -.00233247   4.664
ROVU   4    4.664       .00233247   4.664
ROH3   1    10.785     -.00161456   10.785
ROH2   1    10.785      .00233247   10.785
ROH1   1    5.315       .00233247   5.315
D1     Ø                            2.06
D2     Ø                            4.177
D3     Ø                            4.180
D4     Ø                            0.30
D5     Ø                            4.20
D6     Ø                            13.1
D7     Ø                            5.00
D8     Ø                            6.0
D9     Ø                            22.89
D10    Ø                            7.5
SPH    3
SPV    3
APT    1
MPM    9
NEXT
BLOCK DEFINITIONS----------------------------------------------------------
  4  1  1  1  1
IR   D10  IPQ1 IPQ1 D8   IPQ2 IPQ2 D9   HFQ1 D7   D8
HF   HFQ2 D7   HFQF D7   HFQD D7   HFQF D7   HFQD D7
     HFQF D7   HFQD D7   HFQF D7   HFQD D7   HQ11 D7
HFI  D7   HQ11 D7   HFQD D7   HFQF D7   HFQD D7   HFQF
     D7   HFQD D7   HFQF D7   HFQD D7   HFQF D7   HFQ2
IRI  D8   D7   HFQ1 D9   IPQ2 IPQ2 D8   IPQ1 IPQ1 D10
ROH  HQ12 D6   ROQ1 D5   ROQ2 D5   ROQ3 D4   ROH1
ROHI ROH1 D4   ROQ3 D5   ROQ2 D5   ROQ1 D6   HQ12
ROV  ROVD ROH2 ROVU ROVU ROH3 ROVD D4   ROQ4 D3   ROQ5
     D2   ROQ6
ROVI ROQ6 D2   ROQ5 D3   ROQ4 D4   ROVU ROH3 ROVD ROVD
     ROH2 ROVU
BL4  L    B1   D1   B    L    Q1F
BL4I Q1F  L    B    D1   B1   L
BL5  L    B    L    Q2D
BL5I Q2D  L    B    L
BL6  Q2D  L    B    L    QF2
BL6I QF2  L    B    L    Q2D
HCF  QF2  L    B    L    QD2
HCD  QD2  L    B    L    QF2
NEXT
```

```
STRUCTURE INPUT-------------------------------------------------------
          IR   HF   ROH  ROV  BL4  BL5  SPV  BL6  SPH
     47*[ HCF  MPM  SPV  HCD  MPM  SPH
        ]
          BL6I BL5I BL4I ROVI ROHI HFI  IRI
NEXT
PRINTOUT SELECTION----------------------------------------------------
NEXT------------------------------------------------------------------
LINEAR OPTICS CALCULATION---------------------------------------------
ELEMENT           13
NEXT------------------------------------------------------------------
TUNE VARIATION--------------------------------------------------------
QF        0.15
QD        0.179
NEXT------------------------------------------------------------------
CHROMATICITY CORRECTION-----------------------------------------------
SPH       1.5
SPV       1.5
NEXT------------------------------------------------------------------
INITIAL COORDINATES---------------------------------------------------
          4  15.        90.0       0.5
          4   0.        30.0
NEXT------------------------------------------------------------------
TRACKING PARAMETERS---------------------------------------------------
        100
         20 25.0        10.0
          5 -0.01        0.01
NEXT------------------------------------------------------------------
ENDE=================================================================
ORBIT ADJUSTMENT------------------------------------------------------
   1.5       1.5
MON=SPH
MON=SPV
NEXT------------------------------------------------------------------
MULTIPOLE COEFFICIENTS------------------------------------------------
             25.0    10.06921
      0.          0.0001544 0.          0.0000635
      0.          0.0000833 0.          0.0000833
      0.0030      0.000300  0.          0.00007
      0.          0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
     -0.00029     0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
     -0.00048     0.00007   0.          0.00007
      0.          0.00007   0.          0.00007
NEXT------------------------------------------------------------------
RANDOM FLUCTUATION STARTING NUMBER------------------------------------
          000000000000011822903
NEXT------------------------------------------------------------------
LIMITATION OF APERTURE------------------------------------------------
SPH  RE      28.         28.
SPV  RE      28.         28.
APT  EL      40.         20.
NEXT------------------------------------------------------------------
COMBINATION OF ELEMENTS-----------------------------------------------
QF         - 0.5      QF1
QD           1.234    QD1   -0.233     QD2
SPH          0.8      SPHA
SPV         -0.75     SPVA
NEXT------------------------------------------------------------------
INITIAL COORDINATES---------------------------------------------------
TRAJ        10.6       0.0        5.3        0.0
           -15.0       1.0        6.7       -0.7
             4.0       2.0        3.5        1.8
NEXT------------------------------------------------------------------
INITIAL COORDINATES---------------------------------------------------
SET         0.0        0.0        3.0        0.0
            0.0        0.0        0.15       0.0
NEXT------------------------------------------------------------------
```

APPENDIX III RACETRACK - OUTPUT EXAMPLE

