

Closed orbit analysis for the AGS Booster

J. Milutinovic

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Collider Accelerator Department
Brookhaven National Laboratory

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CLOSED ORBIT ANALYSIS FOR THE AGS BOOSTER

AD

Booster Technical Note

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J. MILUTINOVIC AND A. G. RUGGIERO

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ACCELERATOR DEVELOPMENT DEPARTMENT
Brookhaven National Laboratory
Upton, N.Y. 11973

Abstract

We examine the effects of four types of errors in the AGS Booster dipoles and quadrupoles on the on-momentum closed orbit in this machine. We use PATRIS both to handle statistically the effects of kick-modeled errors and to check the performance of the Fermilab correcting scheme in a framework of a more realistic modeling. For the latter to be effective, we find that the r.m.s. values of the errors should not go much beyond 3×10^{-4} in the appropriate units.

Introduction

An accelerator lattice cannot be expected to be perfect, just as anything else made by man. Fortunately, there are theorems which guarantee the existence of a closed orbit even in an imperfect lattice, provided the deviations from the ideal lattice are not too big. However, large ranges of existing closed orbits will actually be of no value, because such closed orbits might violate aperture and other limitations and therefore be unacceptable. Hence, from the practical point of view, it is of utmost importance to determine both qualitative and quantitative links between the lattice imperfections and the resulting closed orbits. In this note we have addressed this important issue and have estimated the limitations on some of the lattice imperfections for the closed orbit to be correctable. The types of imperfections that we have handled are the dipole integrated field strength error $\Delta(Bl)/Bl$, the dipole axial rotation $\Delta\theta$, and the quadrupole lateral displacements in both planes. In this procedure it is very important that the same error is assigned to one physical magnet even if the magnet is divided in two or more parts. PATRIS now does this error assigning in the correct manner.

Statistical Treatment of Closed Orbit Errors in the Kick Approximation

For the purpose of quick statistical treatment of the effects of magnet imperfections on the closed orbit, PATRIS employs an algorithm whose basic ingredients are given in the Courant-Snyder paper¹. The starting point is the equation of motion for the transverse degrees of freedom

$$\frac{d^2y}{ds^2} + K(s)y = F(s) \quad , \quad (1)$$

where y is the transversal displacement, horizontal or vertical, from the equilibrium orbit and where $F(s)$, a quantity which describes the field errors, is given by

$$F(s) = \Delta B / B\rho \quad . \quad (2)$$

Here ΔB is a deviation from the ideal magnetic field, whereas $B\rho$ is the magnetic rigidity. It is important to keep in mind that (1) does not include the effects of nonlinearities, including those coming from the sextupoles.

PATRIS simulates the effects of imperfections by kicks, i.e. it evaluates the r.m.s. values of closed orbit deviations at various points

of interest by assuming that the right hand side of (1) is a Dirac delta^{F1} function. As previously mentioned, there are four contributors to the distorted closed orbit at each point, which are considered by the code. They are:

1. Cumulative effects of the errors in the dipole integrated strength over the lattice.
2. Cumulative effects of the axial rotations of all the dipoles in the lattice.
3. Cumulative effects of the horizontal lateral displacements of all the quadrupoles in the lattice.
4. Cumulative effects of the vertical lateral displacements of all the quadrupoles in the lattice.

At each point of interest the code computes the above four entities. Each is computed under the assumption that it is the only perturber of the closed orbit and that in average the resulting r.m.s. error in the bending angle, i.e. the imperfection's kick strength, is one milliradian per magnet. Therefore, they portray the isolated influence of specific kinds of imperfections in the whole lattice on the closed orbit at a specific point of interest. The r.m.s. values are taken over 21 different distributions of random errors. These contributions are given in the columns 3 through 6 of Table 1. The last two columns of Table 1 describe the r.m.s. values of horizontal and vertical displacement at the end of each lattice element. These values are obtained by an appropriate weighting and combining of the four entities, 1 through 4, with the actual r.m.s. values of these perturbers (as opposed to those that would yield r.m.s. value of the bending angle exactly one milliradian) taken into account, and a subsequent evaluation of the r.m.s. values of closed orbit displacements over the same 21 distributions of random errors as before. Needless to say, the presence of errors breaks the periodicity of the machine, if any, and the code takes this into account by moving from one superperiod to another in such a manner that different sets of random numbers are being used in different superperiods.

As previously mentioned, Eq.(1) does not include the effects of nonlinearities in determining the closed orbit. However, one consequence of the presence of sextupoles is nevertheless handled. Namely, the distorted closed orbit does not pass through the centers of the sextupoles and, as a result, there is a feed-down effect equivalent to quadrupole gradient errors, with the subsequent tune shifts and beta variations. These are evaluated by PATRIS for each of those 21 distributions of random errors and then printed.

F1: See Appendix A for some details.

Realistic Closed Orbit Calculation and Correction

In addition to the previously described quick statistic treatment of closed orbit distortions, based on the simulation of imperfections by kicks, PATRIS is also able to handle the problem in a more realistic manner. Precise effects of the previously discussed four sources of errors are evaluated and incorporated into the 7×7 transfer matrix employed by PATRIS. Furthermore, nonlinearities are taken into account and simulated by kicks. The code employs one sequence of random errors per run, using different random numbers in different superperiods. This means that at the present time one has to make several runs, if a statistical treatment of the realistic closed orbit is sought. After computing the distorted closed orbit, PATRIS corrects it by using the Fermilab monitoring/correcting scheme^{2,3,4}.

