CLOSED ORBIT DISTORTION IN THE NSNS ACCUMULATOR RING

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Closed Orbit Distortion and Correction in the NSNS Accumulator Ring *

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Introduction

The NSNS Accumulator Ring lattice cannot be expected to be perfect. 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 type of lattice imperfections for the closed orbit to be correctable. The type of imperfections that we have handled are the dipole integrated field strength error $\Delta(Bl / Bl)$, the dipole axial rotation error $\Delta\theta$, and the quadrupole lateral displacements in both planes. A computer code has been written for accurate calculation of the closed orbit distortion. The same program has also been used to determine the feasibility of the closed orbit correction using the local-bump method.

The NSNS Accumulator Ring

The Accumulator Ring has a threefold periodicity with internal mirror symmetry. Two modes of operation are possible: the low-tune mode with betatron tunes $Q_H = 3.82$, $Q_V = 3.78$, described in [1], and the high-tune mode with betatron tunes $Q_H = 4.23$, $Q_V = 4.27$, described in [2]. The determination of the closed orbit distortions and the closed orbit correction analysis have been carried out for both modes of operation. The lattices corresponding to the two modes are of course identical; the only difference is the setting of the quadrupole gradients. The low-tune mode is described by grouping all quadrupoles in two families QF and QD, each with a gradient setting. The high-tune mode has two more quadrupole families, QF1 and QD1, located in the long straight sections. Table 1 gives a summary of the major parameters of relevance to the closed orbit analysis. The lattice is made of 18 FODO cells. The phase advance per cell varies from cell to cell, but it is in average about 90^o.

The Sources of the Errors

We have assumed that the closed orbit distortions can be caused by three different types of magnet field imperfections and misalignment: (1) the integrated field error $\Delta(Bl / Bl)$ of the bending magnets, (ii) the axial rotation angle $\Delta\theta$ of the bending magnets, and (iii) the lateral displace-

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ment d of the quadrupole magnets, which can occur either vertically or radially. These errors have random distribution from magnet to magnet and have no correlation to each other. Thus, maybe needless to say, they break the high periodicity of the ring lattice, lowering it to the lowest value: one. It can be seen that the dipole field errors and the quadrupole radial displacements cause closed orbit distortion in the horizontal plane, whereas the dipole axial rotations and the quadrupole vertical displacements cause closed orbit distortion in the vertical plane. The errors are assumed to have a Gaussian distribution with zero average and a standard deviation that for each error has been taken as follows:

Dipole field error $\langle\Delta(Bl / Bl)\rangle$	0.25×10^{-3}
Dipole axial rotation $\langle\Delta\theta\rangle$	0.25 mrad
Quadrupole lateral displacement (H and V) $\langle d\rangle$	0.25 mm

On a computer, the errors are simulated by generating random numbers with the required distribution. Cuts in the generation are made so that errors of magnitude larger than 2.5 times the standard deviation are rejected. We have assumed that no other magnet or lattice imperfections are present. In particular we have assumed no nonlinear field errors.

Table 1: The NSNS Accumulator Ring

	Low-Tune	High-Tune
Circumference	208.6 m	208.6 m
Periodicity	3	3
Symmetry	yes	yes
Betatron Tunes, H/V	3.82 / 3.78	4.23 / 4.27
Dipole Magnets:		
Number	24	24
Length	1.5 m	1.5 m
Field	9.874 kG	9.874 kG
Quadrupoles:		
Length	0.5 m	0.5 m
QF	18 @ 0.209 kG/cm	9 @ 0.216 kG/cm
QD	18 @ 0.237 kG/cm	12 @ 0.260 kG/cm
GF1	--	9 @ 0.248 kG/cm
GD1	--	6 @ 0.271 kG/cm

Calculation of the Closed Orbit Distortion

We have followed the thin-lens method, where the errors are lumped as kicks in the middle of the corresponding magnets [3]. The closed orbit deviation y_i at the location corresponding of the i-th lattice magnet element, where the envelope function $\beta = \beta_i$ and the betatron phase advance is ψ_i, is given by

$$y_i = \sum_{j>i} \theta_j (\beta_i \beta_j)^{1/2} \cos(\pi Q + \psi_i - \psi_j) \tag{1}$$

where the summation is over all the errors of strength θ_j (in equivalent kick-angle) at the location with $\beta = \beta_i$ and phase advance $\psi_j > \psi_i$.

The equivalent kick-angles of the various errors are calculated as follows:

$$\theta_j = \theta_B \ \Delta(Bl / Bl)_j \quad \text{for the dipole field errors} \tag{2a}$$

$$= \theta_B \ \Delta\theta_j \quad \text{for the dipole rotation} \tag{2b}$$

$$= (GL / B\rho)\, d_j \quad \text{for the quadrupole displacement} \tag{2c}$$

where $\theta_B = 15^o$ is the dipole magnet bending angle, $B\rho = 5.657$ Tm is the proton magnetic rigidity, G the quadrupole gradient, and L the quadrupole length.

The location of the errors are always the middle of the dipole magnets and of the quadrupoles. The locations where the closed orbit distortion is calculated are also the middle of the dipole magnets and of the quadrupoles. We typically generate 101 random error sequences from which we calculate the expectation rms closed orbit deviations and the maximum deviations at the various locations. These are broken down as: contribution from dipole field errors alone, from dipole magnet rotation alone, from quadrupole displacement alone, and all inclusive. Also the behavior on the horizontal plane is distinguished from that on the vertical plane.

