MOTER INSTRUCTIONS FOR MSU

By B.Sherrill
10.12.1987 initial instructions for GSI
rev. 12.18.1987 for MSU
bquad charged to allow input of allowed multipoles 11/18/88 afz larger version now runs as moter_89 – many bugs removed from earlier versions. Old version (moter_87) works for small number of rays and uses less memory.

1. Introduction

These few pages of instructions are ment to supplement the documentation which already exist for MOTER. Further information can be found in the MOTER manual; and for information on the magnetic elements, the RAYTRACE manual.

MOTER is a raytracing-type program for magnetic optic system design. It is roughly based on the program RAYTRACE, and includes the capability of optimizing system parameters (one of few sections of the MOTER manual which is correct describes the optimization features of MOTER). The user can define an error function which the program will minimize. The program simulates the optical phase space by picking rays at random within a user defined region. Fixed rays can also be input.

The program takes as input three files. The three files, the OPT file, the DEM file, and the MAG file are described in section II of this manual. The error function is defined in the section on the DEM File. The optimization parameters are described in the section of the OPT file, and the magnetic system and phase space is described in the section of the MAG file.

The program is presently located on:

NSCL_USER:[NSCL.SPECTR.MOTER]	MOTER_87.EXE	---	executable file
“ “	NEW9A.FOR	---	source code
“ “	MOTER.TXT	---	this text tile
“ “	MOTER.COM	---	sample command file for running MOTER
“ “	MOTER_89.EXE	---	larger code 3/17/89

There are three examples of input for MOTER on the account NSCL_USER:[NSCL.SPECTR.MOTER]. They are:

FRS.DEM,FRS.OPT,FRS.MAG	---	“Big Peter” HO26
S320.DEM,S320.OPT,S320.MAG	---	MSU-NSCL simple spectrometer
QUAD.DEM,QUAD.OPT,QUAD.MAG	---	Doubles showing an example of how parameters are coupled

The program should only be run in batch mode, unless one has great need, or a small job. For a job with the GSI fragment separator (Big Peter), 100 rays and optimizing the sextupoles, the CPU time will be approximately 8 hours. To run a job in batch mode you must have the three input files:

“filename”.MAG
“filename”.OPT
“filename”.DEM

where “filename” is a user defined name. The names of the files must be the same. In the command file defined below is used the output will be written in a file called:

“filename”.OUT

The command for submission to the batch is:

SUBMIT/QUEUE=SYS$BATCH/NOPRINT/LOG/PARAM=(filename) “command file name”

where “filename” is the same user defined file name as above, and the command file must be similar to the example in US4$ROOT:[BRAD]MOTER.COM. The contents of the command file should be:

```
$SET DEFAULT “user disk and area”          e.g. NSCL_USER:[ZELLER]
$ ASSIGN “P1”.DEM FORO14
$ ASSIGN “P1”.DEM FORO08
$ ASSIGN “P1”.DEM FORO12
$ ASSIGN “P1”.DEM FORO06
$ NSCL_USER:[NSCL.SPECGRP]MOTER_87
$ DEASS FORO14
$ DEASS FORO08
$ DEASS FORO12
$ DEASS FORO06
$ EXIT
```

To run MOTER interactively, one need only type:

@”command file name” “filename”

and wait for the cows to come home.

2. Program Input

All input is formatted, and therefore may be entered separated by commans. The input form very similar to that of RAYTRACE.

A. Optimization file.OPT --- this file controls the optimization programs. A full description of all parameters is found in the MOTER manual.

For any of the variables entered in the OPT file, if a –77. is entered the default values will be used.

Line	Variables	Type	Comments (default)
1	NPROBS	I	(1)
	ITERS	I	(10)
	NPO	I	(1)
	NPRINT1	I	(1)

	NPRINT2	I	(0)
	NETASCH	I	(1)
	MONO	I	(1)
	NTABLE	I	(3)
	NPIV	I	(0)
	MXFCN	I	(3)
	ICROW	I	(1)
	KREAD	I	(1)
2	GRSZMIN	R	(1.e-20)
	RHIMIN	R	(1.e-25)
	ZSQMIN	R	(1.e-24) note:moter_87 has a bug so variable should always be set to –1.0E38 FOR moter 87 ONLY
	APZERO	R	(1.e-14)
	CMIN	R	(1.e-13)
	CMAX	R	(1)
3	RELPHI	R	(1.e-13)
	RELPPHI	R	(1)
	RELDGMX	R	(1.e-25)
	ETAVREL	R	(1.5e-2)
	ETAHALT	R	(1.e-2)
	USQMAX	R	(1.e6)

B. Demand File .DEM --- this file defines the error functions for which the program will attempt to minimize. It is recommended that the starting values of the variables be not to far from the desired values.

Line	Variables	Type	Comments
1	NTITLE	A*80	
2	IOPTDUM	I	Normally 0
	ICNORM	I	Normally 1
3	I	I	0 for last demand line, otherwise 1
	LOC	I	magnetic optical number; location
	NCOMP	I	number of optical parameter; 1=x, etc.
	COTIE	I	index for matrix elements; see example
	ISIDE	I	0(1) do not fix element
	CSTOR	R	value of demand; 0.variable, 1. demand, other – fixed
	JRANTIE	I	no. for inclusion of measurement error
	SDEV	R	value of measurement error
3+n	where record 3 is repeated n times for the various components of the error function		

4	WT	R	weight for demand n
	IORD	I	normally 0
	LOCSEX	I	“
	SEXTRO	R	“

Repeat 3 and 4 m times, until m error functions have been defined

5+m -1

6 0

As an example, suppose one would like to optimize an achromatic system to reduce the chromatic abberations. In this case, we want to reduce the horizontal spot size (the x-spot size), but not including the simple effect of the system magnification. Int his casethe series of records would be for a system with 10 elements:

```
SAMPLE DEMAND FOR FILE FOR AN ACHROMATIC SYSTEM WITH 10 ELEMENTS
0,1
1,10,1,1,1,1.,0,0.      ! comment-minimize x-spot size demand
1,0,5,2,0,0.,0,0.       ! comment-included to correct an arbitrary shift of central ray
1,0,1,3,0,0.,0,0.       ! comment-magnification subtracted
1,0,1,4,0,0.,0,0.
1,0,1,4,0,0.,0,0.
1,0,1,5,0,0.,0,0.       ! comment-higher order magnifications also subtracted
1,0,1,5,0,0.,0,0.
0,0,1,5,0,0.,0,0.
0.01,0,0,0.0
1,10,3,1,1,1.,0,0.      ! comment-minimize y-spot size demand
0,0,5,2,0,0.,0,0.
1.0,0,0,0.0
-1,0,0,0,0,0,0.,0,0.
0.0,0,0,0.0
```

C. Magnet file .MAG --- this file defines the magnetic system and the phase space to be simulated.

Line	Variables	Type	Comments
1	NTITLE	A*80	
2	NR	I	Number of rays; 400 MAXIMUM
	NR	I	Print option as in RAYTRACE
	NSKIP	I	
	JRAND	I	
	ICON	I	0(1) Demand coefficients calculated after each pass
	NRAND	I	Number or normally distributed random errors for each ray, to be included in demand evaluation when sdey in .dem in non-zero, eg 200 rays with nrand=3 means 600 rays traced (max=nr*nrand<4000) note: with 3 variables and 400 rays use only nrand=3. Then fix 1 variable and go to nrand=9, starting with parameters arrived at in the previous step. Only use nrand=9 when parameters are very close to their final values.

