MAGIC, A COMPUTER CODE FOR DESIGN STUDIES
OF INSERTIONS AND STORAGE RINGS

A. S. KING, M. J. LEE,* W. W. LEE†

STANFORD LINEAR ACCELERATOR CENTER

STANFORD UNIVERSITY

Stanford, California 94305

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*Author was visiting consultant at Rutherford Laboratory.

†Princeton University, Princeton, New Jersey.

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<u>ABSTRACT</u>

MAGIC is a computer code for design study of storage ring lattices and insertions. The first version[1] of this code was developed during the NAL 1973 Summer Study at ASPEN for the design of lattice insertions. Since that time, the code has been extensively modified at SLAC for the design of storage ring lattices and has been used for the study of the PEP lattices.

We have incorporated into MAGIC the experiences we acquired from the design study of SPEAR, the use of TRANSPORT[2] and SYNCH[3], and the use of the SPEAR control program RING. We hope that users will find MAGIC to be a useful and efficient code for lattice design and configuration survey. In order to save time, MAGIC finds an approximate solution using thin-lens magnets. However, as an option the user can obtain a tabulation of the machine functions and the values of the lattice elements for an equivalent thick-lens solution corresponding to the approximate thin-lens solution. It has been found that the agreement between the results obtained by these solutions is usually better than a few percent, except for the value of quantum lifetime which is more critically dependent upon the machine parameters than other quantities.

Some of the salient features of the code are: (1) the input and output machine parameters are given in the Courant-Snyder notation[4] (β,η-functions, etc); (2) it is possible to design insertion lattices with fitting conditions specified at up to three points along the beam line; (3) it can be used for design of two lattices in cascade with the first equal to either a periodic cell or an insertion; (4) any parameter involving integration of some of the machine functions over the magnets can be easily computed because the integrand is a δ-function in the thin-lens approximation.

For insertion design using a least squares procedure[5], MAGIC finds the values of the magnet strengths or drift lengths for the variable lattice elements such that the values of β, α, η, η' at both ends of the insertion and $\Delta\nu$ through the insertion, or the transport matrix elements are matched to the desired values. For storage ring design, the program finds the parameter values of the variable lattice elements for specified values of ε and η-functions at the interaction point and betatron tune ν, as well as specified matching conditions of the β and η-functions and their

derivatives at some desired points in the ring lattice.

For electron storage ring design[6], the code also computes the synchrotron integrals, the partition constants and damping times, natural beam sizes and energy spread, luminosity for head-on colliding beams and the beam current value imposed by the beam-beam tune shift, transverse beam envelopes, chromaticities, sextupole field values for zero chromaticities, synchrotron frequency, synchrotron phase angle and RF bucket size, bunch length, quantum lifetime and momentum compaction factor.

1. GENERAL DESCRIPTION

MAGIC has been written for the design of two types of lattices, insertion and cell. A cell is defined as a special kind of lattice which has the following properties: (1) $\alpha = \eta' = 0$ at both ends of the lattice; (2) the β and η values at one end of the lattice are equal to those at the other end.

A lattice configuration is specified by a set of values of the machine functions such as β, η, α, η' and $\Delta\nu$ at both ends as well as at the desired fit points along the lattice.

For survey of lattice configurations, the user specifies two sets of values: one set $\{\overline{V}_i\}$ for the initial configuration and the other set $\{\overline{V}_f\}$ for the final configuration. In addition, the code defines N intermediate configurations corresponding to the N sets of machine function values as defined by $\{\overline{V}_k\} \equiv \{\overline{V}_i + k[\overline{V}_f - \overline{V}_i]/(N + 1)\}$ for $k = 1,2,...,N$ where N is a number specified by the user.

To start fitting, the user makes a guess solution for the lattice element values corresponding to the initial configuration. Using the guess values, MAGIC first finds the solution for the initial configuration. Then using the initial solution as the guess solution, MAGIC finds a solution for the first intermediate configuration. This procedure continues until all the solutions are found.

Since thin-lens elements are used in MAGIC, only one value, X, is needed to specify an element. For a drift space, X is specified by the drift length, ℓ, in meters; for a bending magnet X is specified by the angle of bend, ℓ/ρ, in degrees, where ℓ is the effective magnet length and ρ is the bending radius; for a quadrupole magnet X is specified by $g\ell/B\rho$ in meter^{-1}, where ℓ and g are the magnet length and field gradient, and $B\rho$ is the particle rigidity.

