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ACCELERATOR DEVELOPMENT DEPARTMENT

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Accelerator Physics Technical Note No. 8

"ACCELERATOR PHYSICS CODE COMPARISON"

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ABSTRACT

We present a comparison between results obtained from accelerator physics codes used in the design and analysis of accelerators.

I. INTRODUCTION

Comparison of accelerator codes have been the topic of investigation and speculation by many (for sample notes on code comparisons see past issues of the Proceedings of Accelerator conferences). There are several beam optics programs that have been considered as standard codes for design and analysis of accelerators. For example, we have used programs SYNCH (as standard) and MAD for the design and analysis of the AGS - Booster and the proposed Super Conducting Super Collider (SSC).

In Section II, we Tabulate the parameters obtained from the recent Vax - Version of SYNCH* (Table I) for comparison with those obtained from program MAD - Versions 6.01 (Table II) and 4.03 (Table III) for the same sample (AGS - Booster) lattice. Comparison of the parameters in Tables I-III (e.g. items 6) shows a good agreement between the values of the tune shifts (Qx, QZ), lattice functions etc. for DELTA(P)/P = 0 but somewhat differs for DELTA(P)/P $\neq$ 0. The difference become larger when the sextupoles (e.g. Eddy Current) are included in the input lattices since they are handled differently by these programs.

Table II, was obtained using the recent Vax Version of SYNCH* which includes the correction to the chromaticity calculation that was not included (and was inaccurate) in the CDC and previous VAX versions of SYNCH. The effect of the chromaticity calculation correction is two fold:

1) In finding the closed orbit for off momentum, CDC - Version produces the wrong bending angles except for zero - gradient rectangular magnet.

2) In computing chromaticity for bending magnets with nonzero exit and entrance angle one term in the chromaticity formula had the wrong sign, resulting in the wrong sextupole strength correction.

Thus, we recommend the use of the parameters obtained from the corrected Version of SYNCH for the design, analysis or code comparison, since the data produced from the CDC Version of SYNCH is inaccurate.

In conclusion, the parameters obtained from several beam optics programs agree for DELTA(P)/P = 0, but there still are differences in the results obtained from programs SYNCH [1] and MAD [2] for DELTA(P)/P $\neq$ 0.

Acknowledgement

We thank Dr. E. Courant for the information on SYNCH and note that, this code comparison was made at his recommendation for the presentation at the Oct. 15, 1987 A.P. meeting.

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* available in BNLDAG::DUA0:[PARSA1.SYNCH]SYNSEP.EXE

[1]. A. A. Garren, principal author.

[2]. F. C. Iselin, principal author.

TABLE I

SYNCH VAX - Version 987

SYNCH RUN BST AGS-BOOSTER 14-OCT-87 15:40:17

1. DELTA(P)/P = -0.0100 :

```
CIRCUMFERENCE =    201.6976 M        QX =    4.87006      QY =    4.88460
                                     QX'=   -5.03758      QY'=   -5.60968
                                       THETX =   6.28318530 RAD
      RADIUS =     32.1012 M           THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0393852              GAMMA(TR)=(   5.03887,    0.00000)
 MAXIMA     --- BETX(   21) =    13.84289    BETY(   18) =    13.65464
 DX(   35) =     3.00980     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =     3.50410    BETY(   47) =     3.63202
 DX(    1) =     0.44193     DY(   52) =     0.00000
 MAXIMA      XCO(    1)= -4.89001     YCO(   52)=   0.00000
 MINIMA      XCO(   35)= -29.66112     YCO(   52)=   0.00000
```

2. DELTA(P)/P = -0.00800 :

```
CIRCUMFERENCE =    201.7137 M   QX =    4.85992      QY =    4.87337
                                QX' =   -5.01543      QY' =   -5.54011
                                THETX =   6.28318530 RAD
 RADIUS =     32.1037 M          THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0399131              GAMMA(TR)=(   5.00544,    0.00000)
 MAXIMA     --- BETX(   21) =    13.84715    BETY(   18) =    13.65237
 DX(   35) =     2.99672     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =     3.51844    BETY(   47) =     3.64632
 DX(   52) =     0.46227     DY(   52) =     0.00000
 MAXIMA      XCO(   52)= -3.99552     YCO(   52)=   0.00000
 MINIMA      XCO(   35)= -23.70182     YCO(   52)=   0.00000
```