The scheme uses a selected number of monitors and correctors which are in reality placed beside each other and which are identified with each other in the code. The beam position monitors and the sextupoles are assumed to be perfectly aligned with the reference orbit going through the quadrupole without a displacement. In addition, the beam position monitors are supposed to have ideal sensitivity. The best location for such a monitor/corrector element is the place where the relevant beta function is large. Therefore, we place all the horizontal elements beside the horizontally focusing quadrupoles, and we do the equivalent thing with the vertical monitors/correctors, i.e. we place them beside each horizontally defocusing quad. At these locations the distorted closed orbit is monitored and the corrective kicks are being delivered there, by the dipole correctors. To evaluate the strengths of the corrective kicks, the code takes the values of closed orbit displacements at three successive monitors and imposes the conditions necessary to make these displacements vanish in the absence of nonlinearities. Then the code moves one monitor forward and repeats this procedure, thereby obtaining another set of conditions. Going in this manner around the whole lattice, the code sets up a set of N equations with N unknowns, N being the number of monitor/corrector elements in the lattice. Fortunately, they can be solved by a simple successive elimination of the unknowns (see Appendix B for more details), without having to invert an $N \times N$ matrix which might be a prohibitively large task for a big lattice. In doing so, the code evaluates all the kick strengths and then reevaluates the distorted closed orbit in the presence of these corrective kicks. In the absence of nonlinearities, i.e. with the chromaticity sextupoles turned off for instance, PATRIS delivers such kicks that the residual closed orbit is zero at all the monitors, regardless of the r.m.s. values of the errors (except, of course, for grossly exaggerated values which would make the whole problem unstable). In the presence of sextupoles, however, the residual closed orbit cannot be forced to vanish exactly by this linear correcting scheme. Moreover, the presence of sextupoles aggravates the problem and the displacements of the uncorrected closed orbit get noticeably bigger with sextupoles (or other sources of nonlinearities) turned on.

This scheme, as its name indicates, has been successfully used at Fermilab and, in addition to being used in PATRIS, its versions have been incorporated also in some other tracking/analytic codes which handle the origins of closed orbit distortions in different ways.

Results of Statistic Approach to Closed Orbit Distortions in the Kick Approximation

We have made two runs over the same 21 distributions of random errors, with the cut at 2.5σ . First, we selected all four types of errors to have the same r.m.s. value 10^{-3} , in the appropriate units. However, from the subsequent realistic closed orbit analysis, it became clear that the corrected closed orbit would be prohibitively large, at this r.m.s. value of errors. Therefore, we opted for the more stringent 3×10^{-4} r.m.s. values of errors and repeated the run, keeping everything else unchanged. The results are displayed in Tables 1 and 2 and in Figures 1 through 4.

Table 1 represents the r.m.s. values of the closed orbit horizontal and vertical displacement in millimeters (the last two columns), as well as the relative importance of the four types of errors taken individually. Only one superperiod is printed, even though the code runs over all the superperiods, with the periodicity broken by random errors, in order to evaluate what is being printed for one superperiod. Two things are apparent. The r.m.s. value of closed orbit displacement follows the local size of the beta function, as one moves along the lattice. For the horizontal plane, the r.m.s. of displacement is maximum inside the horizontally focusing quad, where β_H attains its maximum, and it is minimum at the defocusing quad due to the minimum of β_H . This is even more transparent from Figures 1 and 2, where the r.m.s. values for x and y are plotted versus the magnet number in the superperiod (roughly versus the distance as one moves along the ring). We notice that the vertical plane displays a picture very similar to that of the horizontal plane except for the fact that it has been shifted by the distance between a QF and the first QD that follows. As far as the ranges are concerned, the r.m.s. value of the displacement varies between about 1.6 and 6 millimeters. Therefore, we expect that few distributions of random errors will cause the closed orbit displacements to significantly exceed 6 millimeters, even though we have been able to find two of them (out of the total of eleven that we have examined) where at one or two monitors the displacement more than doubled this value (13.5 and 13.7mm have been found). The second conclusion that can be inferred from Table 1 is that the quadrupoles have the tendency to create both the peak and average contributions bigger than those of the dipoles. When one combines this with the fact that weighting factors (in the procedure of combining the columns 3 through 6 in order to get 7 and 8) are bigger for the quadrupoles than for the dipoles, the immediate conclusion is that the quadrupole lateral displacement errors will be more important in the Booster than the errors introduced by the dipoles. A similar conclusion applies also to some other machines, the RHIC in particular.

Table 2 displays the tune shifts and the beta variations due to the effective quadrupole gradient errors, as a result of the crossing of the sextupoles by the distorted closed orbit. The beta variations are taken at the beginning of the lattice input, i.e. in the middle of a superperiod. These results are also plotted and represented in Figures 3 and 4.

Results of the Realistic Closed Orbit Calculations

As described in the Introduction, PATRIS can handle the problem of closed orbit in a more realistic and predictive manner than just simulating the lattice imperfections by kicks. However, the code in its present version performs the so-called realistic closed orbit calculations on one string of random numbers. Thus the user has the option to rely on the statistics of the kick-simulated closed orbit distortions, supplemented by a realistic closed orbit calculation for the purpose of finding the kick strengths and the residual corrected closed orbit, or, as an alternative, to run several cases of realistic closed orbit calculations for different random errors and to do statistics "by hand."

We decided to perform some statistics after getting a seemingly peculiar result, from a single realistic closed orbit run, which indicated that the vertical closed orbit displacements tend to be much bigger than the horizontal ones. The kick-simulated run over 21 distributions of random errors did not indicate such a disparity between the two planes. Nor did a realistic closed orbit calculation on the RHIC lattice indicate anything similar.

We performed calculations with 11 different sequences of random errors. Initially, we set the r.m.s. values of the four types of errors to be 10^{-3} , but this proved to be too generous. The residual corrected closed orbit, with the chromaticity sextupoles on, was in most cases still several millimeters in transverse size. Furthermore, we picked up a "bad" distribution of random errors (with the cut at 2.5σ , as mentioned) that made the maximum displacement of the corrected closed orbit to be about 13 millimeters. With sextupoles off, however, the correctors made the closed orbit exactly zero at the monitors, as expected.

Therefore, we repeated the same 11 runs, but this time with the r.m.s. values of the four types of errors reduced to 3×10^{-4} , in the appropriate units. In all of these 11 cases, the corrected closed orbit this time fell within one millimeter. We have also tested how the corrected closed orbit gets worse with an increase of the r.m.s. values of the four kinds of errors, on the worst distribution of random errors that we had encountered. While even this comparatively rather bad distribution yielded a corrected closed orbit that fell within one millimeter for the 3×10^{-4} errors, it reached 1.36 mm at one location for the 4×10^{-4} errors and it barely passed 2 millimeters at four (out of 48) monitors for the 5×10^{-4} errors.