```
OOOOOOOOOOOOOOOOOOOO
O                  O
O R A C E T R A C K O
O                  O
OOOOOOOOOOOOOOOOOOOO
```

**** RING PARAMETERS ****

SINGLE ELEMENTS:

NO	NAME	TYP	1/RHO	STRENGTH	LENGTH	X-POS	X-RMS	Z-POS	Z-RMS
1	QF	2	0.0	-0.114543130	0.760	0.0	0.0	0.0	0.0
2	QD	2	0.0	0.114217710	0.760	0.0	0.0	0.0	0.0
3	QF2	2	0.0	-0.114543130	0.380	0.0	0.0	0.0	0.0
4	QD2	2	0.0	0.114217710	0.380	0.0	0.0	0.0	0.0
5	B	1	0.001555600	0.0	9.709	0.0	0.0	0.0	0.0
6	L	0	0.0	0.0	0.650	0.0	0.0	0.0	0.0
7	Q2D	2	0.0	0.086492384	0.380	0.0	0.0	0.0	0.0
8	Q1F	2	0.0	-0.026962391	0.760	0.0	0.0	0.0	0.0
9	ROQ6	2	0.0	-0.085059812	1.000	0.0	0.0	0.0	0.0
10	ROQ5	2	0.0	0.123413900	1.000	0.0	0.0	0.0	0.0
11	ROQ4	2	0.0	-0.057783393	1.000	0.0	0.0	0.0	0.0
12	ROQ3	2	0.0	0.054818607	1.000	0.0	0.0	0.0	0.0
13	ROQ2	2	0.0	-0.139745820	1.000	0.0	0.0	0.0	0.0
14	ROQ1	2	0.0	0.107564990	1.000	0.0	0.0	0.0	0.0
15	HQ12	2	0.0	0.000988913	1.000	0.0	0.0	0.0	0.0
16	HQ11	2	0.0	-0.084952623	1.000	0.0	0.0	0.0	0.0
17	HFQ2	2	0.0	0.147711940	1.000	0.0	0.0	0.0	0.0
18	HFQ1	2	0.0	0.015175759	1.000	0.0	0.0	0.0	0.0
19	HFQF	2	0.0	-0.157372960	1.000	0.0	0.0	0.0	0.0
20	HFQD	2	0.0	0.163627700	1.000	0.0	0.0	0.0	0.0
21	IPQ2	2	0.0	-0.060778143	1.000	0.0	0.0	0.0	0.0
22	IPQ1	2	0.0	0.100501530	1.000	0.0	0.0	0.0	0.0
23	B1	1	0.001555600	0.0	6.473	0.0	0.0	0.0	0.0
24	ROVD	4	0.0	-0.002332470	4.664	0.0	0.0	0.0	0.0
25	ROVU	4	0.0	0.002332470	4.664	0.0	0.0	0.0	0.0
26	ROH3	1	-0.001614560	0.0	10.785	0.0	0.0	0.0	0.0
27	ROH2	1	0.002332470	0.0	10.785	0.0	0.0	0.0	0.0
28	ROH1	1	0.002332470	0.0	5.315	0.0	0.0	0.0	0.0
29	D1	0	0.0	0.0	2.060	0.0	0.0	0.0	0.0
30	D2	0	0.0	0.0	4.177	0.0	0.0	0.0	0.0
31	D3	0	0.0	0.0	4.180	0.0	0.0	0.0	0.0
32	D4	0	0.0	0.0	0.300	0.0	0.0	0.0	0.0
33	D5	0	0.0	0.0	4.200	0.0	0.0	0.0	0.0
34	D6	0	0.0	0.0	13.100	0.0	0.0	0.0	0.0
35	D7	0	0.0	0.0	5.000	0.0	0.0	0.0	0.0
36	D8	0	0.0	0.0	6.000	0.0	0.0	0.0	0.0
37	D9	0	0.0	0.0	22.890	0.0	0.0	0.0	0.0
38	D10	0	0.0	0.0	7.500	0.0	0.0	0.0	0.0
39	SPH	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	SPV	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	APT	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	MPM	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

RINGSTRUCTURE:

NO. OF SUPERPERIODS AND SYMMETRY	4 1 1 1 1
NUMBER OF DIFFERENT BLOCKS	16
BLOCKS PER PERIOD	298

BLOCKSTRUCTURE:

1	IR	10	D10	IPQ1	IPQ1	D8	IPQ2	IPQ2	D9	HFQ1	D7	D8								
2	HF	20	HFQ2	D7	HFQF	D7	HFQD	D7	HFQF	D7	HFQD	D7	HFQF	D7	HFQD	D7	HFQF	D7	HFQD	D7	HQ11	D7
3	HFI	20	D7	HQ11	D7	HFQD	D7	HFQF	D7	HFQD	D7	HFQF	D7	HFQD	D7	HFQF	D7	HFQD	D7	HFQF	D7	HFQ2
4	IRI	10	D8	D7	HFQ1	D9	IPQ2	IPQ2	D8	IPQ1	IPQ1	D10										
5	ROH	9	HQ12	D6	ROQ1	D5	ROQ2	D5	ROQ3	D4	ROH1											
6	ROHI	9	ROH1	D4	ROQ3	D5	ROQ2	D5	ROQ1	D6	HQ12											
7	ROV	12	ROVD	ROH2	ROVU	ROVU	ROH3	ROVD	D4	ROQ4	D3	ROQ5	D2	ROQ6								
8	ROVI	12	ROQ6	D2	ROQ5	D3	ROQ4	D4	ROVU	ROH3	ROVD	ROVD	ROH2	ROVU								
9	BL4	6	L	B1	D1	B	L	Q1F														
10	BL4I	6	Q1F	L	B	D1	B1	L														
11	BL5	4	L	B	L	Q2D																
12	BL5I	4	Q2D	L	B	L																
13	BL6	5	Q2D	L	B	L	QF2															
14	BL6I	5	QF2	L	B	L	Q2D															
15	HCF	5	QF2	L	B	L	QD2															
16	HCD	5	QD2	L	B	L	QF2															

BLOCKSTRUCTURE OF SUPERPERIODE:

1	IR	HF	ROH	ROV	BL4	BL5	SPV	BL6	SPH	HCF
11	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH
21	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM
31	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF
41	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH
51	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM
61	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF
71	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH
81	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM
91	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF
101	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH
111	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM
121	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF
131	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH
141	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM
151	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF
161	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM	HCD	SPH
171	MPM	HCF	SPV	MPM	HCD	SPH	MPM	HCF	SPV	MPM