3. DELTA(P)/P = -0.00600 :

```
CIRCUMFERENCE =    201.7300 M        QX =    4.84985      QY =    4.86229
                                     QX' =   -4.99358      QY' =   -5.47090
                                     THETX =   6.28318530 RAD
      RADIUS =     32.1063 M          THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0404352              GAMMA(TR)=(   4.97302,    0.00000)
 MAXIMA     --- BETX(   21) =    13.85156    BETY(   18) =    13.65018
 DX(   35) =     2.98438     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =     3.53273    BETY(   47) =     3.66060
 DX(   52) =     0.48223     DY(   52) =     0.00000
 MAXIMA      XCO(   52)= -3.05855     YCO(   52)=   0.00000
 MINIMA      XCO(   35)= -17.75746     YCO(   52)=   0.00000
```

---

4. DELTA(P)/P = -0.00400:

```
CIRCUMFERENCE =     201.7465 M     QX =     4.83984   QY =     4.85137
                                   QX' =   -4.97202  QY'=   -5.40198
                                   THETX =   6.28318530 RAD
  RADIUS =     32.1089 M           THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0409518         GAMMA(TR)=(   4.94155,   0.00000)
 MAXIMA     --- BETX(   21) =     13.85613    BETY(   18) =    13.64807
 DX(   35) =     2.97275     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =      3.54698    BETY(   47) =     3.67487
 DX(   52) =     0.50183     DY(   52) =     0.00000
 MAXIMA      XCO(   52)= -2.07984     YCO(   52)=   0.00000
 MINIMA      XCO(   35)= -11.82661    YCO(   52)=   0.00000
```

---

5. DELTA(P)/P = -0.00200

```
CIRCUMFERENCE =     201.7632 M       QX =     4.82989   QY =     4.84061
                                     THETX =   6.28318530 RAD
       RADIUS =     32.1116 M        THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0414633               GAMMA(TR)=(   4.91098,   0.00000)
 MAXIMA     --- BETX(   21) =     13.86084    BETY(   18) =    13.64603
 DX(   35) =     2.96178     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =      3.56119    BETY(   47) =     3.68911
 DX(   52) =     0.52109     DY(   52) =     0.00000
 MAXIMA      XCO(   52)= -1.06010     YCO(   52)=   0.00000
 MINIMA      XCO(   35)= -5.90789     YCO(   52)=   0.00000
```

---

6. DELTA(P)/P = 0.0000

```
CIRCUMFERENCE =     201.7800 M       QX =     4.82000   QY =     4.83000
                                     QX' =   -4.92970  QY' =   -5.26488
                                     THETX =   6.28318530 RAD
     RADIUS =     32.1143 M           THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0419701               GAMMA(TR)=(   4.88124,   0.00000)
 MAXIMA     --- BETX(   21) =     13.86571    BETY(   52) =    13.64403
 DX(   35) =     2.95145     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =      3.57537    BETY(   35) =     3.70334
 DX(    1) =     0.54003     DY(   52) =     0.00000
 MAXIMA      XCO(   52)=   0.00000     YCO(   52)=   0.00000
 MINIMA      XCO(   35)=   0.00000     YCO(   52)=   0.00000
```

---

7. DELTA(P)/P = 0.00200

```
 CIRCUMFERENCE =     201.7970 M      QX =     4.81017    QY =     4.81955
                                     QX' =   -4.90893   QY' =   -5.19663
                                     THETX =   6.28318530 RAD
    RADIUS =     32.1170 M           THETY =   0.00000000 RAD
 (DS/S)/(DP/P)=  0.0424725           GAMMA(TR)=(   4.85229,   0.00000)
 MAXIMA     --- BETX(   21) =     13.87071    BETY(   52) =    13.65707
 DX(   35) =     2.94173     DY(   52) =     0.00000
```

```
MINIMA     --- BETX(   18) =     3.58950    BETY(   21) =     3.71581
DX(   52) =     0.55866     DY(   52) =     0.00000
MAXIMA      XCO(   35)=   5.89831     YCO(   52)=   0.00000
MINIMA      XCO(   52)=   1.09981     YCO(   52)=   0.00000
```