	ITUNE	I	Not used, should be 0
3	OPTI	A*4	OPTI-> Optimize NOOPTI-> No Optimize traces rays only ISNG= single pass calc w/error fucts
this card not used do not input (4		JOPTIMIZ	I)
5	IRANDUM	I	Normally=0 (=1 use rand seed)
	IRANSTA	I	=0 unless IRANDUM=1 then this is seed
6	ENERGY	R	Particle Momentum (yes, momentum MeV/c)

7…n Elements
The choices for elements are:
DIPO, QUAD, POLE, SHRT, DRFT, SLIT, WEDGE, FOCL, SENT

see below for a description of the input for the various elements.

8	NINDEPN1	I	Number of independent variables must be 1
	ISET	I	
9	DELTA(L) L=1, NINDEPN1		Uncertainty in independent variable L
		R	Normally set these variables to .01 If you get OPTIMIZ 380, ERROR HALT try increasing to .03, or higher.
10	LPRIMP(L) L=1,10		Positions to print ray data. Use –1
		I	to signal no more positions wanted, but all 10 spaces must have values; e.g. 0,5,10,-1,0,0,0,0,0,0 would be used to see the ray data at locations 0,5 and 10.
11	JRKSTMS	I	Variables for integration routines
	JHAMMING	I	3,1 normally used (see moter manual)
12	IBMTYPE	I	Normally 1=0 for tgt in place
	NSIGMA	I	Number of phase space variables
	ISIGMA(1-6)	I	=1 for each phase space variable to generate random rays. eg, for all 5 normal variables with IBMTYPE=1 this card is: 1 5 1 1 1 1 0 1

13	SIG(1), RSIGMA(1-6)	R,R	Half width for x, 1 0 0 0 0 0
	SIG(2) “	R,R	“ theta, 0 1 0 0 0 0
	SIG(3) “	R,R	“ y, 0 0 1 0 0 0
	SIG(4) “	R,R	“ phi, 0 0 0 1 0 0
	SIG(5) “	R,R	“ l, 0 0 0 0 1 0
	SIG(6) “	R,R,	“ delta, 0 0 0 0 0 1

14 A-C as used here if IBMTYPE=0

14 A	SHOOT(1)	R	Tgt to first aper.dist (cm)
	(2)	R	Half size of aper in X (cm)
	(3)	R	-"- Y
	(4)	R	Central momentum (0 for cent)
	(5)	R	Momentum range
	DXINV	R	Inverse dispersion on tgr (% / cm)
14 B	TGTPAR(1)	R	Tgt thickness (cm)
	(2)	R	" interation length (cm)
	(3)	R	Tgt angle (=0 if perp)
	(4)	R	" half size in X (cm)
	(5)	R	" Y
14 C	RKX	R	Kinematic parameters (not normally
	RKXX	R	used, except at 0 deg)
	RKY	R	
	RKYY	R	
14	KRAY	I	Number of fixed rays to be defined by the user always use at least 1 (0 ray)
	KOUT	I	Must be 1 to print rays, =0 no print
15	FRAC	R	Fraction of rays to receive the mass of a pion (=1 for no pions)
16	X		
to	THETA		
16+KRAY	Y		
	PHI		
	LENGTH		
	UNUSED		
	DELTA		
	RMASS		
17	XOFFSET		
	THETAOFFSET		
	YOFFSET		
	PHIOFFSET		
18	J		set = -1

this card not in file

19	IRANCMP
	RANCMP

D. Elements

The input for the elements is basically identical to that used by raytrace. Except for the cases noted all the variable names have the same meaning as in RAYTRACE.

For the sake of time, not all elements are descried. If an element is desired which is not listed below, the user must look in the subroutine MOTR for the proper definitions. The meaning of the variables may have to be taken from the subroutines for that element.

1. Dipole DIPO

Record	Variable	Type	Comments
1	RB	R	Bend Radius in cm
2	LF1	R	
	LU1	R	
	LF2	R	
	DG	R	
	ILTOC	I	Unused, just set to 0
3	A	R	
	B	R	
	D	R	
	BF	R	
4	PHI	R	
	ALPHA	R	
	BETA	R	
5	NDX	R	"n-value" in raytrace
	A01	R	= bet 1 in raytrace
	A02	R	= gamma " "
	A03	R	= delt " "
	RAP 1	R	rap1(raytrace)=2*rap1(moter)/csix**2
	RAP2	R	rap2(raytrace)=2*rap2(moter)/csix**2
6	Z11	R	
	Z12	R	
	Z21	R	
	Z22	R	
7	RW1	R	0 -> use Enge coordinates for curvature
	RW2	R	1.-> use method of closets approach a zero gives the definitions for RAP and RAP2 shown above.
	BR1	R	
	BR2	R	
8	CSIX	R	
	CSVN	R	
	CAT1	R	
	CAT2	R	

9	XCR1	R
	XCR2	R
	DLS1	R
	DLS2	R
10	A04	R
	A05	R
	PBA1	R
	PBA2	R
11	CFV1	R
	CFV2	R
	CNN1	R
	CNN2	R
12	C0	R
	C1	R
	C2	R
	C3	R
	C4	R
	C5	R
13	C6	R
	C7	R
	C8	R
	C9	R
	C10	R
	C11	R
14	YMAX	R
	XMAX	R
	ISPOLE	I
15	ZOT1	R
	ZOT2	R
	ROT1	R
	ROT2	R

2. POLES

Record	Variable	Type	Comments
1	LF1	R	
	LU2	R	
	LF2	R	
2	A	R	
	B	R	

	L	R
	RAD	R
3	BQD	R
	BHX	R
	BOC	R
	BDC	R
	BDD	R
4	Z11	R
	Z12	R
	Z21	R
	Z22	R
5	C0	R
	C1	R
	C2	R
	C3	R
	C4	R
	C5	R
6	C6	R
	C7	R
	C8	R
	C9	R
	C10	R
	C11	R
7	FRH	R
	FRO	R
	FRD	R
	FRDD	R
8	DSH	R
	DSO	R
	DSD	R
	DSDD	R
9	XMAX	R
	YMAX	R

3. SHRT this input is the same as in RAYTRACE

4. FOCL

Record	Variable	Type	Comments
1	RX	R	Radius of curvature of the x-focal plane. + is convex toward last magnet.

	THETA	R	Tilt of the focal plane.
	RY	R	Radius of curvature of the y-focal plane
	XMAX	R	DEFAULTS SHOULD BE USED WHEN ONLY
	YMAX	R	ONE PARAMETER IS USED (eg, THETA) ! DEF=

1.e7, 0,1.e7, 1.e7, 1.e7

5. DRIFT

Record	Variable	Type	Comments
1	DRFT	R	if you can't figure this one out …

BQUAD CHANGES:

N=10, 14, 18,22 terms added to QUAD element (allowed terms=6,10,etc) input via the IM terms: IM(1)=10 pole field at pole tip, IM(3)=14 pole, IM(4)=18 pole, IM(5)=22 pole

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QUAD

1	LF1	R
	LU2	R
	LF2	R
2	A	R
	B	R
	L	R
	RAD	R
	BF	R
3	Z11	R
	Z12	R
	Z21	R
	Z22	R
4	C0	R
	C1	R
	C2	R
	C3	R
	C4	R
	C5	R
5	C6	R
	C7	R
	C8	R
	C9	R
	C10	R
	C11	R

6	YMAX	R	½ aper in x
	XMAX	R	“ y
	ZMQ	R	
	XQMAX	R	½ aper in x for ellip aper
	YQMAX	R	
7	GRAD2	R	Sextupole (NB=+ve X, im2=-ve X so grad2=im2
	GRAD3	R	Octupole
	GRAD4	R	Decapole
	GRAD5	R	dodecapole
	IM1	R	N=10 TERM (ie R**N-1 dependt.)
8	IM2	R	Sextupole (=GRAD2)
	IM3	R	N=14 term
	IM4	R	N=18 term
	IM5	R	N=22 term
SLIT			
1	RAD	R	Default=(0, ie no collimation)
2	XUL	R	(1.E35)X upper size
	VXUL	R	(1.E35)Theta upper
	YUL	R	(1.r35)Y upper
	VYUL	R	(1.e35)Phi upper
	TUL	R	(1.e35)Path length upper
	DUL	R	(1.e35)Delta upper
3	XLL	R	(-1.e35)X lower size
	VXLL	R	
	YLL	R	
	VYLL	R	
	TLL	R	
	DLL	R	
4	SDDEL	R	
	SDVEL	R	

All other elements are not included due to the laziness of the author.