The value of a lattice element can either be a fixed constant or variable as desired by the user. Constraints can be imposed upon some of the values of the variable such that ΣCX is an invariant, where the summation is evaluated over all of the variables to be coupled. The values of the constants C's are specified by the user.

In order to distinguish the values of the machine functions at the beginning of a lattice from those at the fit points or end point, we use a subscript 1 to denote the initial values and a subscript 2 to denote the final values, corresponding to the beginning point. The subscripts i and f are used to refer to those for the initial and final configurations at the fit points and end point.

The functions to be fitted and the desired values at the fit point are specified by the user in the order of the relative position of the fit points along the lattice; those for a fit point closer to the beginning of the lattice are specified before those farther away. Those for the end point are specified last.

To compute the machine and beam parameters for an electron storage ring lattice, the effective lengths of the bending magnets in meters are required for the evaluation of the synchrotron integrals. In addition, sextupole field corrections corresponding to zero chromaticities can be computed.

In addition to the lattice elements the user may specify points of interest such as the locations of an interaction point, fit points and sextupole magnets. Other required input values for the code are: status of the program flags; values of the internal constants; heading for each beam line; an instruction to terminate the input data.

MAGIC can also be used to find the values of the machine functions at each element for an input solution without any fitting for either a thin-lens or thick-lens lattice via the flag status. In the input data the lengths of the drift spaces are the same for both cases. For the thick-lens lattice these drift lengths are modified appropriately by the code, taking into account the finite magnet lengths.

As an example, the input data for a PEP lattice[7] are given in the next section as well as descriptions for the commands in the code.

2. COMMANDS

The code is executed by a set of commands. The commands used for a storage ring lattice are described in this Section to illustrate how to set up the input data. The function of each command is also described.

There are a total of nineteen commands in the code.

A command must be entered between column 8 and 10. The commands may be grouped into eight sets depending upon the tasks they perform:

```
FLG
NUM
DRF, QUA, BBX, BBY
FIT, INT, SEX
REM, INS, CEL, VAR, CON
FUN, VAL
LUM, CLR
FIN
```