```
181 HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF
191 SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH
201 MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM
211 HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF
221 SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH
231 MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM
241 HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF
251 SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH
261 MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM
271 HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH  MPM  HCF
281 SPV  MPM  HCD  SPH  MPM  HCF  SPV  MPM  HCD  SPH
291 MPM  BL6I BL5I BL4I ROVI ROHI HFI  IRI
```

```
 ---ENTRY LINOPT---
 ---ENTRY CLORB---/DPP= 0.00010 /CLOX/  -0.00007   0.00002 /CLOZ/   0.00001   0.00003 /ITERAT.=  2/ ACCURACY= 0.263179540-12
 ---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
```

PLANE	DISP[MM]	DISP[MRAD]
X	-0.750	0.159
Z	0.107	0.262

RELATIVE ENERGY DEVIATION 0.0
FRACTIONAL TUNES -HORICONTAL 0.1500198
-VERTICAL 0.1799380

NR	TYP	L-TOTAL [M]	LENGTH [M]	BETAH [M]	ALFAH	PHIH [QE]	DISH [M]	DISPH [RAD]	CLOH [MM]	CLOPH [MRAD]	BETAV [M]	ALFAV	PHIV [QE]	DISV [M]	DISPV [RAD]	CLOV [MM]	CLOPV [MRAD]
0				3.00	0.00	0.0	-0.00	0.000	0.0	0.0	0.15	0.00	0.0	0.00	0.000	0.0	0.0
1	D10	7.500	7.500	21.75	-2.50	0.19	0.00	0.000	0.0	0.0	374.79	-49.95	0.25	0.00	0.000	0.0	0.0
2	IPQ1	8.500	1.000	29.70	-5.71	0.20	0.00	0.000	0.0	0.0	438.15	-11.27	0.25	0.00	0.000	0.0	0.0
3	IPQ1	9.500	1.000	46.16	-11.30	0.20	0.00	0.000	0.0	0.0	416.92	31.79	0.25	0.00	-0.000	0.0	0.0
4	D8	15.500	6.000	282.08	-28.02	0.21	0.00	0.000	0.0	0.0	122.81	17.23	0.25	0.00	-0.000	0.0	0.0
5	IPQ2	16.500	1.000	321.81	-10.90	0.21	0.00	0.000	0.0	0.0	97.02	9.07	0.25	0.00	-0.000	0.0	0.0
6	IPQ2	17.500	1.000	323.94	8.82	0.21	0.00	-0.000	0.0	0.0	85.02	3.17	0.26	0.00	-0.000	0.0	0.0
7	D9	40.390	22.890	47.66	3.25	0.24	0.00	-0.000	0.0	0.0	8.02	0.20	0.43	-0.00	-0.000	0.0	0.0
8	HFQ1	41.390	1.000	42.06	2.38	0.24	0.00	-0.000	0.0	0.0	7.63	0.18	0.45	-0.00	-0.000	0.0	0.0
9	D7	46.390	5.000	22.25	1.59	0.27	0.00	-0.000	0.0	0.0	9.17	-0.49	0.55	-0.00	-0.000	0.0	0.0
10	D8	52.390	6.000	8.90	0.64	0.34	0.00	-0.000	0.0	0.0	19.97	-1.31	0.62	-0.00	-0.000	0.0	0.0
11	HFQ2	53.390	1.000	9.04	-0.79	0.36	0.00	0.000	0.0	0.0	19.65	1.61	0.63	-0.00	0.000	0.0	0.0
12	D7	58.390	5.000	21.38	-1.68	0.42	0.00	0.000	0.0	0.0	8.14	0.70	0.69	-0.00	0.000	0.0	0.0
13	HFQF	59.390	1.000	21.38	1.68	0.42	0.00	-0.000	0.0	0.0	8.14	-0.70	0.71	-0.00	0.000	0.0	0.0