IMPORTANT: After the parameters for each element, there must be entered a line which contains the information for which parameters are variable. The structure of the line is as follows:

Record	Variable	Type	Comments
1	K	I	Location of the parameter to be varied, relative to the beginning of the element list. For example if one wanted to vary BQD in a POLE, K=8.
	I	I	is the counter for the variables; variables can be coupled by indicating I and –I, or I and I if they are to

		be correlated.
NBD	I	0 = no bounds 1 = lower bound 2 = both lower and upper bound 3 = upper bound only
BL	R	lower bound
BU	R	upper bound

These line are repeated n times for n variable elements. The variable definitions ended by a line of all zeros:
0,0,0,0.,0.

Good Luck.

MOTER

A COMPUTER CODE FOR OPTIMIZED RAY TRACING OF CHARGED PARTICLE BEAM TRANSPORT SYSTEMS

Version 33

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Introduction

MOTER is a ray tracing program intended for analysis and optimization of systems of magnetic elements. Several features are included in MOTER which are not available in other codes. Among these are Monte Carlo simulation of the beam phase space, a sophisticated definition of the performance including the possibility of computer correction of aberrations based on measurements of the trajectory of each event, the automatic optimization of any parameter of the magnet system, the possibility of the use of field maps for dipoles, quadrupoles, and multipoles, and the availability of several new element types including an ExB separator, an r.f. accelerating gap, a wedge degrader, and various slits and scatterers. To the greatestpossible extent, MOTER makes use of the definition of parameters identical of program RAYTRACE. In order to minimize the pitfalls of problem setup, it is suggested that the MOTER user first study his problem with the standard codes TRANSPORT, TURTLE, and RAYTRACE, in that order.

The history of the evolution of MOTER is useful for understanding some of the details of the coding. Starting with the 1969 version of RAYTRACE, written by S.Kowalski and H.Enge of MIT, the following sequence of additions and modifications occurred:

1. Morris M.Klein of LASL installed the demand definition and the linear and nonlinear optimizers;
2. Richard Christian of Purdue University installed the SEPARATOR routine, modified the integration routines to include the Milne method, and modified the dipole routine for efficiency and flexibility;
3. H.A.Thiessen of LASL added the coding for Monte Carlo simulation of the phase space, modified the dipole routine to use distance of closest approach to the effective edge, added the Mappole lement which allows the use of either parameterized fields of field maps for dipoles or midplane symmetric multipoles, added the option o use of the Hamming integration method, added the elements FOCL and Wedge, and converted the QUAD outine to the POLES routine from the 1973 version f Raytrace;
4. K.G.Boyer of the University of Texas Austin added the r.f. accelerating gap, the solenoid, and the FFT QUAD elements, generalized the Monte Carlo ray generator, and converted MOTER to the CDC FTN compiler;
5. Lester E.Smith of The University of Texas at Austin converted the code for use on the Digital Equipment Corporation VAX 11/780 computer; and
6. H.A.Thiessen provided test cases and checked the MOTER results on the two systems and compared them to RAYTRAC.

Two useful auxiliary codes are available. HICOF can operate on the PUNCHIT output file and makes possible analysis of residual aberrations. This is useful as a diagnostic aid to determine which aberrations are important and may indicate whether additional multipole parameters are needed or more detailed analysis of each event would be beneficial. The program MFIT is useful for reduction of raw data from several field maps into a single midplane map for use with the MAPPOLE element. Brief writeups of HICOF and MFIT are included as appendices to this report.

Version 33 will be frozen as a standard version for current distribution. Version 34 contain substantial modifications which will entail at least an additional year’s worth of work. Copies of this manual may be obtained from the following:

H.A.Thiessen
Group Leader / MP-10
Mail Stop #841

Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

The standard version of MOTER has been implemented on the CDC 7600 using the FTN/LTSS compiler. It requires approximately 52,500 decimal words of small core memory and 188,000 decimal words of large core memory. It is normally distributed on 7- or 9- track magnetic tape at 800 BPI in standard CDC, external BCD, line image format; on 9-track magnetic tape at 800 BPI in standard IBM EBCDIC format; or on 7- or 9-track magnetic tape at 800 BPI in standard DEC FILES-ll format. The program may also be obtained from the above address.

The present authors assume responsibility for the contents of this manual, but in no way imply sole responsibility for the entire evolution of the code.

INPUT FORMAT FOR MOTER

The input data for MOTER has been organized into four parameter file sets and up to ten optional files of field maps:

1. OPTPAR: Contains all the information required to tune the optimizer for its most efficient use;
2. DEMANDS: Defines the demand criteria which form the function-of-merit for the optimizer and the histograms to be generated;
3. RAYPAR: Contains all the information required to initialize the Monte Carlo ray generator;
4. MAGPAR: Defines the initial magnet configuration and those parameters which are to be carried; and
5. M21, M22,… M30: Optional files containing externally generated dipole field maps.

Data are formatted either in fixed field format or through a NAMELIST parameter group as indicated in the sections which follow. The general form of the NAMELIST input group is as follows:[1]

Δ $ group name variable = constant,
Δ array name = constant, …, constant,

Δ $

The following NAMELIST rules apply:

1. The NAMELIST delimiter, $, must appear in column 2;
2. Any information in column 1 between the delimiter pair is ignored;
3. All parameters in the input list must be separated by commas, except for the parameter preceeding the terminating $; and
4. Blanks must not appear between the $ and the NAMELIST group name, or within array or variable names.

[1] Fortran Extended Version 4 Reference Manual, CDC Publication No. 60497800, Revision C (4/15/77).

In MOTER, an iteration indicates an optimization cycle in which derivatives are formed. A pass is a sequence of iterations. Therefore, successive passes may be set up so as to permit selective variation of magnet parameters. In general, the basic limitations to the usage of MOTER are finite core availability and finite computing time.

OPTPAR

This input file enables the user of MOTER to tune the optimizer package for its most efficient operation. The optimizer routines are based on the Levenberg algorithm for minimizing a sum of squares.[2] The optimizer first determines a direction of descent lying between that given by first variational principles and the negative gradient. Given this direction, its length is then determined by a quadratic procedure. The parameters which can be set in this file control the operational characteristics at the beginning of each pass, the exit criterion for each pass, and the optimizer print control. All reads are initiated in the subroutine Optimizer.

The general form of the NAMELIST parameter group is as follows:

Δ $ OPTP …

Δ $

The following is a list of legal, relevant OPTP parameters and their definitions: (Underlining indicates the default value)

NPROBS = 1 Problem number

KREAD = 0 (1) OPTP groups will (will not) be defined for succeeding passes.

PASS EXIT CRITERION:

ITERS = 10 Number of allowed iterations per pass.

GRDZMIN = 1.0E-20 Exit when the inner product of the newly chosen Z search direction and the negative gradient evaluated at the same point in parameter space lies between 0.0 and CRDZMIN.

PHIMIN = 1.0E-25 Exit when the merit function, PHI, is less than the non-zero PHIMIN

RELPHI = 1.0E-13 Exit when the relative drop in the merit function, PHI, following an iteration cycle is less than the input value of RELPHI. NOTE: The maximum recommended value of RELPHI is 1.0E-3.

ZSQMIN = 1.0E-24 Exit when Z^2 < ZSQMIN.

