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FORTRAN Code Additions for Inclusion of Special Functions in MAD

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For pure-periodic accelerator lattice, MAD provides a very convenient description due to the feature of line multiplication. For example, consider the AGS Booster which has six superperiods: If one of them is described as

SUPER: LINE = (L1, L2, ..., Ln),

then the whole machine is given by

BOOSTER: LINE = (6 * SUPER).

However, if the machine is not purely periodic, then some of the periods would have to be described individually.

When the differences in the periods can be described in terms of mathematical functions which can be written or accessed in Fortran (or some other machine language), relative simplicity in lattice description can be retained; it is not necessary to go to an enumeration of each and every element in the MAD input file. This can be achieved by producing the necessary machine element definitions as a Fortran output file which looks like lines of MAD definitions and then using this file later to be part of the MAD input definition.

Let us consider the Booster, where each bending magnet has two sextupoles with random strengths. Thus, we have 72 end-sextupoles (with random strengths) in the full lattice. A description of the machine may then be separated into two parts: (1) a description of the 72 sextupoles and (2) a description of the rest of the machine.

Appendix I gives an example of a CDC program whch produces this two-part description. The first part, a (Fortran) program MADINP, generates the set of 72 sextupole definitions which are written in MAD-input format on the output file "Tapell". The strengths for the 72 sextupoles can be evaluated by any desired Fortran program, e.g., a randomly distributed Gaussian, etc. In the second part, the regular MAD input sequence contains the description of the remainder of the machine together with the MAD instruction.

CALL, 11 brings in the previously defined sextupole descriptions from the file "Tapell". The program then operates on a lattice whose complete description is provided by both parts.