14	D7	64.390	5.000	9.03	0.79	0.48	0.00	-0.000	0.0	0.0	19.66	-1.61	0.78	-0.00	0.000	0.0	0.0
15	HFQD	65.390	1.000	9.03	-0.79	0.50	0.00	0.000	0.0	0.0	19.67	1.61	0.79	-0.00	0.000	0.0	0.0
16	D7	70.390	5.000	21.36	-1.68	0.56	0.00	0.000	0.0	0.0	8.16	0.70	0.85	0.00	0.000	0.0	0.0
17	HFQF	71.390	1.000	21.36	1.68	0.57	0.00	-0.000	0.0	0.0	8.16	-0.70	0.87	0.00	0.000	0.0	0.0
18	D7	76.390	5.000	9.03	0.79	0.62	0.00	-0.000	0.0	0.0	19.70	-1.61	0.93	0.00	0.000	0.0	0.0
19	HFQD	77.390	1.000	9.03	-0.79	0.64	0.00	-0.000	0.0	0.0	19.70	1.61	0.94	0.00	-0.000	0.0	0.0
20	D7	82.390	5.000	21.39	-1.68	0.70	-0.00	-0.000	0.0	0.0	8.16	0.70	1.01	0.00	-0.000	0.0	0.0
21	HFQF	83.390	1.000	21.39	1.68	0.71	-0.00	-0.000	0.0	0.0	8.16	-0.70	1.03	0.00	0.000	0.0	0.0
22	D7	88.390	5.000	9.04	0.79	0.77	-0.00	-0.000	0.0	0.0	19.66	-1.61	1.09	0.00	0.000	0.0	0.0
23	HFQD	89.390	1.000	9.04	-0.79	0.78	-0.00	-0.000	0.0	0.0	19.66	1.61	1.10	0.00	-0.000	0.0	0.0
24	D7	94.390	5.000	21.39	-1.68	0.84	-0.00	-0.000	0.0	0.0	8.14	0.70	1.16	0.00	-0.000	0.0	0.0
25	HFQF	95.390	1.000	21.39	1.68	0.85	-0.00	0.000	0.0	0.0	8.14	-0.70	1.18	0.00	-0.000	0.0	0.0
26	D7	100.390	5.000	9.04	0.79	0.91	-0.00	0.000	0.0	0.0	19.66	-1.61	1.25	0.00	-0.000	0.0	0.0
27	HFQD	101.390	1.000	9.04	-0.79	0.93	-0.00	-0.000	0.0	0.0	19.66	1.60	1.26	0.00	-0.000	0.0	0.0
28	D7	106.390	5.000	21.37	-1.68	0.99	-0.00	-0.000	0.0	0.0	8.16	0.70	1.32	-0.00	-0.000	0.0	0.0
29	HQ11	107.390	1.000	22.95	0.14	0.99	-0.00	0.000	0.0	0.0	7.59	-0.11	1.34	-0.00	-0.000	0.0	0.0
30	D7	112.390	5.000	22.64	-0.08	1.03	-0.00	0.000	0.0	0.0	12.00	-0.78	1.43	-0.00	-0.000	0.0	0.0
31	HQ12	113.390	1.000	22.87	-0.15	1.04	-0.00	0.000	0.0	0.0	13.67	-0.89	1.44	-0.00	-0.000	0.0	0.0
32	D6	126.490	13.100	34.38	-0.73	1.11	-0.00	0.000	0.0	0.0	59.72	-2.62	1.52	-0.00	-0.000	0.0	0.0
33	ROQ1	127.490	1.000	39.84	-4.91	1.12	-0.00	-0.000	0.0	0.0	58.52	3.77	1.52	-0.00	0.000	0.0	0.0
34	D5	131.690	4.200	92.23	-7.56	1.13	-0.00	-0.000	0.0	0.0	31.42	2.68	1.54	-0.00	0.000	0.0	0.0
35	ROQ2	132.690	1.000	94.29	5.60	1.13	-0.00	0.000	0.0	0.0	30.41	-1.63	1.54	-0.00	-0.000	0.0	0.0
36	D5	136.890	4.200	53.29	4.16	1.14	-0.00	0.000	0.0	0.0	46.24	-2.14	1.56	-0.00	-0.000	0.0	0.0
37	ROQ3	137.890	1.000	47.99	1.24	1.14	-0.00	0.000	0.0	0.0	47.99	0.42	1.56	-0.00	0.000	0.0	0.0
38	D4	138.190	0.300	47.25	1.22	1.14	-0.00	0.000	0.0	0.0	47.74	0.41	1.56	-0.00	0.000	0.0	0.0
39	ROH1	143.505	5.315	35.75	0.94	1.16	0.03	0.012	0.0	0.0	44.04	0.28	1.58	-0.00	0.000	0.0	0.0