These facts have given us the necessary confidence to claim that if a 3×10^{-4} level of r.m.s. values is attained in the real machine, the Fermilab correcting scheme alone will be able to successfully handle the closed orbit distortions arising from the four types of errors we have discussed. The results of the run over the worst distribution of random errors are shown in Table 3. They deviate quite appreciably from the r.m.s. values of displacements at the same monitors given in Table 1. However, we emphasize

that this is a bad case and that most other cases display displacements whose sizes are much closer to the averaged predictions over 21 cases. The results from Table 3 are also plotted in Figures 5 and 6. These figures represent the uncorrected and corrected closed orbit for the two planes. The reader will undoubtedly notice that the uncorrected closed orbit behaves in the horizontal plane much worse than in the vertical one. This is obviously a consequence of the particular set of random errors. We have inspected the results of all of the eleven runs and have found the closed orbit distortions bigger in the horizontal plane in four cases. It was just the opposite in another group of four cases, whereas in the remaining three runs the distortions were about equal in the two planes.

Conclusion

In this note, we have handled four major sources of closed orbit distortions: errors in the dipole integrated field strength $\Delta(B1)/B1$, axial rotation of the dipole, and the two possible lateral displacements of the quadrupole. This list is by no means exhaustive. Some other major errors that we have not addressed so far are errors due to the axial rotation of the quadrupole, errors in the field gradient strength $\Delta K/K$ for the quadrupole, and various higher order multipoles present both in the dipole and in the quadrupole. We are currently working on some of these issues and we also plan to address some others in the future.

As far as the four types of errors that we have discussed are concerned, our conclusion is clear: one should strive to achieve the 3×10^{-4} level of r.m.s. values and this is very likely sufficient for the Fermilab correcting scheme to work well. We definitely support the implementation of this scheme on the Booster. Its implementation will require installing a beam position monitor, followed by a dipole corrector, beside each quadrupole. The maximum integrated field strength for such a bump corrector, to be able to correct the orbit at the top magnetic rigidity of 18 Tm, is predicted to be about 55 Gauss*meters. This estimation may have to be somewhat changed in the future, once other sources of errors are brought in for an analysis. But the essentials of the correcting scheme should remain unchanged.

However, there is an unpleasant scenario that cannot be completely ruled out. If, by some unfortunate circumstances, on Day 1 we find a very bad orbit, we will have to rely on other means, like physically moving quads and Fourier harmonic compensation, to bring first the errors down to the levels at which the proposed local correction scheme will work.

Appendix A

Here we give the reader a basic idea on how PATRIS handles closed orbit errors in the kick approximations. The closed orbit deviation y_i at the i -th location, where $\beta = \beta_i$ and the phase advance is ϕ_i , is given by

$$y_i = \frac{1}{2 \sin(\pi\nu)} \sum_{j>i} \sqrt{\beta_i \beta_j} \theta_j \cos \nu(\pi + \phi_i - \phi_j) \quad , \quad (A.1)$$

where the summation is over all the errors of strength θ_j (in equivalent kick-angle) at the location with $\beta = \beta_j$ and phase advance $\phi_j > \phi_i$. This formula for y_i is used by PATRIS, which also takes care of the proper ordering of the phase advances (i.e. $\phi_j > \phi_i$). The expression (A.1) can easily be derived by starting from the periodic solution to the equation of motion (Eq. 1 in the main body of this note) rewritten in Floquet coordinates (Eq. (4.6) of Ref. 1) and inserting the appropriate sum of Dirac delta functions as the perturber $f(\psi)$ in Eq. (4.7) of Ref. 1.

Summation in (A.1) is linear and the two degrees of freedom are decoupled

$$y_i^H = \sum_{\text{DIPOLE/H}} + \sum_{\text{QUAD/H}} = y_i^{H,D} + y_i^{H,Q} \quad (A.2)$$

$$y_i^V = \sum_{\text{DIPOLE/V}} + \sum_{\text{QUAD/V}} = y_i^{V,D} + y_i^{V,Q} \quad (A.3)$$

The code first computes each of the above four sums individually, assuming that at each magnet

$$(\theta_j)_{\text{v.m.s.}} = 1 \text{ mrad} \quad (A.4)$$

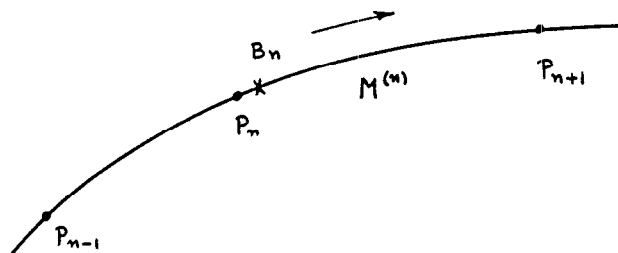
Once the four quantities $y_i^{H,D}$, $y_i^{H,Q}$, $y_i^{V,D}$, $y_i^{V,Q}$ are found for each of 21 distributions of random numbers, the r.m.s. values of these four quantities are evaluated. They describe partial contributions to the total closed orbit distortion, where "partial contribution" means that it is evaluated under the assumption that it is the only present perturber. Since these

quantities are evaluated under the assumption that (A.4) is true at each magnet, they describe the relative importances of various sources of errors.

In order to find the r.m.s. values of the distorted closed orbit displacements, under the r.m.s. error values specified on the input by the user, PATRIS first abandons (A.4) and replaces $(\theta_j)_{r.m.s.}$ by the actual r.m.s. values it computes on the basis of the input given r.m.s. values for the errors. Then it evaluates the four sums on the basis of these actual r.m.s. values for θ_j , adds them up to get (A.2) and (A.3) and then takes the r.m.s. values for y_i^H and y_i^V , over the 21 distributions of random numbers.

Appendix B

In this appendix we sketch the basic principles of the so-called three bump method used in the Fermilab monitoring/correcting scheme. As described in the main text of this note, a certain number of monitors and correctors are placed at preferred locations, i.e. beside the quadrupoles where the relevant beta function is large. It is assumed that the monitors have ideal sensitivity and that they are perfectly alligned with the reference orbit going through the quadrupole without a displacement.