---

8. DELTA(P)/P = 0.00400

```
CIRCUMFERENCE =    201.8142 M     QX =    4.80040     QY =    4.80925
                                  QX' =   -4.88841    QY' = -5.12853
                                        THETX =   6.28318530 RAD
        RADIUS =    32.1197 M           THETY =   0.00000000 RAD
 (DS/S)/(DP/P)= 0.0429707              GAMMA(TR)=(   4.82407,   0.00000)
MAXIMA     --- BETX(   21) =    13.87587    BETY(   52) =    13.67025
DX(   35) =     2.93261     DY(   52) =     0.00000
MINIMA     --- BETX(   18) =     3.60361    BETY(   21) =     3.72813
DX(   52) =     0.57700     DY(   52) =     0.00000
MAXIMA      XCO(   35)=  11.78824     YCO(   52)=   0.00000
MINIMA      XCO(   52)=   2.23873     YCO(   52)=   0.00000
```

---

9. DELTA(P)/P = 0.00600

```
CIRCUMFERENCE =    201.8316 M       QX =    4.79069    QY =    4.79911
                                    QX' =   -4.86812   QY' =   -5.06055
                                    THETX =   6.28318530 RAD
     RADIUS =    32.1225 M          THETY =   0.00000000 RAD
 (DS/S)/(DP/P)= 0.0434650              GAMMA(TR)=(   4.79656,   0.00000)
MAXIMA     --- BETX(   21) =    13.88116    BETY(   52) =    13.68358
DX(   35) =     2.92405     DY(   52) =     0.00000
MINIMA     --- BETX(   18) =     3.61768    BETY(   21) =     3.74028
DX(   52) =     0.59506     DY(   52) =     0.00000
MAXIMA      XCO(   35)=  17.67094     YCO(   52)=   0.00000
MINIMA      XCO(   52)=   3.41617     YCO(   52)=   0.00000
```

---

10. DELTA(P)/P = 0.00800

```
CIRCUMFERENCE =    201.8492 M     QX =    4.78104     QY =    4.78913
                                  QX' =   -4.84806    QY' =   -4.99265
                                  THETX =   6.28318530 RAD
    RADIUS=    32.1253 M          THETY =   0.00000000 RAD
 (DS/S)/(DP/P)= 0.0439557          GAMMA(TR)=(   4.76971,   0.00000)
MAXIMA     --- BETX(   21) =    13.88659    BETY(   52) =    13.69704
DX(   35) =     2.91603     DY(   52) =     0.00000
MINIMA     --- BETX(   18) =     3.63171    BETY(   21) =     3.75227
DX(   52) =     0.61285     DY(   52) =     0.00000
MAXIMA      XCO(   35)=  23.54750     YCO(   52)=   0.00000
MINIMA      XCO(   52)=   4.63157     YCO(   52)=   0.00000
```

```
11.  DELTA(P)/P  = 0.01000
-------------------------
CIRCUMFERENCE =     201.8669 M       QX =     4.77144   QY =     4.77930
                                     QX' =   -4.82823   QY' =   -4.92482
                                          THETX =    6.28318530 RAD
        RADIUS =     32.1281 M           THETY =    0.00000000 RAD
 (DS/S)/(DP/P)=  0.0444431                GAMMA(TR)=(   4.74349,    0.00000)
 MAXIMA     --- BETX(   21) =     13.89216    BETY(   52) =     13.71064
 DX(   35) =     2.90853     DY(   52) =     0.00000
 MINIMA     --- BETX(   18) =      3.64572    BETY(   21) =      3.76410
 DX(   52) =     0.63039     DY(   52) =     0.00000
 MAXIMA      XCO(   35)=  29.41897     YCO(   52)=   0.00000
 MINIMA      XCO(   52)=   5.88440     YCO(   52)=   0.00000

END OF SYNCH RUN  BST
```