40	ROVD	148.169	4.664	28.11	0.70	1.19	0.09	0.012	0.0	0.0	41.93	0.17	1.60	-0.03	-0.011	0.0	0.0
41	ROH2	158.954	10.785	19.23	0.13	1.26	0.36	0.038	0.0	0.0	41.10	-0.09	1.64	-0.14	-0.011	0.0	0.0
42	ROVU	163.618	4.664	19.19	-0.12	1.30	0.54	0.038	0.0	0.0	42.50	-0.21	1.66	-0.17	0.000	0.0	0.0
43	ROVU	168.282	4.664	21.45	-0.37	1.34	0.71	0.038	0.0	0.0	44.97	-0.32	1.68	-0.14	0.011	0.0	0.0
44	ROH3	179.067	10.785	35.47	-0.93	1.40	1.02	0.020	0.0	0.0	54.75	-0.58	1.71	-0.03	0.011	0.0	0.0
45	ROVD	183.731	4.664	45.33	-1.18	1.42	1.12	0.020	0.0	0.0	60.74	-0.70	1.72	-0.00	0.000	0.0	0.0
46	D4	184.031	0.300	46.05	-1.20	1.42	1.12	0.020	0.0	0.0	61.16	-0.71	1.73	-0.00	0.000	0.0	0.0
47	ROQ4	185.031	1.000	45.79	1.45	1.43	1.11	-0.045	0.0	0.0	66.26	-4.49	1.73	-0.00	-0.000	0.0	0.0
48	D3	189.211	4.180	34.86	1.17	1.44	0.92	-0.045	0.0	0.0	109.35	-5.82	1.74	-0.00	-0.000	0.0	0.0
49	ROQ5	190.211	1.000	36.89	-3.27	1.45	0.94	0.069	0.0	0.0	107.41	7.68	1.74	-0.00	0.000	0.0	0.0
50	D2	194.388	4.177	69.77	-4.60	1.46	1.22	0.069	0.0	0.0	53.02	5.35	1.75	-0.00	0.000	0.0	0.0
51	ROQ6	195.388	1.000	73.00	1.46	1.46	1.24	-0.037	0.0	0.0	46.92	0.92	1.75	-0.00	0.000	0.0	0.0
52	L	196.038	0.650	71.11	1.44	1.46	1.22	-0.037	0.0	0.0	45.74	0.90	1.75	-0.00	0.000	0.0	0.0
53	B1	202.511	6.473	54.32	1.16	1.48	1.01	-0.027	0.0	0.0	35.79	0.64	1.78	-0.00	0.000	0.0	0.0
54	D1	204.571	2.060	49.73	1.07	1.49	0.96	-0.027	0.0	0.0	33.31	0.56	1.79	-0.00	0.000	0.0	0.0
55	B	214.280	9.709	33.03	0.65	1.53	0.77	-0.011	0.0	0.0	26.15	0.18	1.84	0.00	0.000	0.0	0.0
56	L	214.930	0.650	32.20	0.62	1.53	0.77	-0.011	0.0	0.0	25.93	0.15	1.84	0.00	0.000	0.0	0.0
57	Q1F	215.690	0.760	30.79	1.22	1.53	0.75	-0.027	0.0	0.0	26.13	-0.41	1.85	0.00	0.000	0.0	0.0
58	L	216.340	0.650	29.23	1.17	1.54	0.73	-0.027	0.0	0.0	26.68	-0.44	1.85	0.00	0.000	0.0	0.0
59	B	226.049	9.709	14.14	0.38	1.62	0.54	-0.012	0.0	0.0	39.42	-0.87	1.90	0.00	0.000	0.0	0.0
60	L	226.699	0.650	13.67	0.33	1.62	0.54	-0.012	0.0	0.0	40.57	-0.90	1.90	0.00	0.000	0.0	0.0
61	Q2D	227.079	0.380	13.60	-0.15	1.63	0.53	0.006	0.0	0.0	40.75	0.43	1.90	0.00	0.000	0.0	0.0
62	SPV	227.079	0.0	13.60	-0.15	1.63	0.53	0.006	0.0	0.0	40.75	0.43	1.90	0.00	0.000	0.0	0.0
63	Q2D	227.459	0.380	13.89	-0.63	1.63	0.54	0.023	0.0	0.0	39.93	1.73	1.91	0.00	-0.000	0.0	0.0
64	L	228.109	0.650	14.75	-0.69	1.64	0.56	0.023	0.0	0.0	37.72	1.67	1.91	0.00	-0.000	0.0	0.0
65	B	237.818	9.709	37.68	-1.67	1.71	0.85	0.038	0.0	0.0	14.78	0.69	1.98	0.00	-0.000	0.0	0.0
66	L	238.468	0.650	39.89	-1.73	1.71	0.88	0.038	0.0	0.0	13.92	0.63	1.98	0.00	-0.000	0.0	0.0