The above drawing displays the particle trajectory through the three points of interest. Consider what is happening at the n-th beam position monitor and its two immediate neighbors. We label the monitor/corrector block by P_n and the phase space point at P_n by X_n , i.e. X_n will be the following column vector

$$X_n = \begin{pmatrix} y \\ y' \\ 1 \end{pmatrix}_{\text{At } P_n} = \begin{pmatrix} y_n \\ y'_n \\ 1 \end{pmatrix} \quad (\text{B.1})$$

We also know the transfer matrix in the absence of errors between any pair of monitors (it is part of the full 7 x 7 transfer matrix between the two monitors in PATRIS). Let $M^{(n)}$ label the transfer matrix between the monitors P_n and P_{n+1} . For one transverse degree of freedom its form is

$$M^{(n)} = \begin{pmatrix} m_{11}^{(n)} & m_{12}^{(n)} & 0 \\ m_{21}^{(n)} & m_{22}^{(n)} & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (\text{B.2})$$

with the symplectic condition $\det M^{(n)} = 1$ being fulfilled

$$m_{11}^{(n)} m_{22}^{(n)} - m_{12}^{(n)} m_{21}^{(n)} = 1 \quad (\text{B.3})$$

Suppose that the correctors deliver kicks with the kick angle Θ_n at the n-th monitor/corrector P_n . The effect of such a kick is described by the following matrix

$$B_n = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & \Theta_n \\ 0 & 0 & 1 \end{pmatrix} \quad (\text{B.4})$$

Let these kicks be such that they steer the on-momentum particle trajectory precisely through the positions X_n (in the absence of errors). Then the condition

$$X_{n+1} = M^{(n)} B_n X_n \quad (\text{B.5})$$

must be fulfilled. Written out in components (B.5) is just

$$y_{n+1} = m_{11}^{(n)} y_n + m_{12}^{(n)} y_n' + m_{12}^{(n)} \Theta_n \quad (\text{B.6a})$$

$$y_{n+1}' = m_{21}^{(n)} y_n + m_{22}^{(n)} y_n' + m_{22}^{(n)} \Theta_n \quad (\text{B.6b})$$

We solve (B.6a) for y_n'

$$y_n' = \frac{y_{n+1} - m_{11}^{(n)} y_n - m_{12}^{(n)} \Theta_n}{m_{12}^{(n)}} \quad (\text{B.7})$$

and increment the label by 1 to obtain

$$y_{n+1}' = \frac{y_{n+2} - m_{11}^{(n+1)} y_{n+1} - m_{12}^{(n+1)} \Theta_{n+1}}{m_{12}^{(n+1)}} \quad (\text{B.8})$$

Now insert y_n' from (B.7) into (B.6b) and equate the resulting y_{n+1}' with (B.8)

$$\frac{y_{n+2} - m_{11}^{(n+1)} y_{n+1} - m_{12}^{(n+1)} \theta_{n+1}}{m_{12}^{(n+1)}} =$$

$$m_{21}^{(n)} y_n + m_{22}^{(n)} \theta_n + m_{22}^{(n)} \left(\frac{y_{n+1} - m_{11}^{(n)} y_n - m_{12}^{(n)} \theta_n}{m_{12}^{(n)}} \right) =$$

$$m_{21}^{(n)} y_n - \frac{m_{22}^{(n)} m_{11}^{(n)}}{m_{12}^{(n)}} y_n + \frac{m_{22}^{(n)}}{m_{12}^{(n)}} y_{n+1} = - \frac{y_n}{m_{12}^{(n)}} + \frac{m_{22}^{(n)}}{m_{12}^{(n)}} y_{n+1} \quad (B.9)$$

where (B.3) has been used to simplify the expression on the right hand side of the above equation. This equation can now be solved for θ_{n+1} , i.e.

$$\theta_{n+1} = \frac{y_{n+2} - m_{11}^{(n+1)} y_{n+1}}{m_{12}^{(n+1)}} + \frac{y_n}{m_{12}^{(n)}} - \frac{m_{22}^{(n)}}{m_{12}^{(n)}} y_{n+1} \quad (B.10)$$

By decrementing the index n by one unit we get

$$\theta_n = \frac{y_{n-1}}{m_{12}^{(n-1)}} - \left(\frac{m_{11}^{(n)}}{m_{12}^{(n)}} + \frac{m_{22}^{(n-1)}}{m_{12}^{(n-1)}} \right) y_n + \frac{y_{n+1}}{m_{12}^{(n)}} \quad (B.11)$$

Therefore, the kick angle θ_n at the n-th bump corrector is completely determined by the displacements at the n-th monitor and at its two immediate neighbors, i.e. at the (n-1)-th and (n+1)th locations.

In the absence of corrective kicks, the n-th beam position monitor P_n will read the closed orbit displacement r_n at the n-th location, the displacement being nonzero due to the presence of errors. To compensate for the effects of errors, one simply sets $y_n = -r_n$ and evaluates the necessary kick angle θ_n to create a reverse displacement in the absence of errors. In the presence of errors and with sextupoles off, these kicks will precisely cancel the actual displacement at the beam position monitors. With sextupoles on, however, a precise cancellation does not occur, but the residual displacements are to a significant degree reduced.

References

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Tables

1. This table represents the output from PATRIS for the kick-modeled statistical handling of closed orbit distortions. The statistics is taken over 21 distributions of random errors, with the r.m.s. values of all errors 3×10^{-4} , in the appropriate units. The random number sequences were cut at 2.5σ .
2. This table represents the tune shifts and beta variations due to the crossing of the sextupoles by the distorted closed orbit, for the same run as the run presented in Table 1. The 21 rows in the table correspond to the 21 distributions of random errors.
3. This table represents the output from PATRIS for the realistic closed orbit calculation over the worst distribution of random errors. Note that the corrected closed orbit falls within one millimeter. Also note that the code supplies the correctors' kick strengths.

Table 1

PAGE 3

CPU-TIME SO FAR = 907 MSEC
CPU-TIME SO FAR = 907 MSEC
CPU-TIME SO FAR = 907 MSEC

KW(12) = 1

CLOSED ORBIT ANALYSIS
QX = 4.81999 QY = 4.83000
LOCAL RMS EXPECT. VALUES OF CLOSED ORBIT DISPLACEMENT FOR FIELD AND MISALIGNMENT ERRORS
CORRESPONDING TO AN RMS ERROR IN BENDING ANGLE OF ONE MILLIRAD
UNITS ARE IN MILLIMETERS