An illustration of output for this combined Fortran-MAD description is given in Appendix II.

```
NAME,STMFZ,T176,P1.      **********  APPENDIX I  **********
ACCOUNT,NAME,Acc#,Acc#.
REQUEST,TAPE11,*PF.
ATTACH(NAG1,NAGSCLIB1)
ATTACH(NAG2,NAGSCLIB2)
ATTACH,BNLX.
LIBRARY(NAG1,NAG2,BNLX)
FTN(ROUND,OPT=2)
MAP(OFF)
LGO.
ATTACH,MADTRK,ID=EHA.
ATTACH,LIB1,MADLIB,ID=EHA.
LIBRARY,LIB1.
MADTRK.
%%EOR
      PROGRAM MADINP (TAPE11,OUTPUT)
C
C       THIS PROGRAM WRITES INTO TAPE 11 EACH OF 72 SEXTUPOLE ELEMENT
C       DEFINITIONS AFTER SEXT. STRENGTHS ARE CALCULATED AS RANDOM
C       NUMBERS WITH GAUSSIAN DISTRIBUTION (MEAN=0, SIGMA=0.5)
C
      REAL G05DDF
      REAL Z
      WRITE(11,90)
C         CALL SEED SUBROUTINE
      CALL G05CBF(0)
      DO 50 K=1,72
C         CALL RANDOM NUMBER GENERATOR
  20  Z=G05DDF(0.0,0.5)
C           CHECK FOR THE RULE OF 3*SIGMA=1.5
      IF (ABS(Z) .GT. 1.5) GOTO 20
      WRITE(11,92) K,Z
  50  CONTINUE
      STOP
  90  FORMAT("TITLE!"/ "BOOSTER RANDOM SEXTUPOLES")
  92  FORMAT(" SEXTUPOLE,S",I2.2,",L=.01,K2=",F10.8)
      END
%%EOR
CALL,11
TITLE!
 * BOOSTER,
!
!
!
!        DIPOLES, QUADS AND CHROMATIC SEXTUPOLES:
!
SBEND,BND,L=2.4,ANGLE=.1745329
!
QUADRUPOLE,QF,L=.5,K1=-.554034
QUADRUPOLE,QD,L=.25,K1=.590959
!
SEXTUPOLE,SF,L=.10,K2=-5.60249
SEXTUPOLE,SD,L=.10,K2=5.10859
!
DRIFT,DR30,L=.30
DRIFT,DR29,L=.29
DRIFT,DR59,L=.59
DRIFT,DR99,L=.99
DRIFT,DR40,L=.40
DRIFT,DR370,L=3.7
```

```
!              LINES:
!
LINE,P1=(QD,DR29)
LINE,P2=(DR59,SF,DR30,QF,DR29)
LINE,P3=(DR59,SD,DR30,2*QD,DR370,QF,DR29)
LINE,P4=(DR59,SD,DR30,2*QD,DR29)
LINE,P5=(DR99,QF,DR370,2*QD,DR29)
LINE,P6=(DR99,QD)
!
LINE, SL(A,B)=(A,BND,B)
!
!        PERIODS AND MACHINE
!
LINE, SUPER(X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,X11,X12) = &
      (P1,SL(X1,X2),P2,SL(X3,X4),P3,SL(X5,X6),P4,SL(X7,X8),P5, &
       SL(X9,X10),P2,SL(X11,X12),P6)
!
!
LINE, BOOSTER=(SUPER(S01,S02,S03,S04,S05,S06,S07,S08,S09,S10,S11,S12), &
      SUPER(S13,S14,S15,S16,S17,S18,S19,S20,S21,S22,S23,S24), &
      SUPER(S25,S26,S27,S28,S29,S30,S31,S32,S33,S34,S35,S36), &
       SUPER(S37,S38,S39,S40,S41,S42,S43,S44,S45,S46,S47,S48), &
       SUPER(S49,S50,S51,S52,S53,S54,S55,S56,S57,S58,S59,S60), &
       SUPER(S61,S62,S63,S64,S65,S66,S67,S68,S69,S70,S71,S72)  )
!
!
!       TRACKING SECTION
!
USE,BOOSTER
TRACK,PARTICLE=PROTON,ENERGY=1.138
START, X= .025, Z=0, S=0,  PX=0, PZ=0, DE=0
START, X=-.025, Z=0, S=0,  PX=0, PZ=0, DE=0
START, X=0.000, Z=0.03, S=0, PX=0, PZ=0,DE=0
!
!
START, X=0.025, Z=0.0, S=0,  PX=0, PZ=0, DE=0.00064
START, X=-.025, Z=0.0, S=0,  PX=0, PZ=0, DE=0.00064
START, X=0.00, Z=0.03, S=0,  PX=0, PZ=0, DE=0.00064
!
START, X=0.025, Z=0.0, S=0,  PX=0, PZ=0, DE=-0.00064
START, X=-.025, Z=0.0, S=0,  PX=0, PZ=0, DE=-0.00064
START, X=0.00, Z=0.03, S=0,  PX=0, PZ=0, DE=-0.00064
RUN, TURNS=300, FPRINT=5,  MODE=SYNCHRO
ENDTRACK
!
PARAMETER,SF[K2]=0.0
PARAMETER,SD[K2]=0.0
!
!
!
TRACK,PARTICLE=PROTON,ENERGY=1.138
START, X= .025, Z=0, S=0,  PX=0, PZ=0, DE=0
START, X=-.025, Z=0, S=0,  PX=0, PZ=0, DE=0
START, X=0.000, Z=0.03, S=0, PX=0, PZ=0,DE=0
!
!