The Results

The results for the NSNS Accumulator Ring are shown in Figures 1 to 4 for the low-tune mode of operation, and in Figures 5 to 8 for the high-tune mode of operation. Because of the very low number of magnets which make the ring lattice, large statistical fluctuations are expected. Thus we decided to show both the rms expectation values and the largest values encountered of the closed orbit distortions. The behavior of each curve can be explained by noting that they correspond to different sets of 101 random number sequences; that is they were not necessarily derived from the same random seed.

The following facts can be observed. The closed orbit deviation is found to be about the same for the two tune modes of operation. The deviations are also about the same in the two planes. Finally, all errors give about the same contribution to the closed orbit distortion.

In any event, the largest deviation observed corresponds to a surrounded betatron emittance of at most 10 π mm mrad. This is small compared to the betatron acceptance of the ring of 480 π mm mrad. Thus it is possible, during the early commissioning period, to establish the first turn around in the ring using a modest pencil beam, of reduced dimension, essentially effortless. In a second phase the closed orbit distortion will be corrected as explained below, and one can then subsequently try multiturn injection of the fully blown beam.

Closed Orbit Correction

The local bump method has been used [3]. A certain number of beam monitors and dipole correctors are placed at preferred locations, which are besides the quadrupoles where the relevant beta function is large. It is assumed that the monitors have ideal sensitivity and that they are perfectly aligned with the reference orbit going through the quadrupole without a displacement. The correctors are small dipole magnets which are assumed here to provide lumped kicks. The monitors and correctors are paired in two families. One family corrects the orbit errors on the horizontal plane and is located next to the QF and QF1 quadrupoles. The other family acts on the vertical plane and is located next to the QD and QD1 quadrupoles. Thus there are 18 monitor/corrector sets working on the horizontal plane, and 18 similar sets working on the vertical plane.

The method used here assumes that the quadrupole, the corrector and the monitor of the same set are so close to each other that they actually share the same location. The required strength of the correctors is then calculated as explained in [3] from the measurements of the closed orbit deviations at the same, previous and subsequent locations of the same family.

The results for the NSNS Accumulator Ring are shown in Figures 9 and 10 for the two modes of operation. The figures show the largest strength of the correctors at various locations, as they have been determined from a series of 101 different statistical cases. It is seen that the strength of the correctors is about the same in the two planes. Also, both tune modes of operation require about the same corrector strength. The results confirm the behavior that, if small errors can cause large closed orbit distortions, the opposite holds, that is small field correctors can then correct large closed orbit deviations. Even including a safety margin factor of two, an integrated corrector field of 40 G-m is adequate for the closed orbit correction. If the correctors have a length of 20 cm, the required field is then only 200 gauss.

References

[1] A.G.Ruggiero, et al., "The NSNS Accumulator Ring", BNL/NSNS Technical Note No. 1. Brookhaven National Laboratory. August 5, 1996.

[2] A.G.Ruggiero, "Tunability of the NSNS Accumulator Ring", BNL/NSNS Technical Note No. 24. Brookhaven National Laboratory. January 31, 1997.

[3] J. Milutinovic and A.G. Ruggiero, "Closed Orbit Analysis for the AGS Booster", AD, Booster Technical Note No. 107, Brookhaven National Laboratory. February 1, 1988.