TABLE II

"MAD" VERSION 6.01/03:

MAD6.01 OUTPUT FOR THE BOOSTER LATTICE WITHOUT SEXTUPOLES [SF, SD, SV=0]

1. For DELTA(P)/P = -0.01:

```
TOTAL LENGTH =  201.780000      QX =  4.869524   QY =  4.882689
                                QX'= -4.974135   QY'= -5.314419
 ALFA  = 0.397978E-01   BETAX(MAX)= 13.981287  BETAY(MAX) =  13.795012
 GAMMA(TR)  =  5.012688  DX(MAX)  =  3.039104     DY(MAX) =   0.000000
                       XCO(MAX)   = 29.938897  YCO(MAX)   =   0.000000
                       XCO(R.M.S.)= 16.640292  YCO(R.M.S.)=   0.000000
```

2. FOR DELTA(P)/P = -0.008000:

```
TOTAL LENGTH =  201.780000      QX = 4.859582   QY =  4.872144
                                QX'=-4.965049   QY'= -5.304147
ALFA     = 0.402414E-01  BETAX(MAX) =13.957912  BETAY(MAX) =  13.764037
GAMMA(TR)  =  4.984983     DX(MAX) = 3.020217  DY(MAX)     =   0.000000
                        XCO(MAX)   =23.879696  YCO(MAX)    =   0.000000
                       XCO(R.M.S.) =13.311186  YCO(R.M.S.)=    0.000000
```

3. FOR DELTA(P)/P = -0.006000:

```
TOTAL LENGTH  =  201.780000     QX  = 4.849659    QY  = 4.861603
                                QX' = -4.956066   QY' = -5.294075
ALFA      = 0.406801E-01  BETAX(MAX) = 13.934668  BETAY(MAX) = 13.733463
GAMMA(TR)= 4.958030          DX(MAX) =  3.002033     DY(MAX) =  0.000000
                          XCO(MAX)   = 17.857561    YCO(MAX) =  0.000000
                         XCO(R.M.S.) =  9.983220  YCO(R.M.S.)=  0.000000
```

4. FOR DELTA(P)/P = -0.004000:

```
TOTAL LENGTH = 201.780000       QX   =  4.839755    QY =   4.851065
                                QX'  = -4.947183    QY'=  -5.284184
 ALFA     =  0.411142E-01  BETAX(MAX) = 13.911553  BETAY(MAX) = 13.703278
 GAMMA(TR) =4.931783          DX(MAX) =  2.984527     DY(MAX) =  0.000000
                            XCO(MAX)  = 11.871112    YCO(MAX) =  0.000000
                         XCO(R.M.S.)  =  6.655764  YCO(R.M.S.)=  0.000000
```

5. FOR DELTA(P)/P = -0.002000:

```
TOTAL LENGTH  = 201.780000      QX =  4.829868  QY  =  4.840531
                                QX'= -4.938396  QY' = -5.274457
 ALFA     = 0.415441E-01  BETAX(MAX)  = 13.888567  BETAY(MAX) = 13.673471
 GAMMA(TR) = 4.906198        DX(MAX)  =  2.967673     DY(MAX) =  0.000000
```

```
                    XCO(MAX)   =  5.919019    YCO(MAX)  =  0.000000
                XCO(R.M.S.)    =  3.328215 YCO(R.M.S.)  =  0.000000
```

6. FOR DELTA(P)/P = 0.000000:

```
TOTAL LENGTH =  201.780000          QX   =  4.820000  QY   =   4.829999
                                    QX'  = -4.929702  QY'  =  -5.264883
 ALFA    =    0.419701E-01  BETAX(MAX) = 13.865707  BETAY(MAX) = 13.644032
 GAMMA(TR) = 4.881238           DX(MAX) =  2.951449     DY(MAX) =  0.000000
                               XCO(MAX) =  0.000000    YCO(MAX) =  0.000000
                           XCO(R.M.S.)  = 0.000000  YCO(R.M.S.) = 0.000000
```