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[2] M.Klein, et al., OPAC, Los Alamos Scientific Laboratory Program Library Write-Up, E401, October 1978 (Ver. 3).

ITERATION TUNING PARAMETERS:

NPO = 0 (1) To by-pass (include) P=0 in the P-table.

NETASCH = 0 (1) To omit (include) a Z (P) n search.

MONO = 0 (1) To continue (halt) the P-table search at the first minima.

NTABLE = 3 Number of P-table entries.

CMIN = 1.0E-3 Starting value of p^2 which is equal to CMIN (DIAGMAX).

RELPPHI = 1.0 Exit from the P-table search when the relative PHI drop is greater then RELPPHI.

RELDGMX = 1.0E-50 Halt the differentiation and the P-table search when the relative change in the matrix diagonal maximum is less than RELDGMX.

ETAVREL = 1.5E-2 Exit from the n search when the parabolic vertex sequence relative change is less than ETAVREL.

ETAHALT= 1.0E-2 Halt the n search when the relative PHI drop is less than ETAHALT times the relative P-table PHI drop.

MXFCN = 3 Maximum number of function evaluations permitted in the search for ETA.

USQMX = 1.0E+6 Freeze a bounded variable when its unconstrained mapping exceeds USQMX in absolute magnitude.

ICROW = 0 (1) Column followed by row maximum scaling not desired (desired).

NPIV = 0 (1) When the maximum modified column vector, the modified length divided by the original length, determines the next pivot.

APZERO = 1.0E-14 Approximate value for zero used in the least squares rank determination.

PRINT CONTROL

NPRINT1 = 0 (1) To by-pass (print) the P-table search performance.

NPRINT2 = 0 (1) To by-pass (print) the n search triplets.

RAYPAR

This input file enables the user of MOTER to initialize the Monte Carlo ray generator. In general, the beam is described by a six-dimensional hyperellipsoid whose parameters are the standard TRANSPORT set, (X, Θ, Y, Φ, ι, δ).[3] The Monte Carlo ray generator will then randomly

[3] K.Brown, et.al., TRANSPORT, SLAC-91, Rev. 2< UC-28 (I/A), May 1977/

choose each parameter independently in the set, according to a specified distribution, and check to see if the ray fits within the hyperllipsoid. Optionally, rays may be input to the program directly, thus by-passing the Monte Carlo ray generator. Finally, an option for target production simulation exists, giving the user additional modeling capability in the design, for example, of spectrometers. All reads are initiated in the subroutine MOTR. Card set number:

1. (215) NR, KRAY

NR: Total number of rays to be traced. Currently< a total maximum of 400 rays may be traced.

KRAY: Number of rays to be read in from the RAYPAR file. At least one ray should be read in order to correctly initialize the code. Normally, this initial ray is the central ray.

2. (I1, 020) IRANDUM, IRANSTA

IRANDUM: 0(1) Do not (Do) use the random number generator seed.

IRANSTA: Random number generator seed. This option allows the user to initialize the random number generator with any desired seed.

3. If KRAY=NR, skip these cards:

    a) (812) IBMTYPE, NSIGMA, (ISIGMA(I), I=1,6)

IBMTYPE: 0(1) Target (No target) in place.

NSIGMA: Number of parameters defining the beam. This can be any subset of the standard TRANSPORT beam parameter set, (X, Θ, Y, Φ, ι, δ).

ISIGMA (I): 0 (1,2,3) The 1^{th} term in the beam parameter set is not defined (is defined). If a term is defined, then random values for that term will be chosen according to (1) a uniform distribution, (2) a Gaussian distribution, or (3) a user-defined distribution.

    b) (6(7F10.6)) (SIGMA(I), (RSIGMA(I,J), J=1,I), I=1.6)

SIGMA(I): Standard deviation f the distribution associated with the 1^{th} term in the beam parameter set. For a uniform distribution, the standard deviation would simply be half the length of the major axis; and, for a user-defined distribution, the standard deviation would be the FWHM / (2*SQRT(2ιn(2))).

RSIGMA(I,J): The lower triangle and diagonal of the R(I,J) matrix as defined in TRANSPORT to describe the beam hyperellipsoid. Therefore, SIGMA(I) is the square root of the associated σ(I,I) diagonal element. Thus, the user is free to use any arbitrary TRANSPORT beam in MOTER.

    c) If (ISIGMA(I), I=1,6) ≠3, skip these cards:

        i) (15) NPOINTS

NPOINTS: Number of points in the user-defined distribution.

ii) (8F10.6) (X(I), Y(I), I=1, NPOINTS)

X(I): 1th abscissa point in the distribution. Note that the X(I) must be ordered in ascending order from the minimum to the maximum value.

Y(I): Area under the curve associated with the corresponding X(I). The total area under the curve must be normalized to unity and must be integrated starting with X(I).

d) If IBMTYPE≠0, skip these cards:
   i) (6F10.6) (SHOOT(I), I=1,5), DXINV

SHOOT(1): Target to first aperture distance (cm).

SHOOT(2): Half size of the aperture X dimension (cm).

SHOOT(3): Half size of the aperture Y dimension (cm).

DXINV: Inverse dispersion of the target: $(\delta p/p)/x$ (%/cm).

ii) (5F10.6) (TGTPAR(I), I=1,5)

TGTPAR(1): Target thickness (cm).

TGTPAR(2): Target interaction length: λ (cm).

TGTPAR(3): Angle of the target with respect to the central axis of the magnet system (deg). Note that TGTPAR(3)=0 if the target is perpendicular to the central axis.

TGTPAR(4): Half size of the target X dimension (cm).

TGTPAR(5): Half size of the target Y dimension (cm).

4. (F10.6) FRAC

FRAC: Total fraction of the rays receiving the mass of a proton. The remainder receive the mass of charged pion.

5. (15) KOUT

KOUT:0: Do not output any Monte Carlo generated ray data.

1. Print the final ray position data on the output file called M33OUT. The final position parameters are (X, Θ, Y, Φ, ι, δ) in (cm, mr, cm, mr, cm, %).
2. Print and punch the final ray position data. Same as for KOUT-1, except that the same information is also written to an additional output file called PUNCHIT.
3. Print and punch the initial ray position data. The initial position parameters are (X, V_x, Y, V_y, Z, V_z, δ) in (cm, cm/sec, cm, cm/sec, cm, cm/sec, %).

4. Print and punch the complete positional ray trace data in HICOF input format. HICOF is a program used to calculate the aberrations present in a magnet system using the positional data from the traced rays. The positional information generated is as follows:

Element no.:

0	$(X, V_x, Y, V_y, Z, V_z, \delta)$
LPRIMP(I),I=1,M	$(X, \Theta, Y, \Phi, Z, \iota, \delta)$
N	$(X, \Theta, Y, \Phi, Z, \iota, \delta)$

Where there are N+1 elements present, element 0 being the source of rays and element N being the last element in the system. LPRIMP(I) is an array whose values denote the element number at which positional ray data is desires. LPRIMP(I) is described in the section on the MAGPAR input file. Finally, IRANSAV is the random number generator seed for the next ray to the generated. Thus, the user can generate additional sets of rays for a particular beam line by simply restarting the random number generator with the seed from the last ray of the most current set.

6. If KRAY=0, skip these cards:

(8F10.6) (XI(I), VXI(I), YI(I), VYI(I), ZI(I), VZI, DELP(I), RMASSCI) I=1,KRAY

XI(I): Horizontal displacement of the ray (cm).
VXI(I): Direction of the ray when projected onto the X-Z plane (mr).
YI(I): Vertical displacement of the ray (cm).
VYI(I): Direction of the ray when projected onto the Y-Z plane (mr).
ZI(I): Axial displacement of the ray (cm).
DELP(I): δ P/p (%).

7. (15) J

J:0: Do not freeze any of the generated input ray parameters to a fixed value.