The first command in the input data must be FLG and the last must be FIN. The names used in each command must be entered between column 21 to 80 with five columns allowed for each name. Each name must be equal to or less than four characters and must be left-justified. If a name has a value, the value must be entered directly below the name on the line below in the same five columns and also must be left-justfied. However, not all commands have values. For the DRF, QUA, BBX, BBY, INS, CEL, VAR, VAL and LUM commands, the user can use as many lines as he may choose for a command provided that there is no blank entry between the names. A blank entry terminates the input data on a line. For convenience, comments can be inserted anywhere in the input data. A comment is indicated by a non-blank character in column 1. These features can be seen from the example given in this section.

```
........................THIS IS AN EXAMPLE TO SHOW HOW TO SET UP THE COMMANDS
........................THE SYMBOLS USED IN THE COMMANDS ARE DESCRIBED IN THE
........................SUBSEQUENT PAGES
........................
........................THIS IS THE INPUT DATA FOR A SURVEY OF PEP LATTICES
........................A BRIEF DESCRIPTION OF EACH COMMAND IS GIVEN
........................ANY NONZERO CHARACTER IN COL 1 DEFINES A COMMENT
........................THE FIRST COMMAND MUST BE FLG
........................THE LAST COMMAND MUST BE FIN
........................


................SET CONTROL FLAGS
     FLG        LB   LQ   ALL  THK
................ENTER PROGRAM CONSTANTS
     NUM        STP  ESP
                3    8
................DEFINE LATTICE ELEMENTS
     QUA        QFH   QDH   Q3H   Q2H   Q1    QF1   QD1   QF2   QF    QD
                .030 -.027 -.103 .077 -.061 .100 -.085 .080 .060 -.054
                .39   .39   1.    1.    1.    1.    .78   .78   .78   .78
     DRF        DC    DQ    D1    D2    D3    D4    D5    DB    DC1   DC2
                4.28  1.0  10.5  3.0   4.0   4.   4.39  5.86  .95   3.33
                D31   D32   K1    K3
                4.5   5.1   .0    .0
     BBX        BB
                1.875
                5.56
................DEFINE POINTS OF INTEREST
     FIT        FIT1
     INT        ***
     SEX        SF   SD
................ENTER BEAM LINE HEADING
     REM        ...      PEP TOLERANCE STUDY    ...(£PEPC1)
................DEFINE BEAM LINE
     INS        ***   D1    Q3H   DC    Q3H   D2    Q2H   DQ    Q2H
                D31   D3    D3    K3    D3    D3    D3    D3
                D3    D3    D3    K1    D32
                Q1    D4    QF1
                D5    BB    DB    BB    DC    QD1   DC1
                DC2   BB    DB    BB    DC    QF2   DC1   SF
                DC2   BB    DB    BB    DC    QD    DC1   SD
                DC2   BB    DB    BB    DC    QF    DC1   SF
                DC2   BB    DB    BB    DC    QD    DC1   SD
                DC2   BB    DB    BB    DC    QF    DC1   SF
```

```
                        DC2   BB    DB    BB    DC    QDH   FIT1 QDH   DC1   SD
                        DC2   BB    DB    BB    DC    QFH
..........VAR...........IDENTIFY VARIABLES
                        Q3H   Q2H   Q1    QF1   QD1   QF2   QD    QF    QDH   QFH
..........CON...........DEFINE CONSTRAINTS BETWEEN SOME OF THE VARIABLES
                        QF    QFH
                        1.0   -2.0
          CON           QD    QDH
                        1.    -2.
..........FUN...........IDENTIFY FUNCTIONS TO BE FITTED AT THE FIRST FIT POINT
                        AX    AY    EXP
..........VAL...........ENTER FUNCTION VALUES FOR THE FIRST FIT POINT
                        AXI   AXF   AYI   AYF   EXPI  EXPF
                        .0    .0    .0    .0    .0    .0
..........FUN...........IDENTIFY FUNCTIONS TO BE FITTED AT THE END POINT
                        AX    AY    EXP   XNU   YNU
..........VAL...........ENTER FUNCTION VALUES FOR THE END POINT
                        AXI   AXF   AYI   AYF   EXPI  EXPF  XNUI XNUF YNUI YNUF
                        .0    .0    .0    .0    .0    .0    1.06 1.07 1.06 1.05
..........................ENTER FUNCTION VALUES FOR THE BEGINNING POINT
                        BX1   BX2   BY1   BY2   EX1   EX2
                        7.00 6.00  .16   .16   -1.40-1.40
..........LUM...........COMPUTE LUMINOSITY AND OTHER MACHINE AND BEAM PARAMETERS
                        NINS PI    PF    DNU1 DNU2 NLUM V1    V2    H     NB
                        12   10.0 10.0  .06   .06   1    45.   45.   2592 3
                        NINT DR    NDR
                        6    .001 10
..........CLR...........COMPUTE NSTD*SIGMA AT EACH ELEMENT
                        NSTD
                        10
..........FIN...........TERMINATE INPUT DATA
```

FLG sets the control flags. The possible flags are: LB, LQ, ALL, SYN and THK. LB is used to read the bending magnet lengths if the user wishes to compute the luminosity for an $e^+ e^-$ storage ring lattice. LQ is used to read the quadrupole magnet lengths. Both LB and LQ are needed if the user wishes to find thick-lens solutions. ALL is used to obtain print out for all of the configurations found by the code: ie, if ALL is omitted, only output for the initial and final configurations is printed. SYN is used if no fitting is required and the machine functions are to be computed directly from the input data values. THK is used for finding thick-lens solutions in addition to the thin-lens solutions.

The input data for the drift lengths are the same for both thin and thick-lens solutions. IF THK is used the drift lengths are adjusted internally by subtracting one half of the lengths of the adjacent magnets from the input values. Drift length between two magnets is given by the distance between the centres of the magnets. The bending magnets are assumed to be rectangular magnets for the thick-lens lattices.

NUM gives the values of two internal constants required by the code, STP and ESP. STP is the total number of configurations desired by the user. The maximum acceptable convergence value is related to 10^{-ESP}. The larger the value of ESP the smaller is the acceptable convergence value. The input data for the values of STP and ESP must be integers. Typical values of ESP are 8 or 9 corresponding to convergence values of 10^{-6}. The user should try different values of ESP in order to establish the acceptable convergence value for a given problem.