J	MAGNET	DIPOLE/H	DIPOLE/V	QUAD/H	QUAD/V	DH	DY
1	SYM	34.1424	62.4629	51.5474	108.2065	3860	4.9726
2	Q	46.9268	91.2395	46.8083	114.4296	3047	4.2139
3	MD/2	41.3758	86.6139	50.8168	114.2536	3411	4.4887
4	MD/Z	32.1750	67.5670	41.9168	118.7633	3144	4.4887
5	QV	40.2450	73.5396	44.5229	87.9374	2125	4.4237
6	DRB	44.9617	75.0459	45.9437	48.6665	2978	4.2975
7	DRB	36.9969	68.3437	49.5803	82.1082	3305	4.3331
8	MBE	37.5177	66.3382	64.4793	109.1401	3400	4.3331
9	BCE/2	56.9980	66.3646	69.4584	96.3424	3095	4.3331
10	BCE/2	51.9800	62.9435	63.9384	70.4031	2756	4.3331
11	SCM	50.3867	63.9388	56.9276	70.4031	2756	4.3331
12	SCM	41.7637	44.4141	59.7711	65.6573	1074	4.3331
13	B/ZE	43.9555	46.1663	81.8561	65.8150	1978	4.3331
14	B/ZE	80.8778	47.9009	86.8561	65.8150	1978	4.3331
15	MBZ	54.6269	48.3038	97.6985	61.0057	4147	4.3331
16	DRLE	74.2516	36.9767	70.0928	46.8606	2038	4.3331
17	DRLE	74.1443	41.9419	80.9928	46.8606	2038	4.3331
18	MF/2	66.4297	35.4465	67.6093	52.9187	3380	4.3331
19	MF/2	45.5008	35.4465	77.2273	52.9187	3380	4.3331
20	DRSE	57.3805	32.3377	84.2536	43.7450	3357	4.3331
21	DRSE	44.3205	32.3377	73.2536	35.4344	3357	4.3331
22	DRLE	29.7447	32.3377	58.2281	72.2046	3357	4.3331
23	QV	38.5559	54.8973	58.2281	99.4180	3357	4.3331
24	QV	38.5559	79.9121	57.2330	83.2162	3357	4.3331
25	MD/2	33.5530	71.8945	59.8777	102.9320	3357	4.3331
26	MD/2	33.5530	68.8945	53.3300	121.5205	3357	4.3331
27	QV	42.1931	75.4537	66.5353	106.1525	3357	4.3331
28	QV	48.1976	59.3912	48.2906	91.9824	3357	4.3331
29	DRS	33.6083	56.4348	45.3234	80.8060	3357	4.3331
30	MBE	31.9831	56.4348	57.1204	83.2017	3357	4.3331
31	B/ZE	53.8505	63.5074	48.8245	55.8617	2277	4.3331
32	B/ZE	53.8505	63.5074	77.8245	55.8617	2277	4.3331
33	SCM	45.8571	60.7091	77.2626	69.6825	2277	4.3331
34	SCM	46.3663	46.8508	79.7879	69.6825	2277	4.3331
35	B/ZE	66.0331	60.0233	98.8891	78.6991	2277	4.3331
36	B/ZE	66.0331	44.9891	111.0294	78.6991	2277	4.3331

(continues on the next page)

Table 2

CLOSED ORBIT ANALYSIS WITH SEXTUPOLES
TUNE SHIFTS AND BETA VARIATIONS

	HORIZONTAL		VERTICAL	
	DBETA/BETA	D-TUNE	DBETA/BETA	D-TUNE
1	0.35986e-02	0.67646e-04	0.20248e-02	0.55865e-04
2	0.87661e-02	0.28109e-02	-0.36719e-02	0.31661e-03
3	-0.34446e-02	0.13982e-02	0.12921e-01	-0.12674e-02
4	-0.51444e-02	-0.30722e-02	0.10382e-01	0.32857e-02
5	0.34473e-02	0.23414e-03	-0.10523e-01	0.82913e-03
6	0.83141e-02	0.15707e-02	-0.84879e-02	0.79469e-03
7	-0.54302e-02	0.28144e-04	0.63170e-02	0.19825e-02
8	0.17500e-01	0.69144e-02	-0.68454e-02	-0.15292e-02
9	-0.20588e-02	0.56023e-03	0.70723e-02	-0.14308e-02
10	-0.56593e-02	-0.33207e-02	-0.76399e-02	0.34624e-02
11	-0.25092e-02	-0.12864e-02	-0.46559e-02	0.58659e-03
12	0.96144e-02	0.13351e-02	-0.28951e-02	0.17469e-02
13	0.11041e-01	0.52351e-02	-0.24901e-02	-0.23369e-02
14	-0.16015e-03	-0.17859e-02	-0.65663e-02	0.36037e-02
15	-0.57906e-02	-0.40243e-04	0.59524e-02	-0.57185e-03
16	-0.42458e-03	-0.18543e-03	0.42070e-02	0.16501e-02
17	-0.87577e-02	-0.47354e-02	-0.84466e-02	0.15660e-02
18	0.14788e-02	-0.15164e-02	-0.71469e-03	0.29325e-02
19	0.17838e-01	0.78069e-02	-0.12690e-01	-0.30189e-02
20	-0.19558e-02	-0.40741e-03	-0.10504e-03	-0.10229e-03
21	0.60399e-02	0.25056e-02	-0.31512e-02	-0.18314e-02

r.m.s.
values: 0.79777e-02 0.32183e-02 0.72304e-02 0.20317e-02

CPU-TII

END OF THE RUN

PATRI5 VR5N 3.2

Table 3

J	CLOSED ORBIT CALCULATION HORIZ. AND VERT. BEAM POSITION IN MILLIMETERS CORRECTION KICKS IN MILLIRADIANS		KICK		CORRECTED	
	HORIZONTAL	VERTICAL	HORIZONTAL	VERTICAL	HORIZONTAL	VERTICAL
6						
23	10.12012	-0.92194	0.18111	-0.45939	0.10218	-0.45939
31	9.57186	3.88861	0.03835	-0.31554	-0.66390	-0.31554
50		3.71855	-0.28239	0.18869		0.18869
67	-8.05008	-0.73995	-0.07223	0.41233	-0.13719	0.41233
86	-13.70112	-3.71346	-0.05798	0.10853	0.70296	0.10853
105	-0.84471	-2.56222	0.01557	-0.22432	0.50068	-0.22432
113	13.41798	-0.32193	0.08472	-0.19626	-0.36154	-0.19626
151	7.45959	1.19418	0.19851	0.12930	-0.10076	0.12930
159	-9.40379	0.07605	0.07847	0.27382	0.54615	0.27382
178	-9.70533	-0.83249	0.09358	0.03075	0.37810	0.03075
195	3.52202	0.90092	0.00510	-0.25459	-0.34181	-0.25459
214	9.48160	0.43608	0.07701	-0.19744	0.51836	-0.19744
233	1.64723	-0.35055	-0.28294	0.13852	0.33447	0.13852
241	-9.10793	-3.78490	-0.02518	0.28323	0.69643	0.28323
262	-7.51194	-1.44904	-0.03315	-0.01733	0.13273	-0.01733
279	5.82112	3.55890	-0.08794	-0.32491	-0.40363	-0.32491
306	10.80783	-3.52998	0.01812	0.07292	0.30167	0.07292
323	1.00263	-6.92929	-0.05165	0.37629	0.17267	0.37629
342	-9.87146	-5.56859	0.03819	0.19539	0.42535	0.19539
361	6.93407	-2.10298	0.00256	-0.39199	0.34849	-0.39199
390	9.17284	4.58607	0.14751	-0.46068	-0.13672	-0.46068
407	-2.86547	3.20464	-0.03338	0.24745	-0.43833	0.24745
415	-10.48586	-3.05295	0.13426	0.61314	-0.16036	0.61314
434			-0.08172			
451			0.11592			
470			-0.00874			
489			0.08569			
497			0.05039			
518			0.13266			
535			0.15280			
543			0.03185			
562			-0.01527			
579			0.13318			
598			0.01124			
617						
625						
646						
663						
671						
690						
707						
726						