```
      OOOOOOOOOOOOOOOOOOOO
      O                  O
      O R A C E T R A C K O
      O                  O
      OOOOOOOOOOOOOOOOOOOO

---ENTRY CLORB---/DPP= 0.00010 /CLOX/  -0.00007   0.00002 /CLOZ/   0.00001   0.00003 /ITERAT.=  4/ ACCURACY= 0.71538874D-10
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP= 0.00010 /CLOX/  -0.00007   0.00002 /CLOZ/   0.00001   0.00003 /ITERAT.=  4/ ACCURACY= 0.71538874D-10
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0

      PLANE   DISP(MM)       DISP(MRAD)     ORBIT-AVE      ORBIT-RMS   (FOR ZERO ENERGY DEVIATION)
        X       -0.750          0.159          0.0            0.0
        Z        0.107          0.262          0.0            0.0

---QMODIF ENTRY---
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
     START-QX-QZ   0.1500198   0.1799380END -QX-QZ   0.1300000   0.2100000
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
     ITER=  1/QUAD=  1/QX-QZ   0.1476848   0.1807368/  /DPP=   0.0
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
     ITER=  1/QUAD=  2/QX-QZ   0.1492425   0.1822344/  /DPP=   0.0
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
     DATA BLOCK TUNE-VARIATION
     TUNE                 THEORET.     AFTER CORRECTION
     HORIZONTAL          0.1300000   0.1299931
     VERTICAL            0.2100000   0.2099912

     QUADRU.STRENGTHS  -0.11454313 -0.11451929   INDEX       3
                       0.11421771  0.11427487                4
     TOTAL TUNE SHIFT       QX = 0.0200198  QZ = 0.0300620
QUADRUPOLE SENSITIVITIES    QX/K1 QX/K2 QZ/K1 QZ/K2  -0.46699998D+03-0.15547170D+03 0.15976764D+03 0.45928531D+03
```

```
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  2/ ACCURACY= 0.21029847D-06
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.21359337D-06
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.13426752D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.21471871D-06
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.13396655D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.21383028D-06
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.12708887D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.75758148D-07
     DATA BLOCK CHROMATICITY CORRECTION
     CHROMATICITIES     BEFORE     AFTER     CORRECTION
     HORIZONTAL        -68.31586    0.42915
     VERTICAL          -95.53581    0.07898

     SEXTUP.STRENGTHS    0.0       -0.20849   INDEX      39
                         0.0        0.40614              40
SEXTUPOLE SENSITIVITIES  XI/M1 XI/M2 ZI/M1 ZI/M2  -0.54538254D+03-0.11175872D+03 0.18328430D+03 0.32931569D+03

---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.15722018D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.75758148D-07
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.15697246D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.76884055D-07
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.15661468D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.75999169D-07
---ENTRY CLORB---/DPP= 0.00002 /CLOX/  -0.00001   0.00000 /CLOZ/   0.00000   0.00001 /ITERAT.=  3/ ACCURACY= 0.15688813D-09
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
---ENTRY CLORB---/DPP=-0.00002 /CLOX/   0.00001  -0.00000 /CLOZ/  -0.00000  -0.00001 /ITERAT.=  2/ ACCURACY= 0.76636230D-07
     DATA BLOCK CHROMATICITY CORRECTION
     CHROMATICITIES     BEFORE     AFTER     CORRECTION
     HORIZONTAL         0.42915   -0.00149
     VERTICAL           0.07898    0.0

     SEXTUP.STRENGTHS   -0.20849   -0.20754   INDEX      39
                         0.40614    0.40538              40
SEXTUPOLE SENSITIVITIES  XI/M1 XI/M2 ZI/M1 ZI/M2  -0.54538254D+03-0.11175872D+03 0.18328430D+03 0.32931569D+03
```

```
DATA BLOCK MULTIPOLE COEFFICIENTS
RADIUS IN MM                    1.0000000
BENDING STRENGTH IN MRAD        1.0000000

                    NORMAL                              SKEW

      MEAN          RMS-VALUE             MEAN          RMS-VALUE

   1  0.0           0.10000000D-03        0.0           0.10000000D-03

DATA BLOCK FLUCTUATIONS OF MULTIPOLES
RANDOM STARTING NUMBER=              9834965
```

```
---ENTRY CLORB---/DPP= 0.00010 /CLOX/  -0.00445   0.01065 /CLOZ/  -0.00292  -0.01127 /ITERAT.=  3/ ACCURACY= 0.10267455D-13
---ENTRY CLORB---/DPP= 0.0     /CLOX/  -0.00406   0.01026 /CLOZ/  -0.00282  -0.01097 /ITERAT.=  3/ ACCURACY= 0.12363080D-13
-------CHANGE OF HORIZONTAL DIPOLSTRENGTH ACCORDING TO REQUEST/ DIP-AV =  0.0          / DIP-RAND =  0.42066791D-02
-------CHANGE OF VERTICAL   DIPOLSTRENGTH ACCORDING TO REQUEST/ DIP-AV =  0.0            DIP-RAND =  0.11201292D-01
---ENTRY CLORB---/DPP= 0.00010 /CLOX/  -0.18482   0.44811 /CLOZ/  -0.32721  -1.26514 /ITERAT.=  3/ ACCURACY= 0.37996013D-12
---ENTRY CLORB---/DPP= 0.0     /CLOX/  -0.17072   0.43154 /CLOZ/  -0.31641  -1.22882 /ITERAT.=  3/ ACCURACY= 0.52779846D-12
```