The set of commands which defines the lattice elements are: DRF, BBX, BBY and QUA. In the example quoted earlier, the drift lengths are DC,DQ,D1,... with their values given as 4.28,1.0,10.5,...m , respectively. The horizontal bending magnet is BB with the angle of bend equal to 1.875 degrees and effective length 5.56 m. The quadrupole magnets are: QFH with strength equal to 0.03 m^{-1} and length 0.39 m; QDH with strength equal to -.027 m^{-1} and length 0.39 m, etc. In MAGIC the convention has been adapted that a positive value of angle is used for normal bend, and a negative value is used for reverse bend. Also, for quadrupole magnets, a positive value of strength defines a radially focussing magnet, and a negative value defines a radially defocussing magnet. The maximum number of elements in DRF, BBX, BBY and QUA commands are 50, 20, 10 and 40, respectively.

Besides the lattice elements defined in the preceding Section, the user may give names of some special points along the beam line. These points are defined by: INT, FIT and SEX. INT is a command which gives the name to be used for the interaction point for an $e^+ e^-$ storage ring such as :::: in the above example. This command is required only if computation of beam parameters is desired. The value of luminosity is to be computed using the values of machine parameters at this point. FIT is used to give the names for the fit points such as FIT1 in this example. The user may use up to three names in this command. The end point is always assumed to be a fit point so that no name is needed for it. If the correction of chromaticities is desired, SEX is used to give the names of two types of sextupole magnets such as SD and SF in this example.

The strengths of these magnets $\lambda\ell/B\rho$ will be found to yield zero chromaticity in both x and y planes, where the field in the magnet B_y is given by $\lambda(x^2-y^2)$.

Unless the user is designing an $e^+ e^-$ storage ring lattice. INT and SEX are not needed.

This set of commands defines the elements in a beam line and specifies the variable elements. REM is used preceding INS or CEL to enter the heading for the beam line. There are two possible types of beam line: INS and CEL. INS is used for an insertion lattice and CEL is used for a periodic cell lattice. No fit point may be used within a cell lattice. In the example of this Section the beam line is an insertion with one fit point. The beam line starts at the interaction point (***) and ends at a symmetry point at the middle of a superperiod (centre of a QF magnet). The fit point (FIT1) is located at the middle of the last cell at the centre of a QD magnet. One of the magnets QF and QD has been split into two halves; each half is labelled by a subscript H (QFH and QDH). The elements in the beam line must be previously defined in the commands for lattice elements and special lattice points. The first element is D1, the second is Q3H which is half of Q3, the third is DQ, the fourth is another Q3H, etc. It has been found from experience that for strong quadrupole magnets such as Q3 and Q2, adjacent to the low-β interaction region, it is necessary to use two thin-lens magnets to represent each of these magnets with the thin-lens magnets located $\ell/4$ from the centre of the magnet. ($DQ = \ell/2$). The other quadrupole magnets are represented by single thin-lens magnets.

VAR is used to identify the names of the variable lattice elements in the beam line. In this example the variables are Q3H, Q2H, Q1 etc. The order in which the variable names appear in VAR is not important.

CON is used to define constraint between a subset of the variables by the equation:

$$\sum_i c_i x_i = \sum_i c_i x_i \quad \text{(input value)}$$

where the C's are constants in the input data and X's are the values of the variables in the subset. In this example the first CON command is used to keep the value of QFH equal to 1/2 of the value of QF.

$$1.0 \ x_{QF} - 2.0 \ x_{QFH} = 1.0 \times 0.06 - 2.0 \times 0.03 \equiv 0$$

Each constraint must be defined by a CON command.

Variable elements in the beam line with the same names are coupled internally in pairs. The total number of constraints has been chosen to be 40. The maximum number of CON commands available to the user is (40 - NC) where NC is the number of constraints used internally for coupling between pairs of variable elements having the same names. In this example the first Q3H is coupled to the second Q3H via an internal constraint with the value of C equal to 1.0 for the first Q3H, and equal to -1.0 for the second Q3H. The Maximum number of variables is 40 and the maximum number of elements in a beam line is 200. Each time a variable name appears in the beam line it should be counted as one variable. The number of internal constraints for coupling between pairs of variables having the same name is equal to (the number of these variables) -1.

FUN is used to specify the machine functions to be fitted. VAL is used to enter the values of these functions at the fit points and at the end point. A pair of FUN/VAL commands must be used for each fit point. The first FUN/VAL pair is taken to be the commands for the nearest fit point from the beginning of the beam line, and the last FUN/VAL pair for the end point.