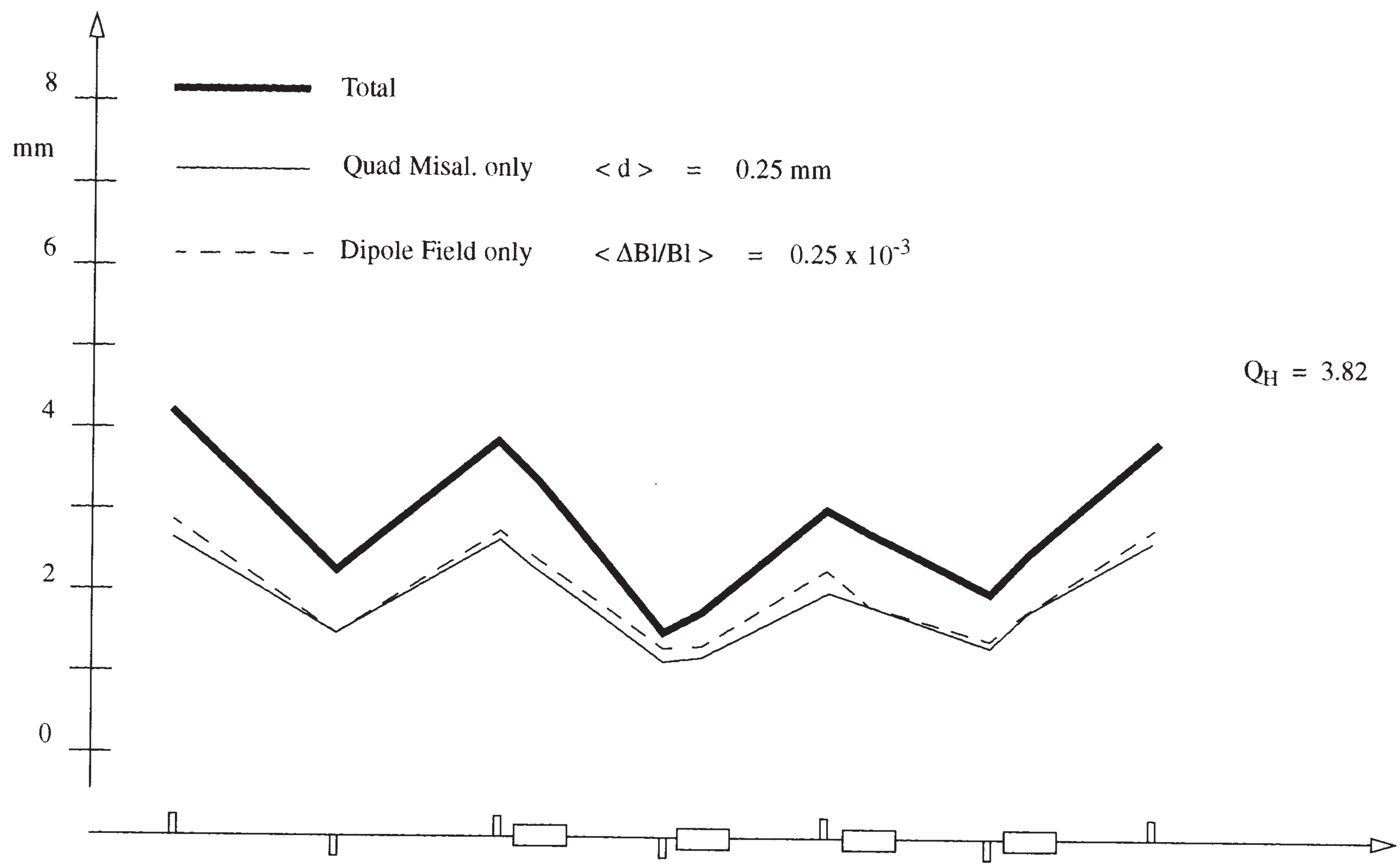

Figure 1. rms Closed Orbit Distortion in Half-Period. Low-Tune Lattice. Horizontal Plane

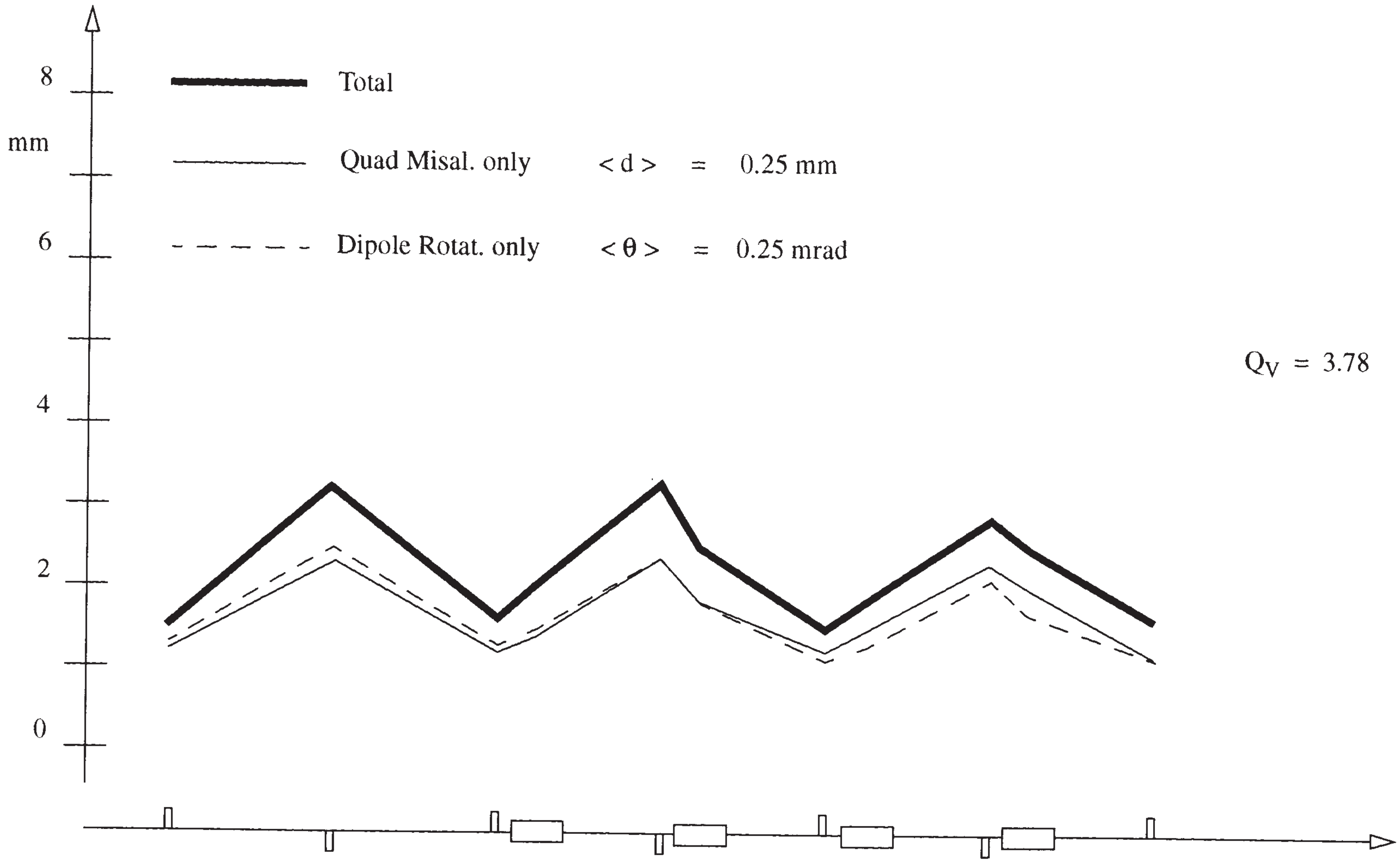

Figure 2. rms Closed Orbit Distortion in Half-Period. Low-Tune Lattice. Vertical Plane