1,2,…,6: Freeze the J^{th} input ray parameter to a fixed value.

8. If J=0, skip this card; else, read this card and read card set 7 again.

(I1, 9X, F10.6) IRANCMP(J), RANCMP(J)

IRANCMP(J), RANCMP(J): If IRANCMP(J) is positive, then the J^{th} Monte Carlo generated ray parameter is geven the fixed value of RANCMP(J).

9. Begin the definition of the next pass by entering new sets of cards 1-8.

MAGPAR

This input file enables the user of MOTER to specify the magnet system layout and the free variables through which the optimizer is to minimize the function-of-merit. The simulator produces a set of rays which pass through the initial unoptimized system. The system is specified by appropriate element keywords and their corresponding NAMELIST parameters. The order in which the elements appear in the setup deck is the order in which they are encountered during a ray trace. Element number zero corresponds to the beam source on the input side to the first magnet. Parameters specified in a NAMELIST may be variable or fixed. If variable, they may be free of tired directly to any other parameter in the magnet. In addition, any variable may be bounded or unbounded. Any parameter which is unspecified is given a default value. Finally, an option in the collimating element known as SLIT provides a convenient way to introduce normally distributed multiple scattering effects at a detector site in the system. All reads are initiated in the subroutine MOTR.

Card set number:

1. (8A10) NTITLE

NTITLE: Appropriate title for identification of the magnet system.

2. (415) NP, ICON, NRAND, ITUNE

NP: Number of integration steps performed per printed line for diagnostic investigation.

ICON: 0(1) Demand coefficients to be determined after each pass (iteration).

NRAND: Number of normally distributed random measurements to be generated for each demand in the DEMANDS deck flagged to received a measurement error. The number of effective rays is equal to (NRAND) * (NR) * (Number of demands containing at least one nonzero JRANTIE + 1). JRANTIE is described in the section on the DEMANDS input file. If NRAND=0< then no measurement error are generated.

ITUNE: 0(1) Generate normally distributed random multiple scattering errors only the the start of each iteration cycle (each trace). This parameter should always be set to zero.

3. (F10.6) ENERGY

ENERGY: Particle momentum (MeV/c).

4. a). (A4) NWD

NWD: Appropriate magnet keyword chosen from the following list:

DIPOLE, MAPPOLE, QUADRUPOLE, SOLENOID, SEPARATOR, ACCELERATOR, WEDGE, FOCL, SHRT, DRIFT, SLIT, SUBSYSTEM, SENTINEL.

Underlined characters must appear in columns 1-4 of this card. The NWD card is followed by the appropriate group of NAMELIST cards. Each set of NWD – NAMELIST cards defines an element in the system. The entrance coordinate system of the 1^{th} element is referenced as location I-1, and its exit is referenced as location i. An ordered set of elements and element parameters define the system to be ray traced. The order in which the elements are read in must be the order in which the rays pass through the system.

The following restrictions apply to the definition of the beam line:

i) The maximum number of elements that may be present in any beam line definition is 40.

ii) The sum of the assigned points for each element in the beam line may not exceed 1200. The point assignments for a given element are as follows:

Element	Points
DIPOLE	66
MAPPOLE	151
QUADRUPOLE	38
SOLENOID	11
SEPARATOR	39
ACCELERATOR	
WEDGE	16
FOCL	5
SHRT	6
DRIFT	1
SLIT	15
SUBSYSTEM	0
SENTINEL	0

Note that the SUBSYSTEM and SENTINEL are special elements with no parameters:

SUBSYSTEM: This card signals the code that ray tracing is required only up to the previously defined element. The complete system, however, should be defined up to the SENTINEL card.

SENTINEL: This card indicates that the beam line definition has been completed.

b) Appropriate NAMELISTs corresponding to the elements specified by the previous NWD card. This set of cards may then be followed by either another NWD-NAMELIST card set, or either a SUBSYSTEM or a SENTINEL card. The NAMELIST data for each element much be in the following order:

Δ$NAMELISTP ….
Δ$
Δ$NAMELISTF ….
Δ$
Δ$NAMELISTD ….
Δ$
Δ$NAMELISTL ….
Δ$
Δ$NAMELISTU ….
Δ$

If all the parameters in the D NAMELIST are either zero or left blank, then the last two NAMELISTs must not appear. If the D NAMELIST contains any nonzero or non-blank information, then both the last two NAMELISTs must appear. NAMELISTs required to complete a data set or act as an appendum to a data set can be set up by assigning the value of one (1) to the variable MOR.

The meaning of the NAMELISTs used for element data is as follows:

P NAMELIST: This is the basic parameter list for reading in the element data. The meaning of all presently defined parameters is given in later sections for each element.

F NAMELIST: This is the list of flags indicating which parameters are to be varied. The allowed flag names in the NAMELIST are the corresponding variable names in the P NAMELIST prefixed with the character F. In order to indicate that a parameter is to be varied, the appropriate flag is given a nonzero integer value. Unnamed flags or flags given the value of zero fix the value of their corresponding parameters. All parameters associated with flags that have different integer absolute values are treated as independent variables. If two or more flags have the same integer absolute value, then those corresponding parameters are said to be tied together such that, whenever the optimizer makes a change, the same change is added to all the tied parameters. If any of the flags has an opposite sign, then the change added to the associated parameter is added with the corresponding sigh. The integer flags can appear in any order, but the set of such flags must in absolute value form a natural sequence beginning with the integer 1 and ending with the integer N where N represents the total number of basic free variable groups. A total number of basic free variable groups. A maximum of 30 free groups may be defined. Note that at least one flag in the beam line definition must be nonzero whether or not optimization is desired.

D NAMELIST: This is the list of flags specifying the bounds associated with any parameter which may be varied by the optimizer. The allowed flag names in this NAMELIST are the corresponding variable names in the P NAMELIST suffixed with the character D. Flags in this NAMELIST may be assigned only the following integer values:

0: The parameter is unbounded.
1: The parameter is bounded from below only.
2: The parameter is bounded from above and from below.
3: The parameter is bounded from above only.

U NAMELIST: This is a list of the upper bounds for the corresponding parameters having upper bounds. The allowed variable names in this NAMELIST are the corresponding variable names in the P NAMELIST suffixed with the character U.

L NAMELIST: This is a list of the lower bounds for the corresponding parameters having lower bounds. The allowed variable names in this NAMELIST are the corresponding variable names in the P NAMELIST suffixed with the character L.

The following is a list of the legal NWD – NAMELISTs card sets:

DIPOLE	MAPPOLE	
Δ$DIPP…	Δ$MAP…	Δ$MAPDAT…
Δ$	Δ$	Δ$
Δ$DIPF…	Δ$MAPF…	Δ$FITMAT
Δ$	Δ$	Δ$
Δ$DIPD…	Δ$MAPD…	
Δ$	Δ$	
Δ$DIPL…	Δ$MAPL…	

Δ$	Δ$
Δ$DIPU…	Δ$MAPU…
Δ$	Δ$

QUADRUPOLE	SOLENOID
Δ$QUADP…	Δ$SOLNP…
Δ$	Δ$
Δ$ QUADF…	Δ$ SOLNF…
Δ$	Δ$
Δ$ QUADD…	Δ$ SOLND…
Δ$	Δ$
Δ$ QUADL…	Δ$ SOLNL…
Δ$	Δ$
Δ$ QUADU…	Δ$ SOLNU…
Δ$	Δ$

SEPARATOR	ACCELERATOR
Δ$SEPP…	Δ$ACCP…
Δ$	Δ$
Δ$SEPF…	Δ$ACCF…
Δ$	Δ$
Δ$SEPD…	Δ$ACCD…
Δ$	Δ$
Δ$SEPL…	Δ$ACCL…
Δ$	Δ$
Δ$SEPU…	Δ$ACCU…
Δ$	Δ$

WEDGE	FOCL
Δ$WEDP…	Δ$FOCLP…
Δ$	Δ$
Δ$WEDF…	Δ$FOCLF…
Δ$	Δ$
Δ$WEDD…	Δ$FOCLD…
Δ$	Δ$
Δ$WEDL…	Δ$FOCLL…
Δ$	Δ$
Δ$WEDU…	Δ$FOCLU…
Δ$	Δ$

SHRT	DRIFT
Δ$SROP…	Δ$DRFP…

Δ$	Δ$
Δ$SROF…	Δ$DRFF…
Δ$	Δ$
Δ$SROD…	Δ$DRFD…
Δ$	Δ$
Δ$SROL…	Δ$DRFL…
Δ$	Δ$
Δ$SROU…	Δ$DRFU…
Δ$	Δ$

SLIT
Δ$SLITP…
Δ$

The slit elements functions as a collimator or as a detector introducing multiple scattering or both. As such, its parameters are never altered during optimization. Hence, only the …P NAMELIST is defined.