START, X=0.025, Z=0.0, S=0,  PX=0, PZ=0, DE=.00064
START, X=-.025, Z=0.0, S=0,  PX=0, PZ=0, DE=.00064
START, X=0.00, Z=0.03, S=0,  PX=0, PZ=0, DE=.00064
```

```
START, X=0.025, Z=0.0, S=0,  PX=0, PZ=0, DE=-.00064
START, X=-.025, Z=0.0, S=0,  PX=0, PZ=0, DE=-.00064
START, X=0.00, Z=0.03, S=0,  PX=0, PZ=0, DE=-.00064
RUN, TURNS=300, FPRINT=5,  MODE=SYNCHRO
ENDTRACK
|
STOP
|
%%EOR
%%EOF
```

```
      PROGRAM MADINP (TAPE11,OUTPUT)
C
C       THIS PROGRAM WRITES INTO TAPE 11 EACH OF 72 SEXTUPOLE ELEMENT
C       DEFINITIONS AFTER SEXT. STRENGTHS ARE CALCULATED AS RANDOM
C       NUMBERS WITH GAUSSIAN DISTRIBUTION (MEAN=0, SIGMA=0.5)
C
      REAL G05DDF
      REAL Z
      WRITE(11,90)
C         CALL SEED SUBROUTINE
      CALL G05CBF(0)
      DO 50 K=1,72
C         CALL RANDOM NUMBER GENERATOR
   20 Z=G05DDF(0.0,0.5)
C           CHECK FOR THE RULE OF 3*SIGMA=1.5
      IF (ABS(Z) .GT. 1.5) GOTO 20
      WRITE(11,92) K,Z
   50 CONTINUE
      STOP
   90 FORMAT("TITLE!"/ "BOOSTER RANDOM SEXTUPOLES")
   92 FORMAT(" SEXTUPOLE,S",I2.2,",L=.01,K2=",F10.8)
      END
```

```
CALL,11

... READING LOGICAL UNIT NUMBER 11

TITLE!
BOOSTER RANDOM SEXTUPOLES
 SEXTUPOLE,S01,L=.01,K2= .26815150
```

```
SEXTUPOLE,S02,L=.01,K2= .84841882
SEXTUPOLE,S03,L=.01,K2= .79001896
SEXTUPOLE,S04,L=.01,K2=-.01327741
SEXTUPOLE,S05,L=.01,K2= .75835111
SEXTUPOLE,S06,L=.01,K2=-.21552251
SEXTUPOLE,S07,L=.01,K2=-.38512580
SEXTUPOLE,S08,L=.01,K2= .11723182
SEXTUPOLE,S09,L=.01,K2= .10217494
SEXTUPOLE,S10,L=.01,K2=-.72525848
SEXTUPOLE,S11,L=.01,K2= .02999574
SEXTUPOLE,S12,L=.01,K2= .77338946
SEXTUPOLE,S13,L=.01,K2=1.37537151
SEXTUPOLE,S14,L=.01,K2= .30314707
SEXTUPOLE,S15,L=.01,K2=-.29468836
SEXTUPOLE,S16,L=.01,K2=-.07936180
SEXTUPOLE,S17,L=.01,K2= .69791837
SEXTUPOLE,S18,L=.01,K2=-.43058779
SEXTUPOLE,S19,L=.01,K2= .20387384
SEXTUPOLE,S20,L=.01,K2= .16482684
SEXTUPOLE,S21,L=.01,K2= .04465487
SEXTUPOLE,S22,L=.01,K2=-.57972974
SEXTUPOLE,S23,L=.01,K2= .53289603
SEXTUPOLE,S24,L=.01,K2= .31352783
SEXTUPOLE,S25,L=.01,K2=-.16475909
SEXTUPOLE,S26,L=.01,K2=1.08157838
SEXTUPOLE,S27,L=.01,K2= .19049634
SEXTUPOLE,S28,L=.01,K2= .20850194
SEXTUPOLE,S29,L=.01,K2= .24068340
SEXTUPOLE,S30,L=.01,K2= .13841114
SEXTUPOLE,S31,L=.01,K2= .17414591
SEXTUPOLE,S32,L=.01,K2= .76470717
SEXTUPOLE,S33,L=.01,K2= .17242488
SEXTUPOLE,S34,L=.01,K2=-.47699144
SEXTUPOLE,S35,L=.01,K2= .01524153
SEXTUPOLE,S36,L=.01,K2= .79970981
SEXTUPOLE,S37,L=.01,K2=-.62777513
SEXTUPOLE,S38,L=.01,K2=-.61049466
SEXTUPOLE,S39,L=.01,K2= .09185146
SEXTUPOLE,S40,L=.01,K2=-.77409697
SEXTUPOLE,S41,L=.01,K2= .25334724
SEXTUPOLE,S42,L=.01,K2= .17851318
SEXTUPOLE,S43,L=.01,K2= .06885764
SEXTUPOLE,S44,L=.01,K2=-.77904951
SEXTUPOLE,S45,L=.01,K2=-.04736759
SEXTUPOLE,S46,L=.01,K2=-.66891014
SEXTUPOLE,S47,L=.01,K2=-.07114592
SEXTUPOLE,S48,L=.01,K2=-.45242919
SEXTUPOLE,S49,L=.01,K2=-.18299022
SEXTUPOLE,S50,L=.01,K2= .69621176
SEXTUPOLE,S51,L=.01,K2= .23569769
SEXTUPOLE,S52,L=.01,K2=-.28320422
SEXTUPOLE,S53,L=.01,K2= .46958441
SEXTUPOLE,S54,L=.01,K2=-.86768501
SEXTUPOLE,S55,L=.01,K2= .54240583
SEXTUPOLE,S56,L=.01,K2=-.47645909