```
      PLANE   DISP(MM)      DISP(MRAD)     ORBIT-AVE     ORBIT-RMS   (FOR ZERO ENERGY DEVIATION)
        X      -140.979       165.777        -0.001         2.500
        Z      -108.004      -363.199        -0.015         2.500

DI0,DIP0/-140.97857-108.00397 165.77722-363.19900/VAR/  1.00000  1.00000  1.00000  1.00000  1.00000
---ENTRY CLORB---/DPP= 0.0     /CLOX/  -0.17072   0.43154 /CLOZ/  -0.31641  -1.22882 /ITERAT.=  3/ ACCURACY= 0.52779846D-12
     TRACKING FOR CONSTANT ENERGY DEVIATION

              TUNE          CLO           CLOP          BET0          ALF0
        X  0.1499996    -0.1707210     0.4315372     2.9975159    -0.0000000
        Z  0.1800018    -0.3164103    -1.2288178     0.1500939     0.0000000


     REL. ENERGY DEVIATION=   0.0
     ============================
 ---ENTRY ANFB---/ITRA/ 16/AMP/  30.000     2.123/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

     AMPLITUDE-X =          30.000          AMPLITUDE-Z =          2.123  MM
     EMITTANCE-X =         300.249          EMITTANCE-Z =         30.025  PI*MRAD*MM
+++LAST STABLE REVOLUTION =      1  +++
```

*** TRACKING PARAMETERS ***

NUMBER OF REVOLUTIONS	3
APERTURE LIMIT HORIZONTAL	500.000 (MM)
APERTURE LIMIT VERTICAL	500.000 (MM)
TRACKING START AT ELEMENT NO.	14
INITIAL AMPLITUDE-H IN (MM)	30.000
COUPLING EPS-Z/EPS-X	0.100
NUMBER OF PARTICLES	16

```
OOOOOOOOOOOOOOOOOOOO
O                  O
O R A C E T R A C K O
O                  O
OOOOOOOOOOOOOOOOOOOO
```

PLANE	DISP(MM)	DISP(MRAD)	ORBIT-AVE	ORBIT-RMS	(FOR ZERO ENERGY DEVIATION)
X	-0.750	0.159	0.0	0.0	
Z	0.107	0.262	0.0	0.0	

```
DI0,DIP0/  -0.74996   0.10664   0.15893   0.26188/VAR/   1.00000   1.00000   1.00000   1.00000   1.00000
---ENTRY CLORB---/DPP= 0.0     /CLOX/   0.0       0.0     /CLOZ/   0.0       0.0     /ITERAT.=  2/ ACCURACY= 0.0
```

TRACKING FOR CONSTANT ENERGY DEVIATION

	TUNE	CLO	CLOP	BET0	ALF0
X	0.1500198	0.0	0.0	2.9979498	0.0004461
Z	0.1799380	0.0	0.0	0.1501238	0.0009684

REL. ENERGY DEVIATION= 0.0

```
==============================
---ENTRY ANFB---/ITRA/ 16/AMP/  30.000     2.123/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0
```

AMPLITUDE-X =	30.000	AMPLITUDE-Z =	2.123 MM
EMITTANCE-X =	300.205	EMITTANCE-Z =	30.021 PI*MRAD*MM

```
*****   TRACKING ENDED ABNORMALLY   *****
PARTICLE NO.   1 LOST IN REVOLUTION     1 AT ELEMENT    7
HORIZ:  AMPLITUDE =          -30.975   APERTURE =          40.000
VERT:   AMPLITUDE =           32.999   APERTURE =          20.000
ELEMENT - LIST NUMBER   40 TYP NUMBER    3 NAME SPU
```

```
   ---ENTRY ANFB---/ITRA/ 16/AMP/  15.000     1.061/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

       AMPLITUDE-X =          15.000          AMPLITUDE-Z =          1.061  MM
       EMITTANCE-X =          75.051          EMITTANCE-Z =           7.505  PI*MRAD*MM

       *****   TRACKING ENDED ABNORMALLY   *****
       PARTICLE NO.    5 LOST IN REVOLUTION     1 AT ELEMENT    9
       HORIZ:  AMPLITUDE =          55.162   APERTURE =          40.000
       VERT:   AMPLITUDE =           9.959   APERTURE =          20.000
       ELEMENT - LIST NUMBER   39 TYP NUMBER    3 NAME SPH

   ---ENTRY ANFB---/ITRA/ 16/AMP/   7.500     0.531/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

       AMPLITUDE-X =           7.500          AMPLITUDE-Z =          0.531  MM
       EMITTANCE-X =          18.763          EMITTANCE-Z =           1.876  PI*MRAD*MM


ZEIT  00 H  00 MIN  00.56 SEC


       ********************************
       **** ALL PARTICLES STABLE ****
       ********************************

   ---ENTRY ANFB---/ITRA/ 16/AMP/  11.250     0.796/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