5. (215) NINDEP1, ISET

NINDEP1: Number of independent variable groups.

ISET: ISET-1 derivative refinements desired for each of the independent variable groups. Through this option, the user may determine a lower bound for DELTA(I).

6. (8F10.6) (DELTA(I), I-1, NINDEP1)

DELTA(I): Differential step size for calculating the numerical derivatives of error components with respect to the independent variable group I. Here, I denotes the order in which a variable group appears physically in the composite list of …P parameters. It does not refer to its absolute flag value.

7. Δ$LPRIM LPRIMP=…,…,…
   Δ$

(LPRIMP(I), I=1, N): Element numbers at which positional data for the Monte Carlo generated rays is to be saved. Note that there can be at most 41 elements in a system including the beam source at element number zero.

8. Δ$METHOD JRKSTMX= …, JHAMMING= …
   Δ$

JRKSTMX: The maximum number of fourth order Runga-Kutta integration steps to be taken prior to switching to the Milne or Humming integration methods. Note that when beginning to integrate from the edge of a field region, a minimum of three Runga-Kutta steps is necessary in order to prime either the Milne or Hamming methods.

JHAMMING: 0(1) Use the Milne (Hamming) integration method after the Runga-Kutta integration has ended.

9. Begin the definition of the next pass by entering new sets of cards 1-8.

MAPPOLE

The mappole element provides the capability for ray tracing from a field map. Parameters are provided for the purpose of making small perturbations of the map, as would be accomplished with shimming, field clamp changes, or a "snake". The field map may be read in from an external data file, or can be created from parameters identical to those used in the DIPOLE element. This option is useful in the design stage and is a check on calculations made with the DIPOLE routine, since the mathematics used for field reconstruction off the median plane are completely different in the two elements.

Briefly, the field map is assumed to consist of data for B_y on a uniform rectangular grid in the median plane. (Median plane symmetry requires that B_x and B_z are zero on this plane). To calculate the field at the point (x, y, z), B_y at n_x by n_y nearest neighbor points on the median plane are least squares fit to a set of harmonic polynomials (polynomials which satisfy Laplace's Equation in three dimensions). These polynomials are then evaluated at the point (x, y, z) to give the three components of the magnetic field. The possibility of using a least squares fit to many more data points than the number of free coefficients can be used the eliminate the difficulties that can be created by measurement error in field measurements. The degree of polynomials used is free to be adjusted by the user. The possibilities of truncation at a low order or of use of a higher order than DIPOLE are available.

The MAPPOLE element has "P, F, and D" parameter lists similar to DIPOLE. In addition to these, two additional data lists are required. The first, MAPDAT, specifies parameters of the map(s) to be used. The second, FITMAT, specifies the parameters of the fitting matrix used in reconstructing the field. The order of data lists required for MAPPOLE is:

MAPP
MAPF
MAPD
(MAPU) optional
(MAPL)
MAPDAT
FITMAT

The MAPP parameter list consists of the following parameters for each MAPPOLE element:

BO	Central field (Tesla)
RHO	Layout radius (cm)
GAP	Full gap (cm)
FCG (2)	Field Clamp Gap, Entrance (Exit) (cm)
DRIFT (2)	Entrance (Exit) Drift (cm)
XCR (2)	Co-ordinate system offset, entrance (exit) (cm)
RW (2)	Reference width, entrance (exit)
NREG	Number of separate regions of map (6 maximum)
MAPPNO	Sequence number (6 maximum)

REDGE (6,2) Reference edge of entrance (exit)

$$Z_{efb}^{(J)} = REDGE(1,J)\sum_{I=Z}^{6} REDGE(I,J)*\left(\frac{x}{RW(J)}\right)^{I}$$

CENGE (6,2) Field Falloff parameters, entrance (exit)

$$\frac{B_y(x,o,z)}{B_o} = \frac{1}{1+Exp(-\sum CENGE(I,J)*\left(\frac{z}{GAP}\right)^{J})}$$

The following three parameter sets define perturbations which modify either measured or calculated maps.

AFC (6, 2) Field clamp perturbation parameters at entrance (exit) edge. Adds a gaussian perturbation to the midplane map

$$\frac{\Delta B(x,y)}{B_o} - \frac{\Delta EFB(x)}{Norm} + \exp\left(\frac{[z - REDGE(Z)]^2}{0.36(FCGAP)_2}\right)$$

where

$$\int_{-\infty}^{\infty} dz \frac{\exp()}{norm} = 1$$

and

$$\Delta EFB(J) = AFC(1,J) - \sum_{I=2}^{6} AFC(I,J)*\left(\frac{x}{RW(J)}\right)^{I}$$

where J=1,2 are entrance (exit) parameters.

RN (6) Radial midplane map perturbation

$$\frac{\Delta B}{B} = \sum_{J=1}^{6} RN(J)*\left((R - R\ \ Layout)**(J-1)\right)$$

HT (4, 6) Similar to AFC except always moves edge in toward center of magnet as occurs when iron is added to field clamp nose pieces. See coding near Subroutine MAPSET statement Number 430 for details.

In addition to the parameters of each magnet, each MAPPOLE may have up to 6 regions with separately calculated (or measured) maps. These parameters are part of the MAPP data list and are given below:

ANG (6) Angle between +X axis and +R Degrees

PHI (6) Origin in layout system with respect to previous system Degrees
ZSTA (6) Starting Boundary Line cm
ASTA (6) Z=ZSTP-TAN (ASTA) *X Degrees
ZSTP (6) Stopping Boundary Line cm
ASTP (6) Z=ZSTP-TAN (ASTP) *X Degrees
STEP (6) Integration Step Length cm
XMAX (6) Half size of X aperture at Z=0 cm
YMAX (6) Half size of y aperture at Z=0 cm
NMAP (6) Map number (12 max)
NFITM (6) Fitting Matrix Number (5 max)
ITYPE (6) Defines Co-ordinate System Type
+(-) Exit type (Entrance Type)
1 Neither Starting nor stopping region
2 Starting Region
4 Stopping Region
6 Neither of above

For an entrance (exit) type coordination system, the positive z axis is nearly parallel (antiparallel) to the beam direction. The starting and stopping type regions have been defined to allow the possibility of examining the ray set inside a magnet (i.e. it is possible to stop integration in one MAPPOLE, and start again from this same point in the next MAPPOLE). These options are useful for placing constraints inside elements or for starting a system inside a magnet as is sometimes needed for a backwards scattering system.