The names of the functions are: BX, BY, AX, AY, EX, EY, EXP, EYP, XNU and YNU, for the functions β_x, β_y, α_x, α_y, η_x, η_y, η_x', η_y', $\Delta\nu_x$ and $\Delta\nu_y$, respectively. The names used in VAL are the same as those used in FUN but with a subscript I or F added to those names; I refers to the value of a function for the initial configuration and F refers to the value for the final configuration.

In addition to the machine functions the user may specify fitting conditions for the transport matrix elements: XIJ and YIJ for the (ij) matrix elements. Similarly, the names to be used in VAL are XIJI, XIJF, YIJI and YIJF.

If fitting of the machine functions is desired, the user must also enter the value of these functions at the beginning point of the beam line. These values could be entered in any of the VAL commands. The subscripts 1 and 2 are used to denote the values of these functions for the initial and final configuration, respectively.

Since a periodic cell lattice has some special properties the possible machine functions to be used are: BX, BY, EX, EY, XNU and YNU. Furthermore, only one pair of FUN/VAL is needed if the CEL command is used for the beam line because no fit point is allowed.

In the example chosen here STP = 3, so that only one intermediate configuration will be found by the code. The variations of betatron tune values and beta values at the interaction point are: for the initial configuration $\Delta\nu_x$ = 1.06, $\Delta\nu_y$ = 1.06 and β_x = 7.0 m; for the intermediate configuration $\Delta\nu_x$ = 1.065, $\Delta\nu_y$ = 1.055 and β_x = 6.5 m; for the final configuration $\Delta\nu_x$ = 1.07, $\Delta\nu_y$ = 1.05 and β_x = 6.0 m. For all three configurations $\alpha_x = \alpha_y = \eta' = 0.0$ at the fit point and at the end point; η = -1.4 m and β_y = 0.06 m at the interaction point. Since the value of any function not specified in the VAL commands is set equal to zero internally by the code, then at the interaction point $\alpha_x = \alpha_y = \eta' = 0.0$ by default.

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Furthermore, if the input value for XNUI, YNUI, XNUF or YNUF is given by $\Delta\nu = k.xxx$ the integer k is ignored, eg, XNUI = 1.06 is taken to be XNUI = 0.06 by the code. Thus, it is possible to find solutions having tune variations between two adjacent integers, $n + 1 > \Delta\nu > n$, by making a single run of the code.

To find solutions with tune variations crossing an integer it is necessary to make successive runs. For example, consider the case $2.4 \gtrsim \Delta\nu_x \gtrsim 1.5$. These solutions can be found by making two successive runs. The first run for $2.4 \gtrsim \Delta\nu_x \gtrsim 2.0$ and the second run for $1.999 \gtrsim \Delta\nu_x \gtrsim 1.5$. The solution for $\Delta\nu_x = 2.0$ obtained by the first run should be used as a guess solution in the second run in order to be sure that all the solutions belong to the same family.

LUM is used for computation of natural beam size and luminosity for an e^+ e^- storage ring. In each run, the energy of the beam can be varied for different configurations: PI and PF are the beam energy for the initial and final configuration in GeV, respectively. More than one luminosity and beam size computation can be made for each configuration depending on the value of NLUM. NINS is the number of beam lines as defined in the INS command which makes up the storage ring. DNU1, and V1 are the value of beam-beam tune shift and total RF voltage in MeV to be used for the first luminosity computation. DNU2 and V2 are those for the last computation. H is the RF harmonic number. NB is the number of bunches in one beam.

The values of luminosity and beam size are normally computed for the optimum coupling[8] case assuming equal beam-beam tune shift values for both radial and vertical motion. It is possible to compute these quantities for input values of coupling constant by adding A1 and A2 in the LUM command. A1 is the value of coupling constant for the first computation of luminosity and beam size and A2 for the last computation.

In addition, the effects upon the value of beta-function and betatron tunes for different off-momentum particles due to the sextupole corrections can be computed by adding the names DR and NDR in the LUM command. These effects will be computed for particles with energy deviations $\Delta p/p$ equal to $k(DR)$ for $k = -NDR, \ldots, 0, \ldots, NDR$. NINT is the number of interaction points in a storage ring. If NINT is used in the LUM command the limiting value of the linear tune shift imposed by the change in momentum compaction value due to beam-beam interaction[9] is computed. The data values for NINS, NLUM, NINT, NDR, H and NB must be integers.