SEXTUPOLE,S57,L=.01,K2=-.27468882
SEXTUPOLE,S58,L=.01,K2=1.32968569
SEXTUPOLE,S59,L=.01,K2= .03429897
SEXTUPOLE,S60,L=.01,K2=-.22696696
SEXTUPOLE,S61,L=.01,K2=-.58914480
```

```
        SEXTUPOLE,S64,L=.01,K2= .07698321
        SEXTUPOLE,S65,L=.01,K2=-.71879778
        SEXTUPOLE,S66,L=.01,K2=-.59758812
 70     SEXTUPOLE,S67,L=.01,K2=-.50851717
        SEXTUPOLE,S68,L=.01,K2=-.35915669
        SEXTUPOLE,S69,L=.01,K2= .39290994
        SEXTUPOLE,S70,L=.01,K2=-.35093736
        SEXTUPOLE,S71,L=.01,K2= .32627242
 75     SEXTUPOLE,S72,L=.01,K2= .37872534
.. READING STANDARD INPUT FILE
        TITLE!
         * BOOSTER,
        !
 80     !
        !
        !        DIPOLES, QUADS AND CHROMATIC SEXTUPOLES:
        !
        SBEND,BND,L=2.4,ANGLE=.1745329
 85     !
        QUADRUPOLE,QF,L=.5,K1=-.554034
        QUADRUPOLE,QD,L=.25,K1=.590959
        !
        SEXTUPOLE,SF,L=.10,K2=-5.60249
 90     SEXTUPOLE,SD,L=.10,K2=5.10859
        !
        DRIFT,DR30,L=.30
        DRIFT,DR29,L=.29
        DRIFT,DR59,L=.59
 95     DRIFT,DR99,L=.99
        DRIFT,DR40,L=.40
        DRIFT,DR370,L=3.7
        !
        !              LINES:
100     !
        LINE,P1=(QD,DR29)
        LINE,P2=(DR59,SF,DR30,QF,DR29)
        LINE,P3=(DR59,SD,DR30,2*QD,DR370,QF,DR29)
        LINE,P4=(DR59,SD,DR30,2*QD,DR29)
105     LINE,P5=(DR99,QF,DR370,2*QD,DR29)
        LINE,P6=(DR99,QD)
        !
        LINE, SL(A,B)=(A,BND,B)
        !
110     !        PERIODS AND MACHINE
        !
        LINE, SUPER(X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,X11,X12) = &
              (P1,SL(X1,X2),P2,SL(X3,X4),P3,SL(X5,X6),P4,SL(X7,X8),P5, &
               SL(X9,X10),P2,SL(X11,X12),P6)
115     !
        !
        LINE, BOOSTER=(SUPER(S01,S02,S03,S04,S05,S06,S07,S08,S09,S10,S11,S12), &
              SUPER(S13,S14,S15,S16,S17,S18,S19,S20,S21,S22,S23,S24), &
              SUPER(S25,S26,S27,S28,S29,S30,S31,S32,S33,S34,S35,S36), &
120            SUPER(S37,S38,S39,S40,S41,S42,S43,S44,S45,S46,S47,S48), &
               SUPER(S49,S50,S51,S52,S53,S54,S55,S56,S57,S58,S59,S60), &
               SUPER(S61,S62,S63,S64,S65,S66,S67,S68,S69,S70,S71,S72)  )
```

```
        !
        !
125     !%%EOR
        !       TRACKING SECTION
        !
        USE,BOOSTER

.. BEAM LINE "BOOSTER" EXPANDED:       312 ELEMENTS,       482 POSITIONS
.. END OF "USE" COMMAND, ELAPSED CPU TIME =   2.413 SECONDS

        TRACK,PARTICLE=PROTON,ENERGY=1.138

.. ENTER TRACKING MODULE, ELAPSED CPU TIME =   2.531 SECONDS

130     START, X= .025, Z=0, S=0,  PX=0, PZ=0, DE=0
        START, X=-.025, Z=0, S=0,  PX=0, PZ=0, DE=0
        START, X*0.000, Z*0.03, S*0, PX*0, PZ*0,DE*0
        !
        !
135     START, X=0.025, Z=0.0, S=0,  PX=0, PZ=0, DE=0.00064
        START, X=-.025, Z=0.0, S=0,  PX=0, PZ=0, DE=0.00064
        START, X=0.00, Z=0.03, S=0,  PX=0, PZ=0, DE=0.00064
        !
        START, X=0.025, Z=0.0, S=0,  PX=0, PZ=0, DE=-0.00064
140     START, X=-.025, Z=0.0, S=0,  PX=0, PZ=0, DE=-0.00064
        START, X=0.00, Z=0.03, S=0,  PX=0, PZ=0, DE=-0.00064
        RUN, TURNS=300, FPRINT=5,  MODE=SYNCHRO
```