The MAPDAT parameter list is given below. An opportunity to read in the MAPDAT data set occurs in each data set. If MOR=1 is included in data set, then a second MAPDAT read in initiated. An empty MAPDAT data set has no effect. Each map must have its parameters defined somewhere in the MAGPAR file, but not necessarily in the MAPPOLE element in which it is used. The MAPDAT parameters are:

ORG (2,12) (x, z) Co-ordinates of first point in MAP cm
DELTA (2,12) (DX, DZ) Grid size for map cm
NPTS (2,12) (NX, NZ) Number of steps in map
NFIL (12) Location of map on input files (corresponds to NMAP in MAPP)
JTYPE (12) 0(2) use no (use entrance) parameters
0(4) use no (use exit) parameters
0(6) use no (use both entrance and exit parameters)
Add 0(1) to both reading
(compute) map
‘MOR 0(1) No more (another) MAPDAT data set follows
(default =0)

The parameter, which define the field reconstruction calculation are defined in the FITMAT data set. Np to 5 (maximum) data sets may be defined. Each required set must appear somewhere in the MAGPAR file, not necessarily the same MAPPOLE element in which it is used. An empty FITMAT data set has no effect, MOR =1 in a data set causes the code to read an additional FITMAT data set. The FITMAT parameters:

NFIT (4) First 2 not used. Third and fourth are number NX (NZ) of nearest data points used in field reconstruction.

NDEG (2) First not used, second is NDEG, the maximum degree of polynomial used in field reconstruction.

NLIM (4) The first 2 are not used. The third and fourth are the maximum degree of x (z) terms in polynomial for field reconstruction.

RATIO92) The first not used. The second is the ratio of DZ to DX for the map grid. This ratio must agree with the ratio of DZ and DX defined in the MAPDAT parameters.

NF Field reconstruction parameter set index (5 max) used to identify parameter set. (Corresponds to NFITM in MAPP data set).

The NLIM parameters are useful if the map is expected to vary much more slowly with position in the x or z direction. The method of calculation is as follows: All terms up to NDEG are included in the fit except terms including x terms of degree higher than NDEGX or z terms of degree higher than NDEGZ. If this feature is not used, set NDEG =9, 9, 9, 9.

ELEMENTS

The following represents the complete lists of NAMELISTs together with their corresponding legal parameters. The …P, …F, and …D NAMELISTS represent the basic parameter set, the integer ties for optimization, and the integer classification for the type of bound, respectively. These 3 NAMELISTs must appear for each element and be in the following order: …P, …P, -…P, …F, …F, -…F; …D, …D, -…D. When a NAMELIST having the same identifier as the one preceeding it is present, the preceeding NAMELIST must have the parameter MOR set to one (1). Failure to set MOR equal to 1 will cause all previous identical NAMELIST name sets for the current element to be ignored. If any parameter of NAMELIST sets must also be given in the element specification.

Parameters unmentioned through the NAMELIST option are preset internally. In the first pass, default values are obtained from the compiled data statements. In successive passes, the new default parameters are assigned the values they possessed at the exit from the preceding pass.

Each element is distinct from all other elements. It is the user's responsibility to note if the ties and parameter values have physical sense. If more details of the parameter definitions are required than are available in this manual, it may be useful to consult the element subroutine source listing.

DIPOLE

LFI: Integration step size for the entrance fringe field region (cm)

DG: Differential step size used in determining the off mid-plane components of B using numerical differential methods (cm)

A: Distance from the input coordinate system A origin to the coordinate system B origin situated at the entrance edge EFB (effective field boundary) of the magnet element (cm).

B: Distance from the coordinate system C origin situated at the exit edge EFB of the magnet element to the output coordinate system D origin (cm).

D: Gap width between between the magnet pole faces (cm).

RB: Radius of curvature used in the geometrical construction of the magnet element layout (cm).

BF: Nominal value of the magnetic field along the central radius R (Webers/m^2).

PHI: Angular extent extent between the entrance EFB of system B and the exit EFB of system C. This parameter is nominally equivalent to the magnet bend angle (degrees).

ALPHA: Angle between the central ray trajectory and the normal to the entrance EFB at the system B origin (degrees).

BETA: Angle between the central ray trajectory and the normal to the exit EFB at the System C origin (degrees).

Note: Both ALPHA and BETA are considered positive for transferse plane focusing.

NDX: "n value" of field index for non-uniform filed magnets.

Aϕ1, Aϕ2, Aϕ3, Aϕ4, Aϕ5: Coefficients defining the non-uniform field expansion

$$B_o(\varepsilon) = B_0\left(1 + \sum_{n=\phi}^{5} A\phi n\, \varepsilon^n\right)$$

where

Aϕϕ = NDX,

ε= r/R-1,

r is the distance from the ray being traced to the layout center, and R is the layout radius.

RAP1: Inverse radius of curvature of the entrance boundary (cm^{-2})

Note: Convex surfaces are positive.

RAP2: Inverse radius of curvature of the exit boundary (cm^{-2}).

Z11: Start of the entrance fringing field region as measures in coordinate system B tired to the entrance EFB (cm).

Z12: Termination of the entrance fringing field region as measures in coordinate system B tired to the entrance EFB (cm).

Z21: Start of the exit fringing field region as measures in coordinate system C tired to the exit EFB (cm).

Note: Z11 and Z22 are normally positive; and Z1 and Z21, normally negative.

RW1: Pole width at the entrance to the magnet (cm).

RW2: Pole width at the exit to the magnet (cm).

BR1: Correction for the presence of a constant field in the region of the entrance fringe field, e.g., a field clamp (webers/m^2).

BR2: Correction for the presence of a constant field in the region of the exit fringe field, e.g., a field clamp (webers/m^2).

CAT1: Parameter describing the third-order curvature of the entrance boundary surface ($cm^{\pm 3}$).

CAT2: Parameter describing the third-order curvature of the exit boundary surface ($cm^{\pm 3}$).

XCR1: Translation of coordinate system B along the negative x-axis relative to coordinate System B (cm).

XCR2: Translation of coordinate system D along the positive x-axis relative to coordinate System C (cm).

Note: XCR1 and XCR2 represent misalignment in a magnet system.

CFV1: Parameter describing the fourth-order curvature of the entrance boundary surface (cm^{-4}).

CFV2: Parameter describing the fourth-order curvature of the exit boundary surface (cm^{-4}).

CNN1: Parameter describing the fifth-order curvature of the entrance boundary surface (cm^{-5}).

CNN2: Parameter describing the fifth-order curvature of the exit boundary surface (cm^{-5}).

Cϕ, C1, C2, C3, C4, C5: Coefficients used in the expansion of the fringing field fall-off at the entrance to the magnet element.

C6, C7, C8, C9, C10, C11: Coefficients used in the expansion of the fringing field fall-off at the exit to the magnet element.

Note: The expansion of the fringe field fall-off is defined in the midplane of the magnet to be

$$B_y(x,\phi,z) = B_o\, h(s)$$

where

$$h(s) = \frac{B_0}{1+e^{C(s)}},$$

$$C(s) = \sum_{n=0}^{5} c_n s^n ,$$

and S is the normalized distance along the normal to the EFB in gap widths.

ZOT1: Parameter describing the zeroth order curvature of the entrance boundary surface.

ZOT2: Parameter describing the zeroth order curvature of the exit boundary surface.

ROT1: Parameter describing the first order curvature of the entrance boundary surface (cm^{-1}).

ROT2: Parameter describing the first order curvature of the exit boundary surface (cm^{-1}).

XMAX, YMAX: Half aperture collimation limits set on a ray passing through the magnet. If either quantity is exceeded in absolute magnitude, a message is issued indicating that the aperture has been grazed. If the excess is greater than a factor of 1.3, a message is issued indicating that the ray is outside the aperture and the offending ray component is reset with proper sigh to the collimation limit and its corresponding velocity to zero.

MOR: $\phi(1)$ Do not read (Read) Additional parameters.

Undebugged Parameters:

The following additions have been made in order to simulate the starting or stopping of rays in a target located in a dipole. This option has never been tested.