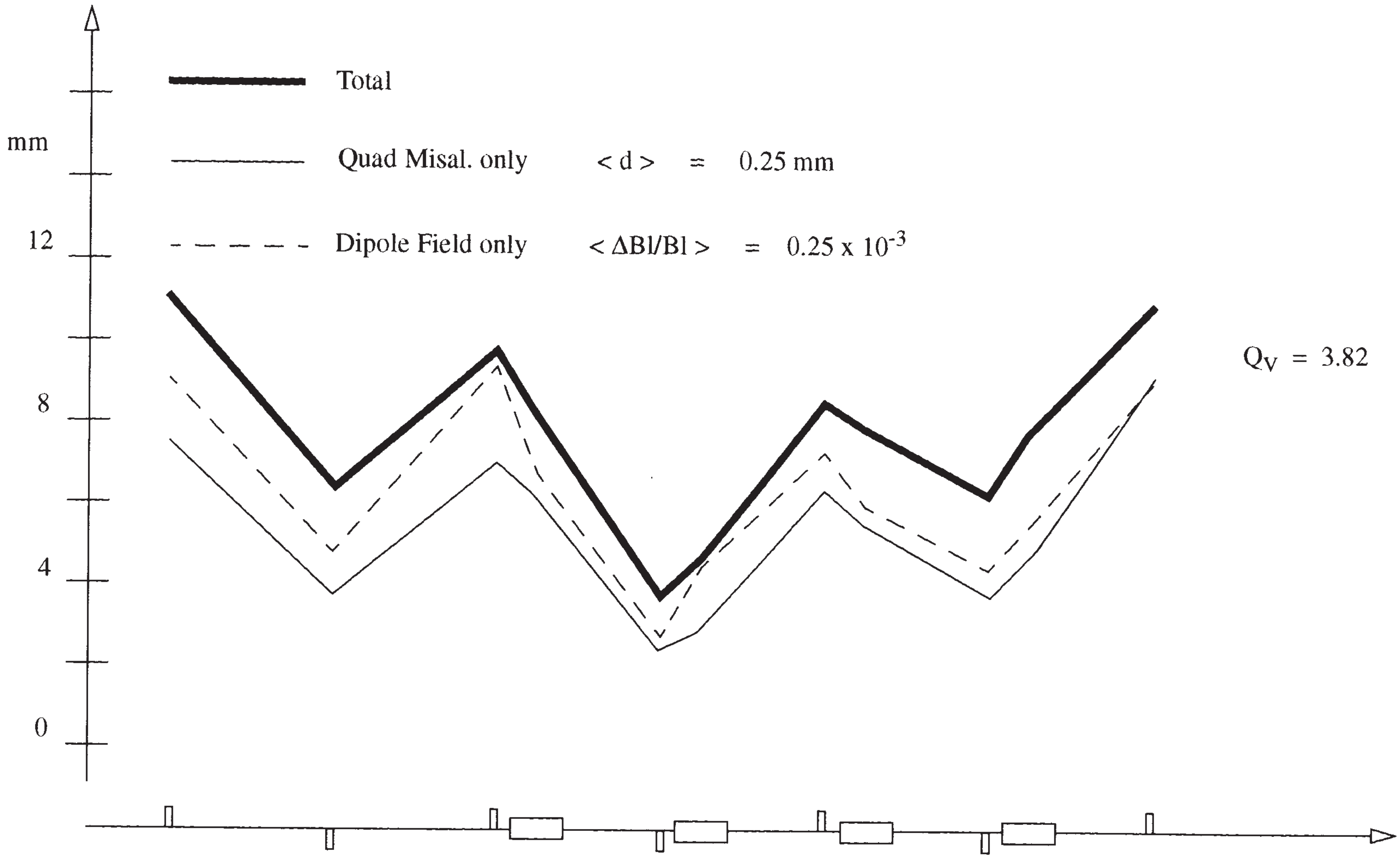

Figure 3. Largest Closed Orbit Distortion in Half-Period. Low-Tune Lattice. Horizontal Plane