Figure Captions

1. This figure represents the r.m.s. values of the closed orbit horizontal displacement at the end of each magnet, as given in Table 1.
2. This figure represents the r.m.s. values of the closed orbit vertical displacement at the end of each magnet, as given in Table 1.
3. This figure represents the plot of the tune shifts due to the crossing of the sextupoles by the distorted closed orbit. The 21 points in the diagram correspond to the 21 different random error distributions.
4. This figure represents the plot of the beta variations due to the same reason as the tune shifts represented in Figure 3.
5. This figure represents the plot of the closed orbit horizontal displacement at each horizontal monitor/corrector element. The results are those obtained from the "worst" encountered random error distribution in the set of realistic closed orbit calculations. The term "worst" here means to describe the case of the biggest displacements in either of the two planes, seen in the group of 11 runs. The plot also includes the corrected closed orbit.
6. This figure represents the results of the same run, with the same "worst" distribution of errors, as in Figure 5, but for the vertical plane.

Figure 1

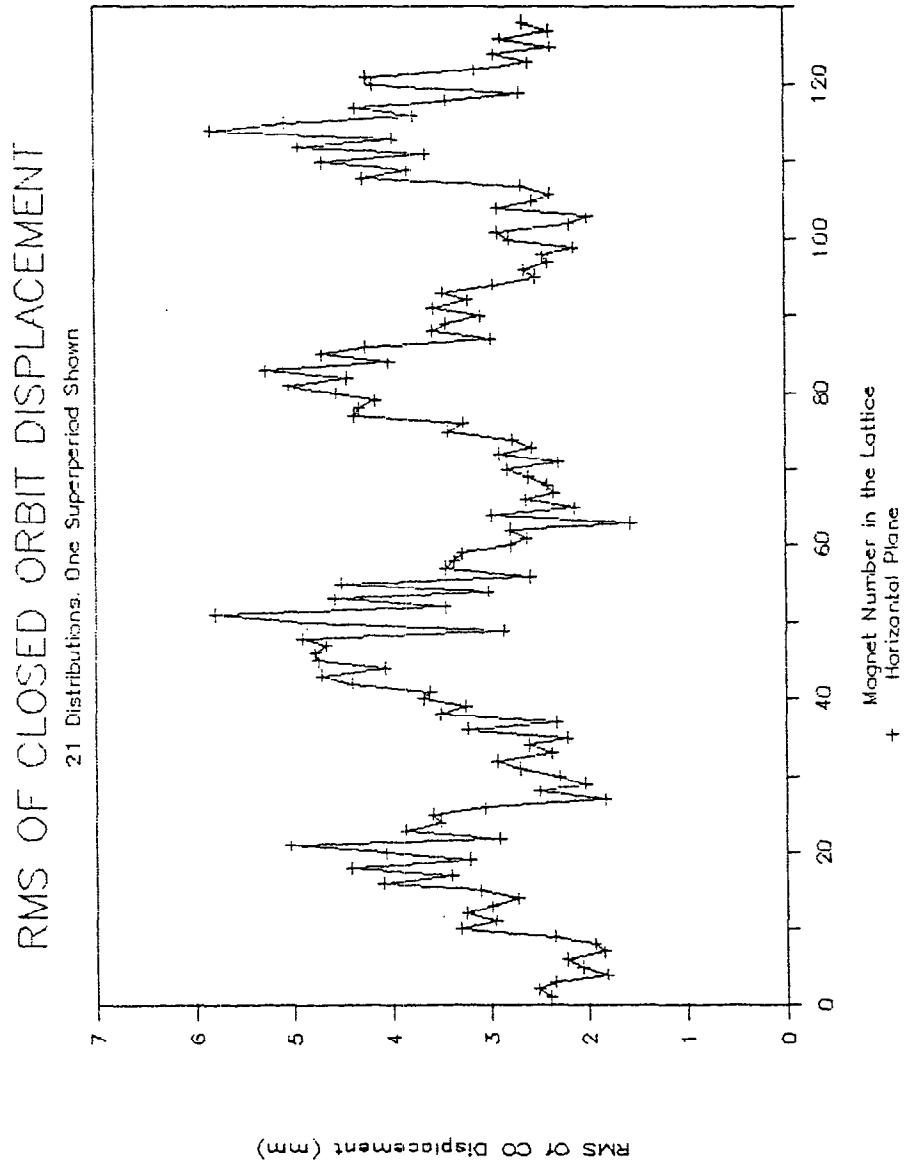


Figure 2

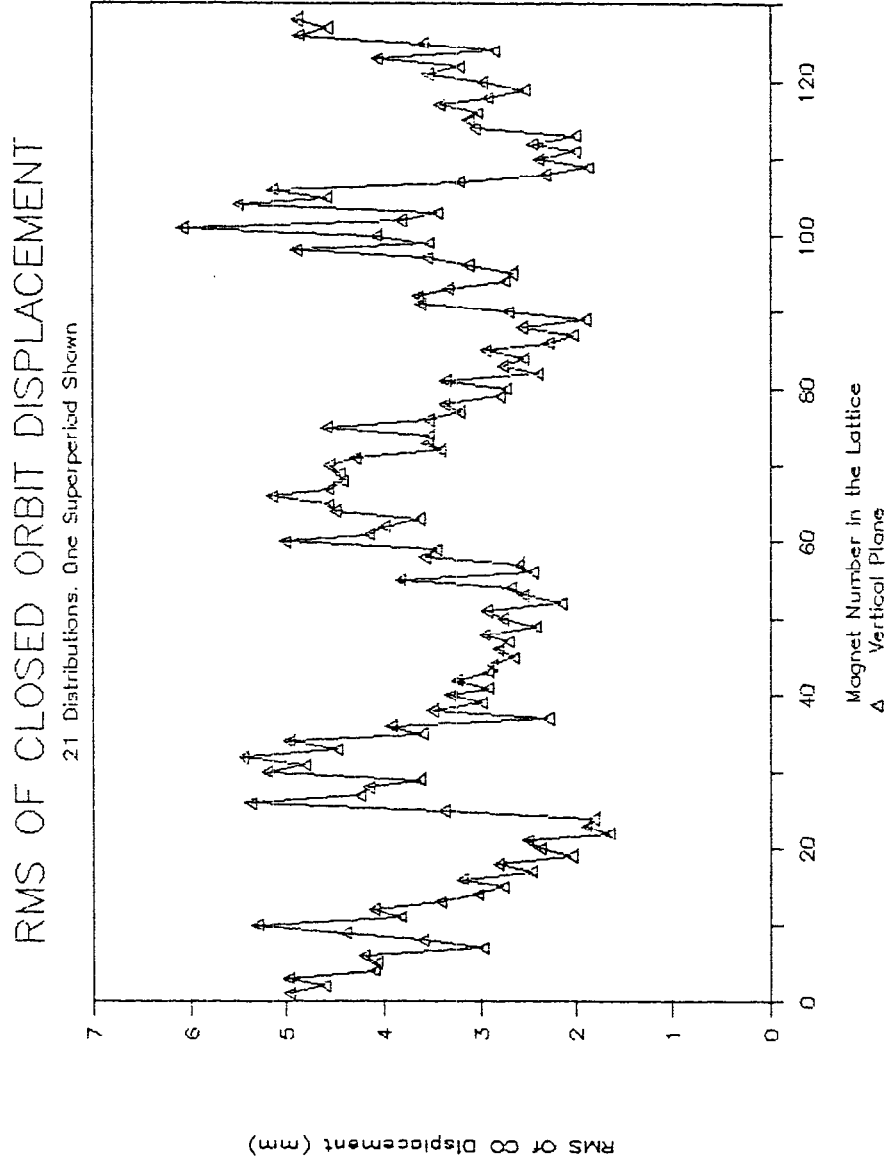


Figure 3

TUNE SHIFTS FOR 21 DISTRIBUTIONS

Source: CO Crossing With Sextupoles

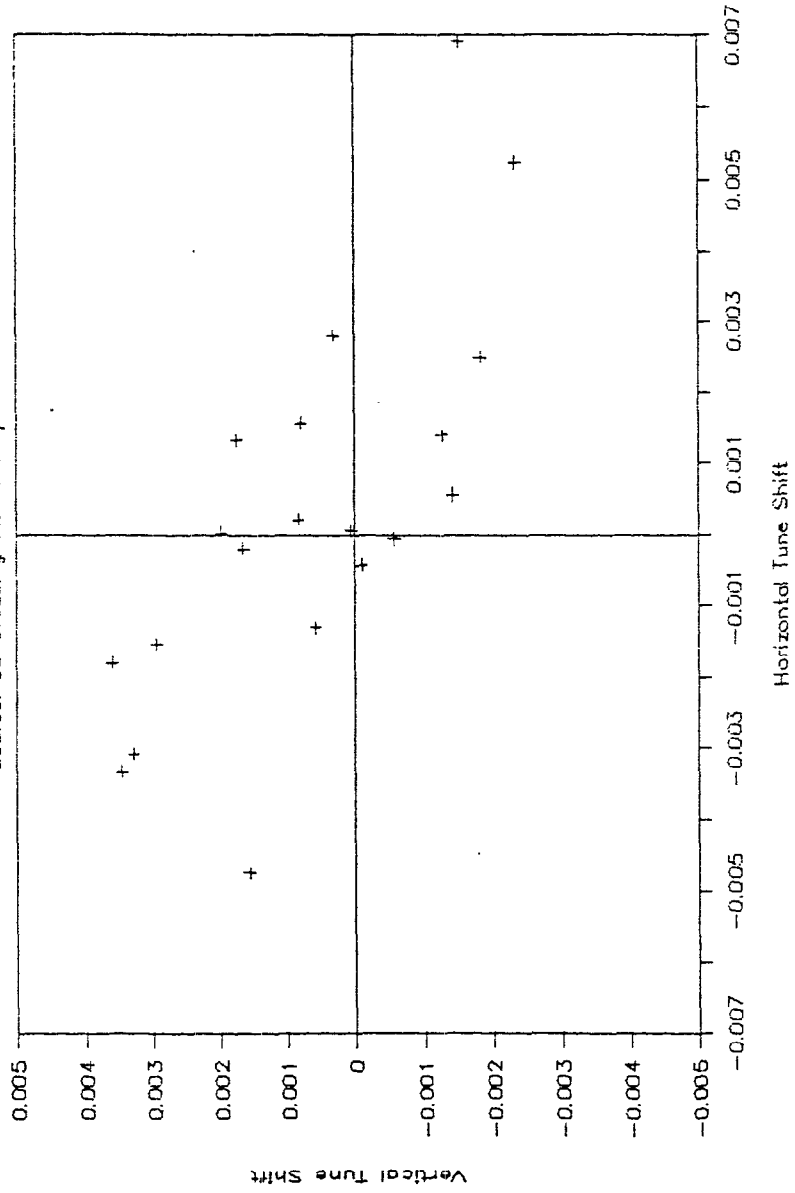
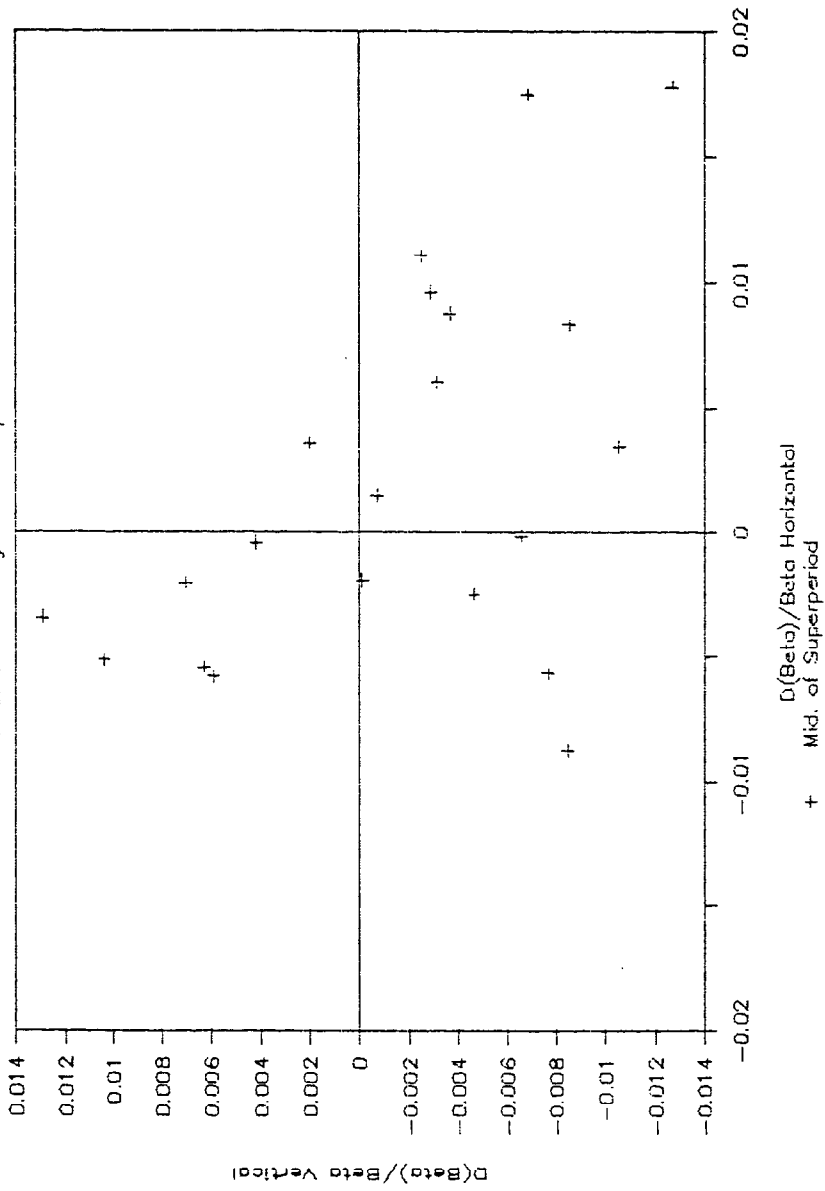