7. FOR DELTA(P)/P = 0.002000:

```
TOTAL LENGTH =   201.780000         QX   =   4.810150  QY   =  4.819471
                                    QX'  =  -4.921099  QY'  = -5.255452
 ALFA  =      0.423924E-01    BETAX(MAX)=  13.842974  BETAY(MAX) = 13.629735
 GAMMA(TR) = 4.856865           DX(MAX) =   2.935830     DY(MAX) =  0.000000
                               XCO(MAX) =   5.887179    YCO(MAX) =  0.000000
                           XCO(R.M.S.)  =   3.329428 YCO(R.M.S.) =  0.000000
```

8. FOR DELTA(P)/P = 0.004000:

```
 TOTAL LENGTH =  201.780000     QX    =   4.800317   QY =  4.808946
                                QX'   =  -4.912583   QY'= -5.246156
 ALFA =      0.428113E-01 BETAX(MAX) =  13.820366   BETAY(MAX) =  13.615495
 GAMMA(TR)   = 4.833046      DX(MAX) =   2.920797      DY(MAX) =   0.000000
                            XCO(MAX) =  11.743710     YCO(MAX) =   0.000000
                        XCO(R.M.S.) =   6.660591  YCO(R.M.S.) =   0.000000
```

9. FOR DELTA(P)/P = 0.006000:

```
TOTAL LENGTH = 201.780000     QX      =    4.790501  QY          =  4.798424
                              QX'     =   -4.904152  QY'         =  -5.236988
 ALFA  = 0.432270E-01   BETAX(MAX)     =  13.797883  BETAY(MAX) = 13.601316
 GAMMA(TR) =   4.809750     DX(MAX)    =   2.906327     DY(MAX) =  0.000000
                           XCO(MAX)    =  17.570742    YCO(MAX) =  0.000000
                       XCO(R.M.S.)     =   9.993989    YCO(R.M.S.) = 0.000000
```

10. FOR DELTA(P)/P = 0.008000:

```
TOTAL LENGTH =    201.780000   QX      =  4.780703    QY          =  4.787905
                               QX'     = -4.895804    QY'         = -5.227943
 ALFA  =  0.436398E-01  BETAX(MAX)      = 13.775524  BETAY(MAX) = 13.587203
 GAMMA(TR) =    4.786948   DX(MAX)     =  2.892402     DY(MAX) =  0.000000
                          XCO(MAX)     =  23.369382    YCO(MAX) =  0.000000
                      XCO(R.M.S.)      =  13.330097  YCO(R.M.S.)=  0.000000
```

11. FOR DELTA(P)/P = 0.010000 :

```
TOTAL LENGTH =  201.780000      QX  =  4.770922   QY =  4.777389
                                QX' = -4.887536   QY'= -5.219016
 ALFA =  0.440499E-01  BETAX(MAX) =  13.753287  BETAY(MAX) =  13.573160
 GAMMA(TR) =  4.764614    DX(MAX) =   2.879003DY(MAX) =   0.000000
                         XCO(MAX) =  29.140701    YCO(MAX) =   0.000000
                      XCO(R.M.S.) =  16.669372  YCO(R.M.S.) =  0.000000
```

TABLE III

"MAD" VERSIN 4.03

MAD403 OUTPUT FOR AGS BOOSTER LATTICE WITHOUT SEXTUPOLES [SF,SD,SV=0]

1. FOR DELTA(P)/P = -0.010000 :

```
TOTAL LENGTH = 201.780000    QX  =  4.869536     QY    =  4.882249
                             QX' = -4.974658     QY'   = -5.291287
ALFA  =  0.397978E-01 BETAX(MAX) = 13.981250 BETAY(MAX)= 13.796343
GAMMA(TR) =  5.012688 DX(MAX)    =  3.039108   DY(MAX) = 0.000000
```

2. FOR DELTA(P)/P = -0.008000 :

```
TOTAL LENGTH =  201.780000 QX     =  4.859589       QY   =  4.871899
                           QX'    = -4.965323       QY'  = -5.292399
ALFA  =  0.402414E-01  BETAX(MAX) = 13.957891 BETAY(MAX) = 13.764777
GAMMA(TR)  = 4.984983  DX(MAX) =  3.020219  DY(MAX) = 0.000000
```