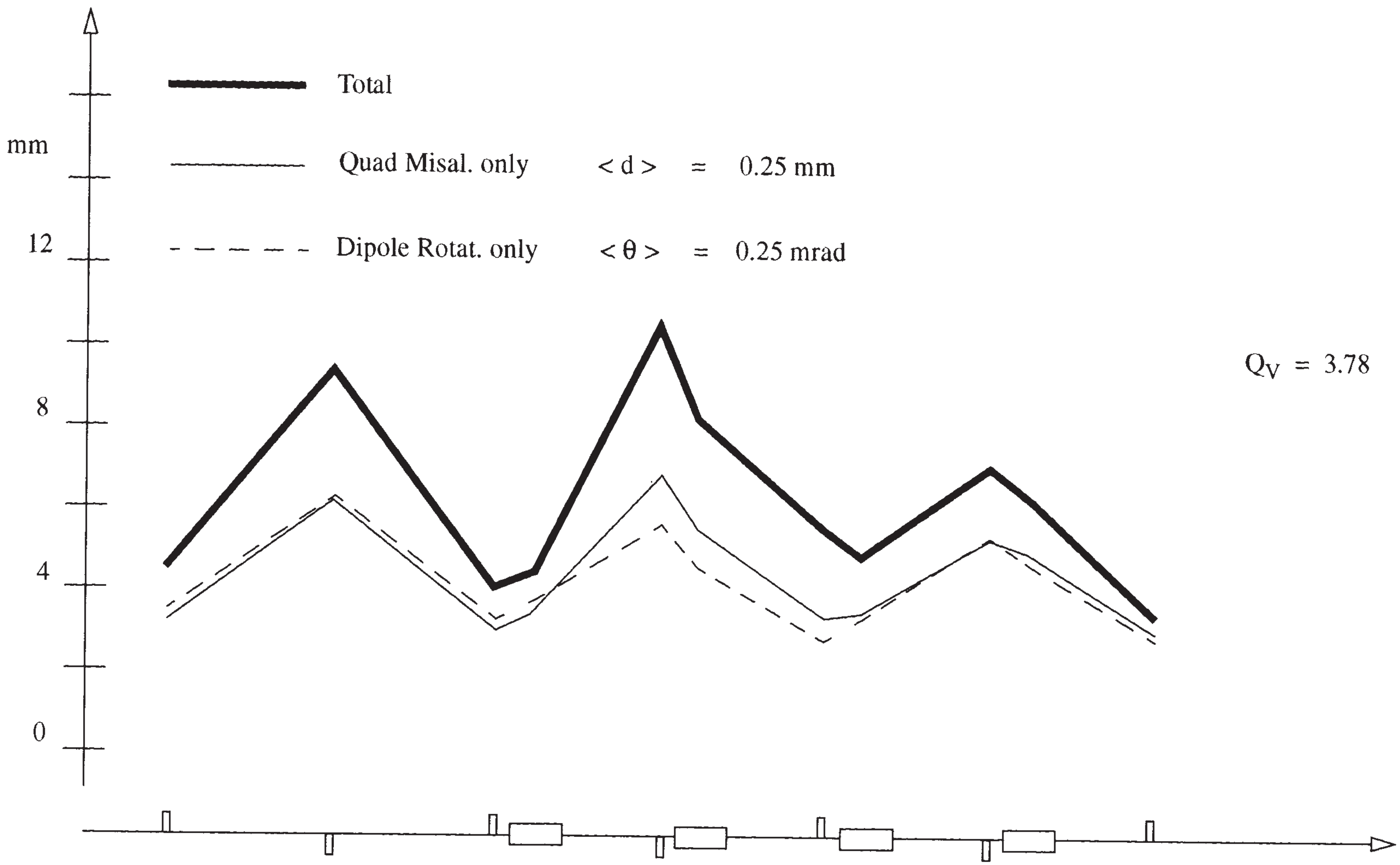

Figure 4. Largest Closed Orbit Distortion in Half-Period. Low-Tune Lattice. Vertical Plane

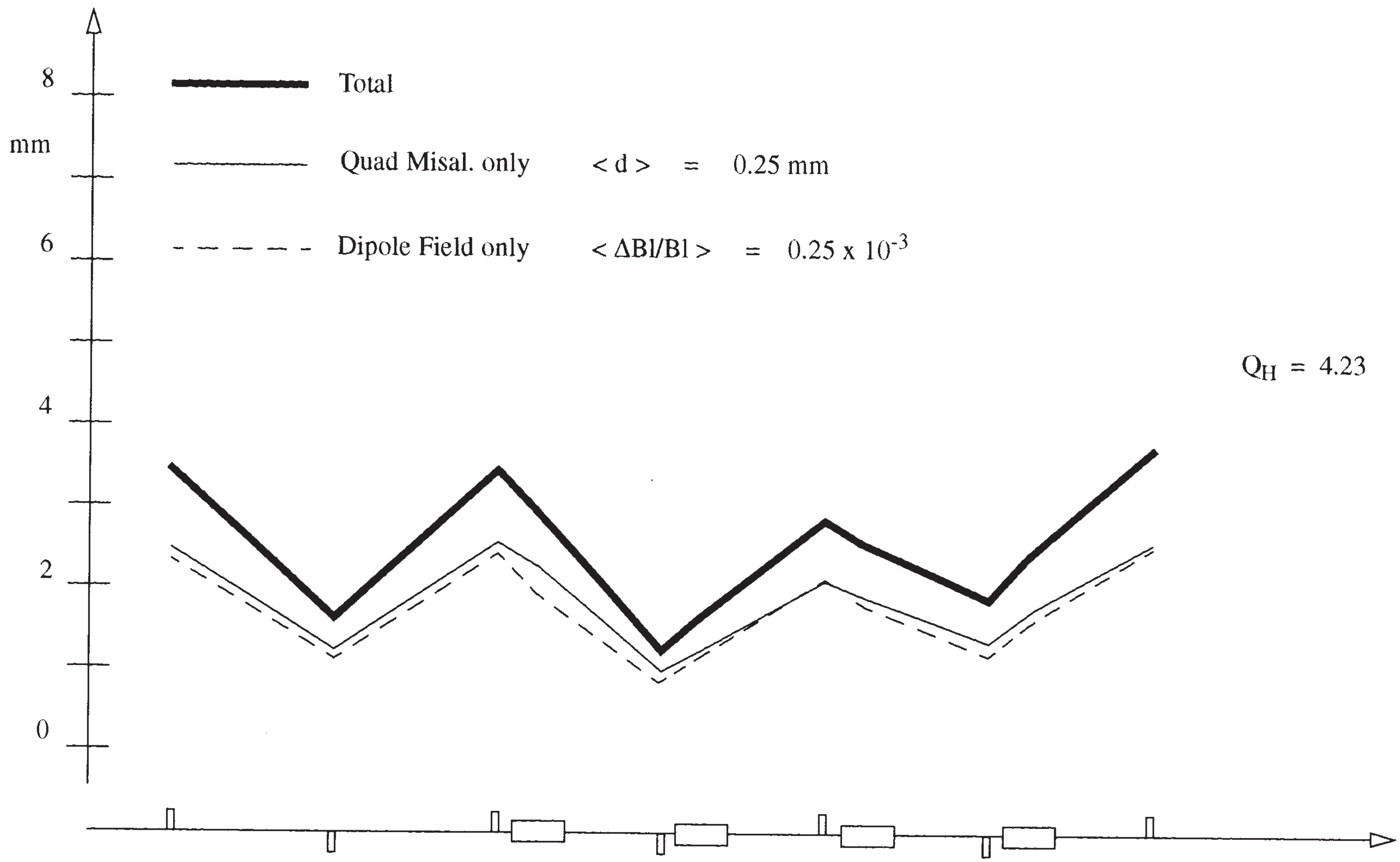

Figure 5. rms Closed Orbit Distortion in Half-Period. High-Tune Lattice. Horizontal Plane