FOCL

The element FOCL is used to represent a focal plane in the beam line. The parameters defined for FOCL are as follows:

THETA: Angle of rotation of the focal plane about the y axis (degrees).

RX: Radius of curvature of the focal plane about the y axis (cm).

RY: Radius of curvature of focal plane about the x axis (cm). (Not implemented).

XMAX: Half aperture of the local plane in the x direction (cm).

YMAX: Half aperture of the local plane in the y direction (cm).

MOR: $\phi(1)$ Do Not read (read) additional parameters.

The element FOCL allows for a rotation, THE TA, of the focal plane
t the y axis where the rotation is defined in a right-handed sense
that a zero degree rotation means that the focal plane is
endicular to the central ray. In addition, a cylindrical focal
e with radius of curvature, Rx, parallel to the y axis is allowed.
Sense of Rx is such that if Rx is greater than zero then the concave
of the focal surface faces the preceeding element.

Note that the aperture limits XMAX and YMAX are used only in
un on with the random ray generator in the determination of a ray

No changes are made to any rays passing outside the aperture.

The function of the Focl element is to drift each ray until it
rsects with the focal surface. The output from the subroutine FOCL
hen in the form of $(x, \theta, y, \phi, L, \delta)$ at the intersection of the ray
the focal surface.

At present, there is no way to perform the inverse of the Focl
ation, that is, to go from the coordinates expressed in the focal
ace system to the coordinates in the normal beam line system.
efore, FOCL must be the last element in a system if it is used. To

extent, it is possible to get around this restriction by using
ward transport from the end of the system to the focal surface, that
by using a negative value of TDRIFT in the element DRIFT.

SHROUT

The element SHROT is used to perform translations and rotations on the normal beam line coordinate system. The parameters defined for SHROT are as followed:

xϕ: Translation in the x direction (cm)
yϕ: Translation in the y direction (cm)
zϕ: Translation in the z direction (cm)
x: Rotation about the x axis (degrees)
z: Rotation about the z axis (degrees)
MOR: ϕ(1) Do not read (read) additional parameters.

Translations are made first in the following sense:

x	x-xϕ
y	y-yϕ
z	z-zϕ

After the translations are made, rotations are made in the following order:
1. Rotate x degrees about the x axis.
2. Rotate y degrees about the y axis.
3. Rotate z degrees about the z axis.

All rotations are in a positive, right-handed sense about the indicated axis.

SLIT

The element SLIT is used to simulate the truncation of the phase space of the beam which occurs due to an aperture in the beam line. In addition, this element can be used to make small random perturbations in rays passing through this element such as would occur due to energy loss or multiple scattering in a window, detector, or target. The parameters defined for SLIT are as follows:

XUL: Aperture upper limit in the +x direction (cm)
XLL: Aperture lower limit in the –x direction (cm)
YUL: Aperture upper limit in the +y direction (cm)
YLL: Aperture lower limit in the –y direction (cm)
RAD: Circular aperture radius (cm).
VXUL: Aperture upper limit for +θ angle (mrad)
VXLL: Aperture lower limit for –θ angle (mrad)
VYUL: Aperture upper limit for +ϕ angle (mrad)
VYLL: Aperture lower limit for –ϕ angle (mrad)
TUL: Aperture upper limit for +L path length (cm)
TLL: Aperture lower limit for –L path length (cm)
DUL: Aperture upper limit for +γ momentum (%)

DLL: Aperture lower limit for $-\gamma$ momentum (%)
AZTGT(I), I=1,5: Atomic number of 1th element.
AWTGT(I), I=1,5: Atomic weight of 1th element.
RHOTGT(I), I=1,5: Density of 1th element (gm/cm^3)
THKTGT(I), I=1,5: Total thickness of the 1th element (cm)
SLCTGT(I), I=1,5: Slice thickness of 1th element (cm)
DEPXTGT(I), I=1,5: Most probable straggling energy loss in the 1th element slice (MeV/cm).

Note that the parameter RAD provides collimation only when it has a nonzero value. Also note that the aperture limits are only used in conjunction with the random ray generator in the determination of a ray set. No changes are made to any ray passing outside of the aperture.

Up to five elements may be present which represent mediums through which all rays must sequentially pass. These contiguous mediums generate multiple scattering and straggling effects on each ray. These random perturbations are applied either one time only during the first ray trace, or each time a ray is traced according to whether parameter ITUNE of the MAGPAR input file is set at ϕ or 1.

Note that element SLIT is defined in such a way that none of its parameters may be treated as variable. Therefore, only the … P Namelist is read when a SLIT element is encountered. The namelists …F, …D, …L, and …U must not be defined.

NCΘMP = A number in the range 1-6 designating X, θ, Y, ϕ, 1, δ respectively. NCΘMP=5 permits introduction of a constant term (independent of ray data) into the demand definition

CΘTIE = An integer designating possible ties within demand grouping. Any number of LΘC, NCΘMP cards may be tied. A maximum of 40 coefficients may be defined in any given demand with a total of 400 such coefficients defined for all demands. (e.g., … x at loc 1 may be tied to δ at loc 0 to form an $(x|\delta)$ term in the demand). Integers used for cotie should be equal for components to be paired; unequal for components not to be paired; and form a monotone nondecreasing natural sequence (no integer skipped).

ISIDE = 00 Coefficient of demand subcomponent defined by present grouping of cotie cards is to be determined by program.

= 01 Coefficient defined by present grouping of COTIE cards is present and frozen; must appear at least once in each demand definition and appear on the card introducting (through COTIE) the terms corresponding to this coefficient.

CSTΘR = Value of present coefficient; must appear on same card as ISIDE=01.

JRANTIE – positive integer … Individual components which form terms in the demands may be tagged to receive normally distributed measurement error having mean zero and standard deviation SDEV. All components tagged with identical integers receive an identical measurements error independent to the demand grouping in which they reside. Each distinct ray receive NRAND(FSET12) distinct measurement errors. This increases the effective number of rays composing the demands to NR-NRAND rays. The distribution is redefined at the beginning of each optimization iteration cycle. A blank or zero indicates no error desired. The integers need not appear in any particular order. However, to promote efficient use of computer space all integers up to the maximum one should be defined. If the maximum integers up to the maximum one should be

defined. If the maximum integer times NRAND exceeds 100, NRAND will be reset to the largest integer such that max JRANTIE X NRAND ≤ 100.

SDEV = Standard deviation attached to measurement error; need to be defined only once for each integer JRANTIE defined.

4. (E20.7, I1, 9X, I3, 7X, E20.7)
WT, IΘRD, LΘCSEX, SEXTZRΘ
WT = positive number – relative weight for proceeding demand; not normalized
= 0. FSET14 complete; no more data
= negative number – sextupole strength demand being defined with weight equal to AB2(WT)

IΘRD = 2,3,4,5 RAP, CAT, CSVN, CNN terms to be treated as penalty demand. If previous I=-1 then ignore LΘCSEX, SEXTZRΘ and use all terms of given order from all dipoles as a group. If previous I=-2 use only the order term tagged by LΘCSEX.

LΘCSEX = FLΘC integer; If integer is negative then pickup order component from entrance fringe field; if positive use component from exit frienge field.

SEXTZERΘ = NUMBER penalty demand is to be defined as a deviation from the value set in SEXTZERΘ.

Successive passes defining new demand definitions may now be set up beginning with card 1 of this file set. It is important to note that each new pass requires a new collection of both FSER12 and FSET14 cards. If KREAD was not specified or was set equal to 0 in FSET8, a new SOPTP card must be given as well.

ELEMENTS

The following represents the complete list of namelists together with their corresponding legal parameters. Namelists …P, …F, and …D represent the basic parameter set, the integer ties for optimization, and the integer classification for type of bound respectively. These three namelists must appear for each element and be in the order …P, …P, -…P; …F, …F, - …F; …D, …D, - …D. When a namelist having the same

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