       AMPLITUDE-X =          11.250          AMPLITUDE-Z =          0.796  MM
       EMITTANCE-X =          42.216          EMITTANCE-Z =           4.222  PI*MRAD*MM

       *****   TRACKING ENDED ABNORMALLY   *****
       PARTICLE NO.    5 LOST IN REVOLUTION     1 AT ELEMENT    9
       HORIZ:  AMPLITUDE =          41.371   APERTURE =          40.000
       VERT:   AMPLITUDE =           7.469   APERTURE =          20.000
       ELEMENT - LIST NUMBER   39 TYP NUMBER    3 NAME SPH

   ---ENTRY ANFB---/ITRA/ 16/AMP/   9.375     0.663/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

       AMPLITUDE-X =           9.375          AMPLITUDE-Z =          0.663  MM
       EMITTANCE-X =          29.317          EMITTANCE-Z =           2.932  PI*MRAD*MM


ZEIT  00 H  00 MIN  00.57 SEC


       ********************************
       **** ALL PARTICLES STABLE ****
       ********************************

    ---ENTRY ANFB---/ITRA/ 16/AMP/  10.313     0.730/ITR,CHI0,CHID/  4    15.     90.0/I4,PSI0,PSID/  1     0.0    30.0

       AMPLITUDE-X =          10.313          AMPLITUDE-Z =          0.730  MM
       EMITTANCE-X =          35.473          EMITTANCE-Z =           3.547  PI*MRAD*MM


ZEIT  00 H  00 MIN  00.57 SEC
```

```
      ********************************
      **** ALL PARTICLES STABLE ****
      ********************************

   ---ENTRY ANFB---/ITRA/ 16/AMP/  10.781     0.763/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

      AMPLITUDE-X =          10.781          AMPLITUDE-Z =           0.763  MM
      EMITTANCE-X =          38.772          EMITTANCE-Z =           3.877  PI*MRAD*MM

ZEIT  00 H  00 MIN  00.56 SEC


      ********************************
      **** ALL PARTICLES STABLE ****
      ********************************

   ---ENTRY ANFB---/ITRA/ 16/AMP/  11.016     0.780/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

      AMPLITUDE-X =          11.016          AMPLITUDE-Z =           0.780  MM
      EMITTANCE-X =          40.476          EMITTANCE-Z =           4.048  PI*MRAD*MM

      *****   TRACKING ENDED ABNORMALLY   *****
      PARTICLE NO.    5 LOST IN REVOLUTION     1 AT ELEMENT    9
      HORIZ:  AMPLITUDE =          40.509   APERTURE =          40.000
      VERT:   AMPLITUDE =           7.313   APERTURE =          20.000
      ELEMENT - LIST NUMBER   39 TYP NUMBER    3 NAME SPH

   ---ENTRY ANFB---/ITRA/ 16/AMP/  10.898     0.771/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

      AMPLITUDE-X =          10.898          AMPLITUDE-Z =           0.771  MM
      EMITTANCE-X =          39.619          EMITTANCE-Z =           3.962  PI*MRAD*MM

      *****   TRACKING ENDED ABNORMALLY   *****
      PARTICLE NO.    5 LOST IN REVOLUTION     1 AT ELEMENT    9
      HORIZ:  AMPLITUDE =          40.078   APERTURE =          40.000
      VERT:   AMPLITUDE =           7.236   APERTURE =          20.000
      ELEMENT - LIST NUMBER   39 TYP NUMBER    3 NAME SPH

   ---ENTRY ANFB---/ITRA/ 16/AMP/  10.840     0.767/ITR,CHI0,CHID/  4    15.0    90.0/I4,PSI0,PSID/  1     0.0    30.0

      AMPLITUDE-X =          10.840          AMPLITUDE-Z =           0.767  MM
      EMITTANCE-X =          39.194          EMITTANCE-Z =           3.919  PI*MRAD*MM

ZEIT  00 H  00 MIN  00.57 SEC


      ********************************
      **** ALL PARTICLES STABLE ****
      ********************************
```

DATA BLOCK MULTIPOLE COEFFICIENTS
RADIUS IN MM 25.0000000
BENDING STRENGTH IN MRAD 10.0692100

	NORMAL		SKEW	
	MEAN	RMS-VALUE	MEAN	RMS-VALUE
1	0.0	0.154400000D-03	0.0	0.244200000D-03
2	0.0	0.833000000D-04	0.0	0.833000000D-04
3	0.600000000D-02	0.300000000D-03	0.0	0.700000000D-04
4	0.0	0.700000000D-04	0.0	0.700000000D-04
5	0.0	0.700000000D-04	0.0	0.700000000D-04
6	0.0	0.700000000D-04	0.0	0.700000000D-04
7	-0.290000000D-03	0.700000000D-04	0.0	0.700000000D-04
8	0.0	0.700000000D-04	0.0	0.700000000D-04
9	-0.480000000D-03	0.700000000D-04	0.0	0.700000000D-04
10	0.0	0.700000000D-04	0.0	0.700000000D-04

DATA BLOCK FLUCTUATIONS OF MULTIPOLES
RANDOM STARTING NUMBER= 9834965