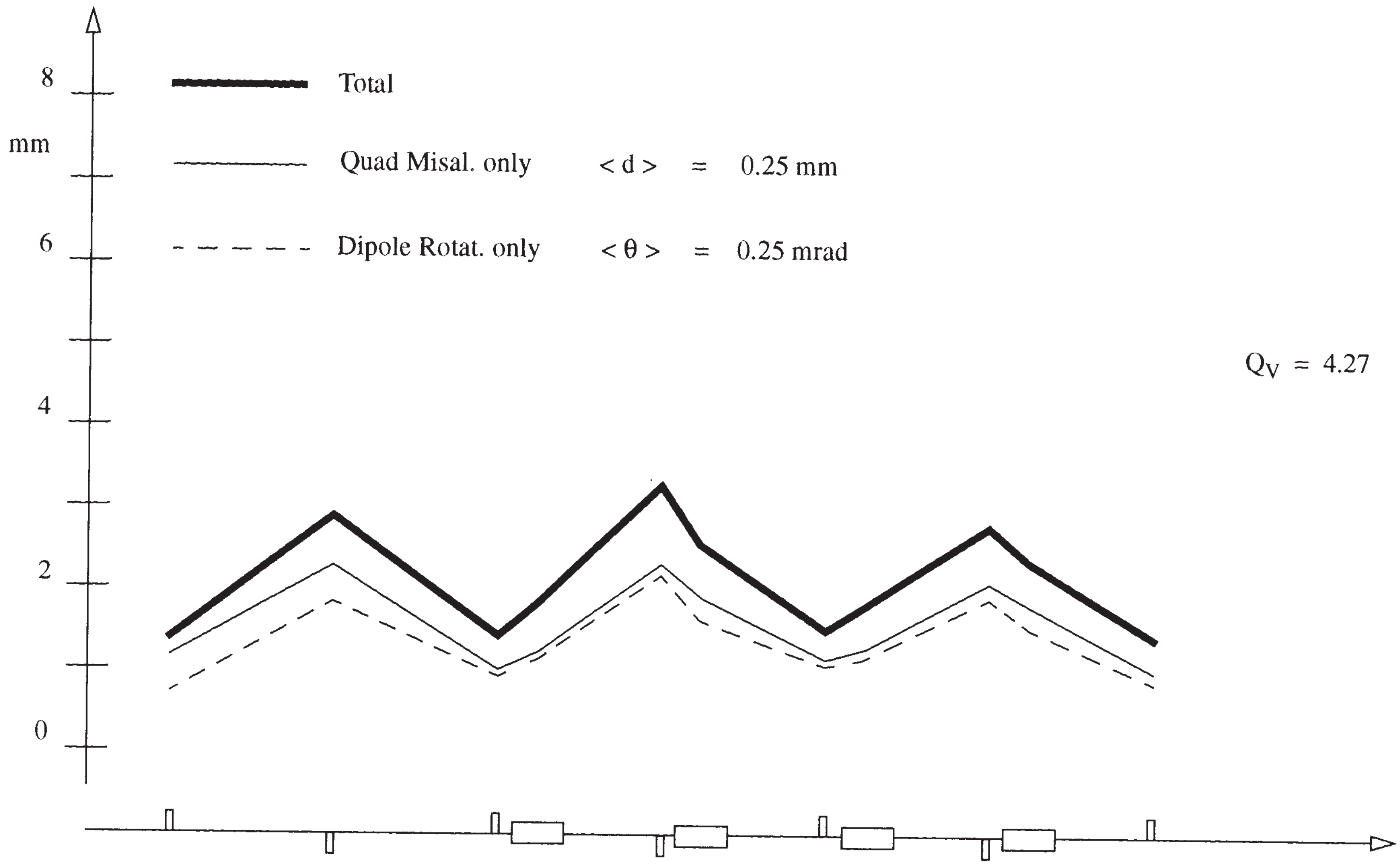

Figure 6. rms Closed Orbit Distortion in Half-Period. High-Tune Lattice. Vertical Plane