CLR is used to compute the values of $n\sigma$ and $n\sigma'$ at every element along a beam line, where σ is the standard deviation value for a Gaussian particle distribution and n is any integer. The values of σ and σ' are those obtained by the LUM command. The value for n is given by NSTD which must be an integer.

It is also possible to compute $n\sigma$ and $n\sigma'$ for input values of σ and $\Delta p/p$ at the beginning point of an insertion. For this case the names SIGX, SIGY and SIGE are added to the data in the CLR command, where SIGX and SIGY are the values of σ in cm and SIGE is the value of $\Delta p/p$. The values of σ'_x and σ'_y are assumed to be zero.

The following table gives a summary of some of the conditions imposed, or the types of names allowed, in each command.

COMMAND	CONDITIONS
FLG	LB,LQ,ALL,SYN,THK
NUM	STP,ESP
DRF	Maximum elements 50
QUA	Maximum elements 40
BBX	Maximum elements 20
BBY	Maximum elements 10
FIT	Maximum elements 3
INT	Maximum elements 1
SEX	Elements 2
REM	1 per beam line
INS	Maximum elements 200; 2 per run
CEL	Maximum elements 200; 1 per run
VAR	40 per beam line
CON	40-number of internal constraints
FUN	BX,BY,AX,AY,EX,EY,EXP,EYP,XNU,YNU,XIJ,YIJ
VAL	Same names as FUN with subscripts 1,2,I,F
LUM	NINS,NLUM,NB,NINT,PI,PF,DNU1,DNU2,V1,V2, A1,A2,H,DR,NDR
CLR	NSTD,SIGX,SIGY,SIGE
FIN	1 per run

Integer values must be used for STP,ESP,NINS,NLUM,NB,NINT,NDR,H and NSTD.

Each time a variable name appears in the beam line it is counted as one variable. The number of internal constraints for coupling between pairs of variables having the same name is equal to (the total number of variables in the beam line - the total number of elements in the VAR command).

As an option the user can use ten columns for each input data value in the DRF,BBX,BBY and QUA commands. For this option a non-blank character must be used in column 12 of the lines containing the names of those elements whose values require greater accuracy. The names of the elements in these lines must be less

than five characters, with the first element name between column 21 and 30, the second between column 31 and 40, etc. Each element name and value must be left-justified. This feature is needed when SYN is used in the FLG command to get a tabulation of the machine functions for a known solution. Whenever SYN is used the beam line must be defined for one machine superperiod.

3. CASCADED BEAM LINES

The commands for two beam lines in cascade are described in this Section via an example. In the example of the preceding Section, solutions are found for configurations having different desired values of betatron tune shifts for one half of a storage ring superperiod. Alternatively, it is possible to use the code to find solutions having different desired values of betatron tune shifts per periodic cell. This can be done by using two beam lines in cascade.

In this example the first beam line is used to define the elements in the cell. The second beam line is used to define the elements in one half of a superperiod beginning at a symmetry point and ending at an interaction point. The desired values of tune shift per cell are found by varying the values of the strengths of QFH and QD in the first beam line. The desired values of β_x and β_y and $\alpha_x = \alpha_y = \eta' = 0.0$ at the interaction point are obtained by varying the strengths of the other quadrupole magnets in the second beam line.

Since the first beam line is a CEL command, the values of β and η for the beginning point of the lattice are not needed in the VAL command. The values of machine functions at the beginning of the second beam line, however, are given by those found for the end point of the first beam line. The values of the machine functions are matched between the two beam lines internally by the code.

In general four types of lattice are possible: a single cell, a single insertion, a cell and an insertion in cascade, and two insertions in cascade. For the multiple beam line case, the elements in both beam lines must be defined in the same commands at the beginning of the input data. The first beam line is defined by a REM command followed by INS or CEL, CON and FUN/VAL commands. The second beam line is defined by another REM command followed by the corresponding INS, CON and FUN/VAL commands. The first beam line can be either a CEL or an INS command, but the second beam line must be an INS command. For the case of two insertions in cascade, only one insertion can have fit points. The ame values of STP and ESP are used for both beam lines. In the output, tabulations of the values of the machine functions for both beam lines are printed.