Figure 4

BETA VARIATIONS OVER 21 DISTRIBUTIONS

Source: 00 Crossing With Sextupoles



+ Mid. of Superperiod

Figure 5

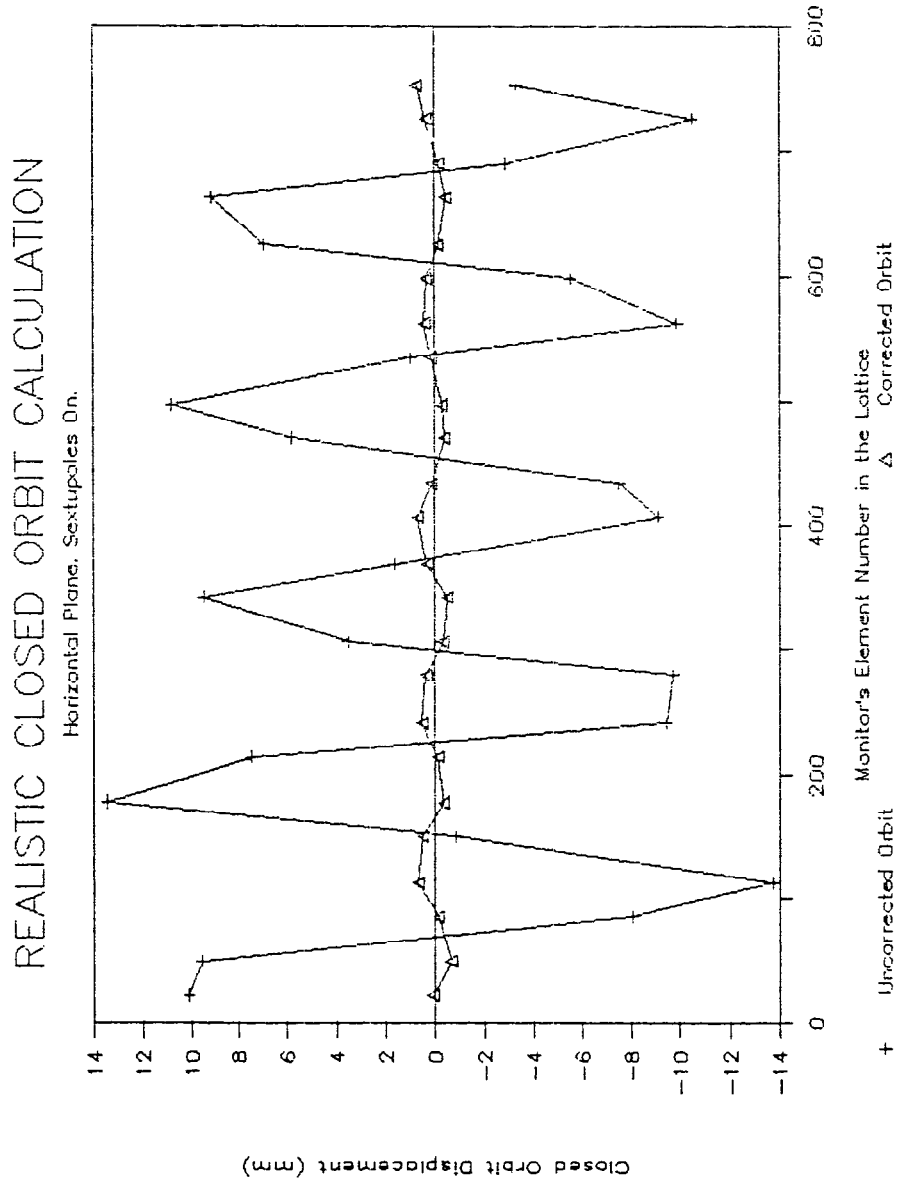


Figure 6

REALISTIC CLOSED ORBIT CALCULATION

Vertical Plane. Sextupoles On.