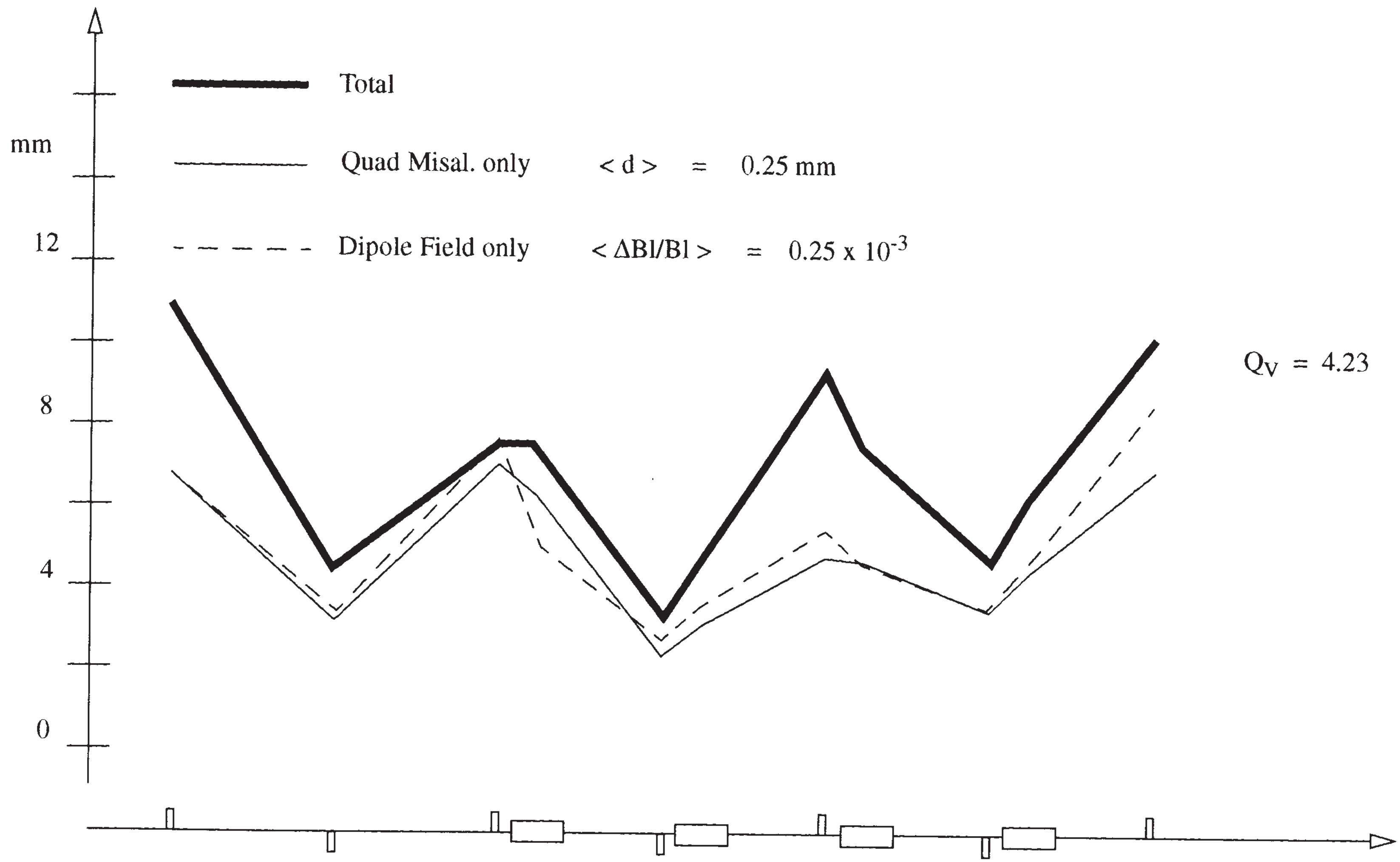

Figure 7. Largest Closed Orbit Distortion in Half-Period. High-Tune Lattice. Horizontal Plane