CENTERED HEADER

EXAMPLE

```
FLG        ALL  LU    LB
NUM        STP  ESP
           3    9
FIT        FIT
QUA        QFH  Q3H   Q2H   Q1    QF1   QD1    QF2   QF    QD
           .030 -.103 .077 -.061 .100 -.085 .080  .060 -.054
           .39  .39   1.    1.    1.    1.    .78   .78   .78  .78
DRF        DC   DU    D1    D2    D3    D4    D5    DB
           4.28 1.0   10.5  3.0   4.0   45.6  4.39  5.86
BBX        BB
           1.875
           5.56
REM        ***    CELL LATTICE    ***
CEL        QFH  DC    BB    DB    BB    DC
           QD
           DC   BB    DB    BB    DC    QFH
VAR        QFH  QD
FUN        XNU  YNU
VAL        XNUI XNUF  YNUI  YNUF
           .16  .17   .12   .11
REM        ***   1/2 OF A SUPERIOD   ***
INS        QFH  DC    BB    DB    BB    DC
           QD
           DC   BB    DB    BB    DC    QFH
           QFH  DC    BB    DB    BB    DC
           QD
           DC   BB    DB    BB    DC    QFH
           QFH  DC    BB    DB    BB    DC
           QD
           DC   BB    DB    BB    DC
           QF2  DC    BB    DB    BB    DC
           QD1
           DC   BB    DB    BB    D5    QF1
           D4   Q1    D3    Q2H   DQ    Q2H   D2   Q3H   DQ   Q3H   D1
VAR        Q3H  Q2H   Q1    QF1   QD1   QF2
FUN        AX   AY    EXP
           BX   BY
VAL        AXI  AXF   AYI   AYF   EXPI  EXPF
           .0   .0    .0    .0    .0    .0
           BXI  BXF   BYI   BYF
           7.0  6.0   .16   .16
FIN
```

4. OUTPUT

The normal output for each configuration is: convergence value; values of the transport matrix elements; values of β,α,η,η' and $\Delta\nu$ at each element (BX, BY, AX, AY, EX, EY, EPX, EPY, NUX, NUY); element values (ℓ in m for a drift space, $g\ell/B\rho$ in m^{-1} for a quadrupole magnet, ℓ/ρ in degrees for a bending magnet); location of an element from the beginning of the beam line (LENGTH); values of $\Delta\nu/(\Delta p/p)$.

Additional output can be obtained using the LUM command. The normal output computed by the LUM command is:

NOTATION	PARAMETER
I_1, I_2, I_3, I_4, I_5	Synchrotron integrals
$(\Delta L/L)/(\Delta p/p)$	Momentum compaction factor
L	Circumference
TO	Revolution time
JX, JY, JE	Partition numbers
BX*, BY*, ETAX*, ETAY*	Machine functions at the interaction point
E	Beam energy
A	Aspect ratio
DNU	Beam-beam tune shift
UO	Energy radiation/turn
SIGE	Energy spread
BRHO	Particle rigidity
TAUX, TAUY, TAUE	Damping times
SIGX(0), SIGY(0)	σ_x and σ_y due to betatron motion with no coupling
SIGX(C), SIGY(C)	σ_x and σ_y due to betatron motion with coupling
SIGX(T), SIGY(T)	σ_x and σ_y due to both betatron motion and energy spread
LX,LY	Luminosity at the x and y tune shift limit

NOTATION	PARAMETER
NX,NY,IX,IY	Number of particles per beam and beam current values at the tune shift limit
FRF/FO	RF harmonic number
VRF,FRF	RF voltage and frequency
PHIS	Synchrotron phase angle
NUS,FS	Synchrotron tune and frequency
DE/E	RF Bucket
SIGZ	Bunch length
TAUQ*	Quantum life time

If sextupole magnets are used in the beam line the output will include the strengths, $\lambda\ell/B\rho$, of the sextupole corrections in m^{-2} where the field value, B_y, is given by $\lambda(X^2 - Y^2)$. In addition, if DR and NDR are used in the LUM command the output will include the variations of beta and betatron tune values for particles with different momentum.

The output computed by the CLR command is: the number of standard deviations n(NSTD) used in the computation; the values of σ_x, σ_y and $\Delta p/p$ at the beginning point of the beam line (SIGX, SIGY, SIGE); the values of $n\sigma_x$, $n\sigma_x'$, $n\sigma_y$ and $n\sigma_y'$ at each element in the beam line.

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*The value of TAUQ is very sensitive to the values of DE/E and TAUE; a few percent error in the values of these quantities could lead to a much larger error in the value of TAUQ.

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