3. FOR DELTA(P)/P = -0.006000 :

```
TOTAL LENGTH =  201.780000  QX  =  4.849663      QY     = 4.861481
                            QX' = -4.956193      QY'    = -5.288761
ALFA  =  0.406801E-01 BETAX(MAX)= 13.934657  BETAY(MAX) = 13.733831
GAMMA(TR)=  4.958030    DX(MAX) = 3.002034 DY(MAX) =  0.000000
```

4. FOR DELTA(P)/P = -0.004000 :

```
TOTAL LENGTH =  201.780000  QX   = 4.839756       QY    =   4.851017
                            QX' = -4.947229       QY'   =  -5.282268
ALFA =  0.411142E-01 BETAX(MAX) = 13.911549  BETAY(MAX) =  13.703424
GAMMA(TR) =  4.931783  DX(MAX) = 2.984527  DY(MAX) = 0.000000
```

5. FOR DELTA(P)/P = -0.002000 :

```
TOTAL LENGTH =  201.780000 QX    =  4.829869      QY     =  4.840520
                           QX'   = -4.938405      QY'    = -5.274067
ALFA = 0.415441E-01  BETAX(MAX) = 13.888566  BETAY(MAX) = 13.673504
GAMMA(TR)    = 4.906198  DX(MAX) =  2.967673  DY(MAX) =  0.000000
```

6. FOR DELTA(P)/P = 0.000000 :

```
TOTAL LENGTH = 201.780000   QX    = 4.820000       QY    =  4.829999
                            QX'   =-4.929702       QY'   = -5.264883
ALFA = 0.419701E-01   BETAX(MAX) =13.865707  BETAY(MAX) = 13.644032
GAMMA(TR)     = 4.881238  DX(MAX)  = 2.951449   DY(MAX)  =  0.000000
```

7. FOR DELTA(P)/P = 0.002000:

```
TOTAL LENGTH = 201.780000  QX    =   4.810150     QY     = 4.819462
                           QX'   =  -4.921105     QY'    =-5.255196
ALFA  =  0.423924E-01 BETAX(MAX) =  13.842973 BETAY(MAX) = 13.629764
GAMMA(TR)     = 4.856865    DX(MAX= 2.935830       DY(MAX)=  0.000000
```

8. BEAM DELTA(P)/P = 0.004000:

```
TOTAL LENGTH =  201.780000 QX  =    4.800318     QY      = 4.808910
                           QX' =   -4.912603     QY'     =-5.245338
ALFA  = 0.428113E-01 BETAX(MAX) =  13.820363   BETAY(MAX)= 13.615603
GAMMA(TR)    = 4.833046  DX(MAX) =    2.920797  DY(MAX)    =  0.000000
```

9. FOR DELTA(P)/P = 0.006000:

```
TOTAL LENGTH =   201.780000  QX    =   4.790504        QY   =  4.798347
                             QX'   =  -4.904188        QY'  = -5.235560
ALFA  =  0.432270E-01  BETAX(MAX) = 13.797876  BETAY(MAX)= 13.601548
GAMMA(TR)     =  4.809750 DX(MAX)  =  2.906328    DY(MAX) =  0.000000
```

10. FOR DELTA(P)/P = 0.008000 :

```
TOTAL LENGTH = 201.780000          QX    =  4.780707      QY =  4.787774
                                   QX'   = -4.895849      QY'= -5.226062
ALFA    = 0.436398E-01  BETAX(MAX) = 13.775511  BETAY(MAX)= 13.587601
GAMMA(TR)  = 4.786948      DX(MAX) =  2.892404   DY(MAX) =    0.000000
```

11. FOR DELTA(P)/P = 0.010000 :

```
TOTAL LENGTH = 201.780000        QX   =  4.770928          QY =    4.777190
                                 QX'  = -4.887580          QY'=   -5.21701
ALFA    =  0.440499E-01  BETAX(MAX) = 13.753267 BETAY(MAX) =  13.573763
GAMMA(TR)     = 4.764614   DX(MAX)  =    2.879005  DY(MAX)  =    0.000000
```