INITIAL PARTICLE POSITIONS
NORMALIZED TO EX = 1.00000000E+00 EZ = 1.00000000E+00 ES = 1.00000000E+00

NUMBER		Q	P	QN	PN	W	PHI
1	X	2.50000000E-02	.00000000E+00	.01291623	.00010209	.00016684	.00125793
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	.00000000E+00	.00000000E+00				
2	X	-2.50000000E-02	.00000000E+00	-.01291623	-.00010209	.00016684	-.49874207
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	.00000000E+00	.00000000E+00				
3	X	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	Z	3.00000000E-02	.00000000E+00	.00820490	.00000000	.00006732	.00000000
	S	.00000000E+00	.00000000E+00				
4	X	2.50000000E-02	.00000000E+00	.01291623	.00010209	.00016684	.00125793
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	.00000000E+00	6.40000000E-04				
5	X	-2.50000000E-02	.00000000E+00	-.01291623	-.00010209	.00016684	-.49874207
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	.00000000E+00	6.40000000E-04				
6	X	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	Z	3.00000000E-02	.00000000E+00	.00820490	.00000000	.00006732	.00000000
	S	.00000000E+00	6.40000000E-04				
7	X	2.50000000E-02	.00000000E+00	.01291623	.00010209	.00016684	.00125793
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	.00000000E+00	-6.40000000E-04				
8	X	-2.50000000E-02	.00000000E+00	-.01291623	-.00010209	.00016684	-.49874207
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	.00000000E+00	-6.40000000E-04				
9	X	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	Z	3.00000000E-02	.00000000E+00	.00820490	.00000000	.00006732	.00000000
	S	.00000000E+00	-6.40000000E-04				

PARTICLE POSITIONS AT "# E" DURING TURN 5

NUMBER		Q	P	QN	PN	W	PHI
1	X	-1.86852505E-02	-4.03457691E-03	-.00965372	-.00788543	.00015537	-.39099191
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	-3.34901807E-03	.00000000E+00				
2	X	2.13423492E-02	3.66770164E-03	.01102651	.00718617	.00017322	.09192503
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	3.07763013E-03	.00000000E+00				
3	X	-2.60792840E-04	2.72930532E-04	-.00013474	.00052721	.00000030	.28982294
	Z	2.99438545E-02	-2.52046378E-05	.00818954	-.00009216	.00006708	-.00179090
	S	4.25440833E-04	.00000000E+00				
4	X	-1.77652269E-02	-4.04959454E-03	-.00917839	-.00791074	.00014682	-.38678434
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	-3.26525212E-02	6.40000000E-04				
5	X	2.24115729E-02	3.62974731E-03	.01157892	.00711708	.00018472	.08771472
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	-2.60942268E-02	6.40000000E-04				
6	X	4.45412351E-04	3.53062243E-04	.00023012	.00068519	.00000052	.19843131
	Z	2.98139777E-02	-2.73736858E-05	.00815402	-.00010009	.00006650	-.00195347
	S	-2.90247935E-02	6.40000000E-04				
7	X	-1.96290376E-02	-4.00749193E-03	-.01014132	-.00783686	.00016426	-.39529006
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	2.58445178E-02	-6.40000000E-04				
8	X	2.03121497E-02	3.68954748E-03	.01049425	.00722425	.00016232	.09595428
	Z	.00000000E+00	.00000000E+00	.00000000	.00000000	.00000000	.00000000
	S	3.21514759E-02	-6.40000000E-04				