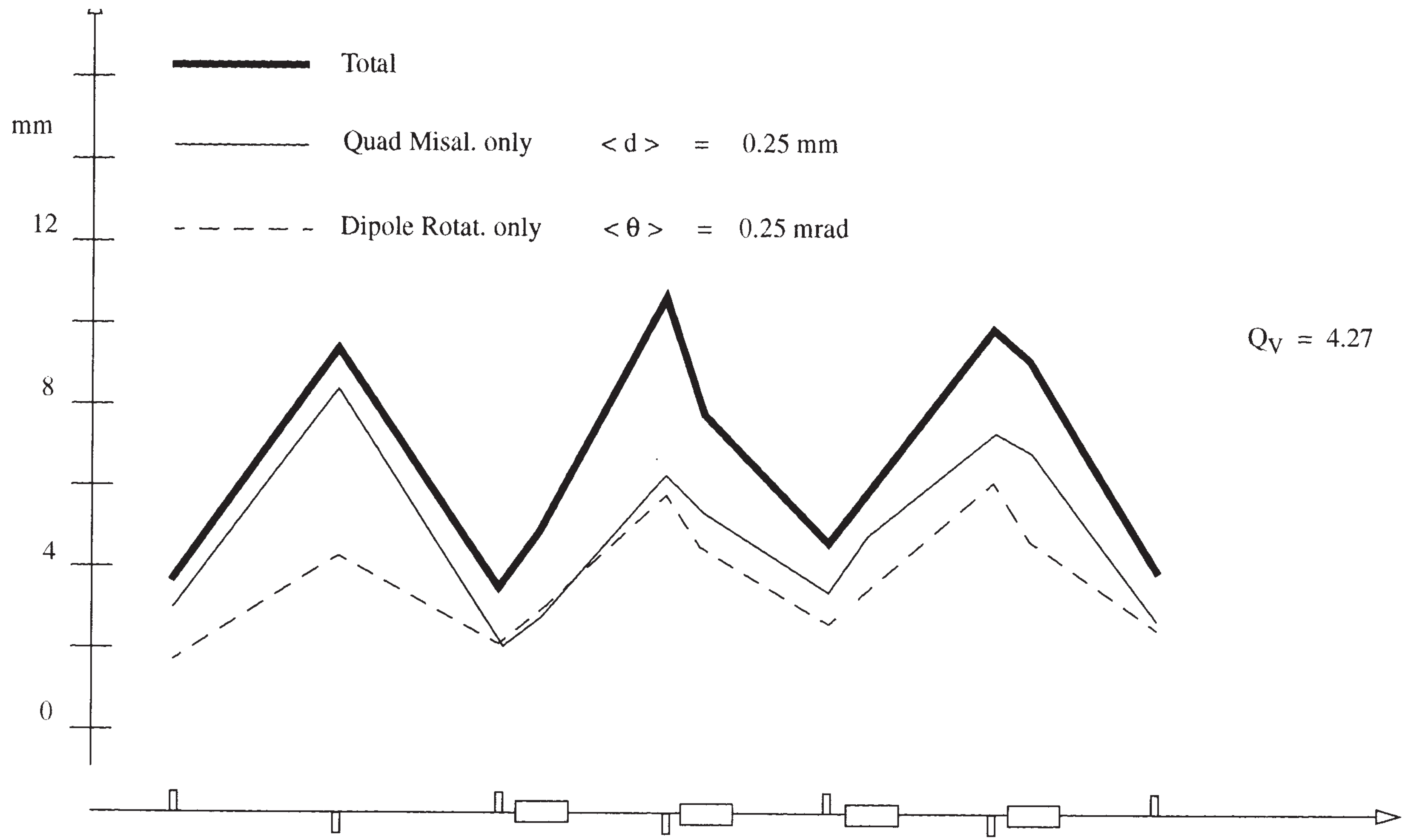

Figure 8. Largest Closed Orbit Distortion in Half-Period. High-Tune Lattice. Vertical Plane

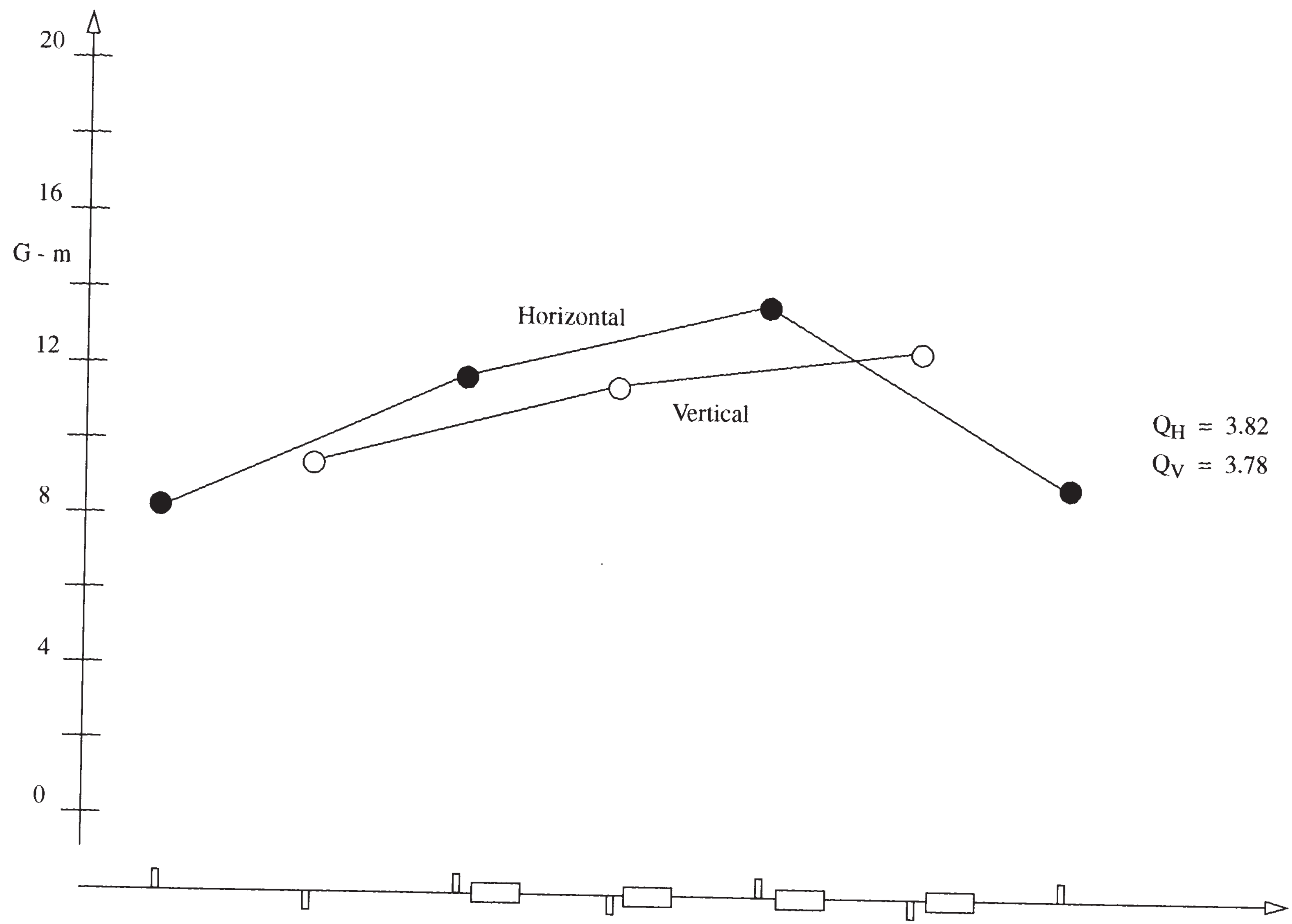

Figure 9. Maximum Corrector Strength in Half-Period. Low-Tune Lattice.

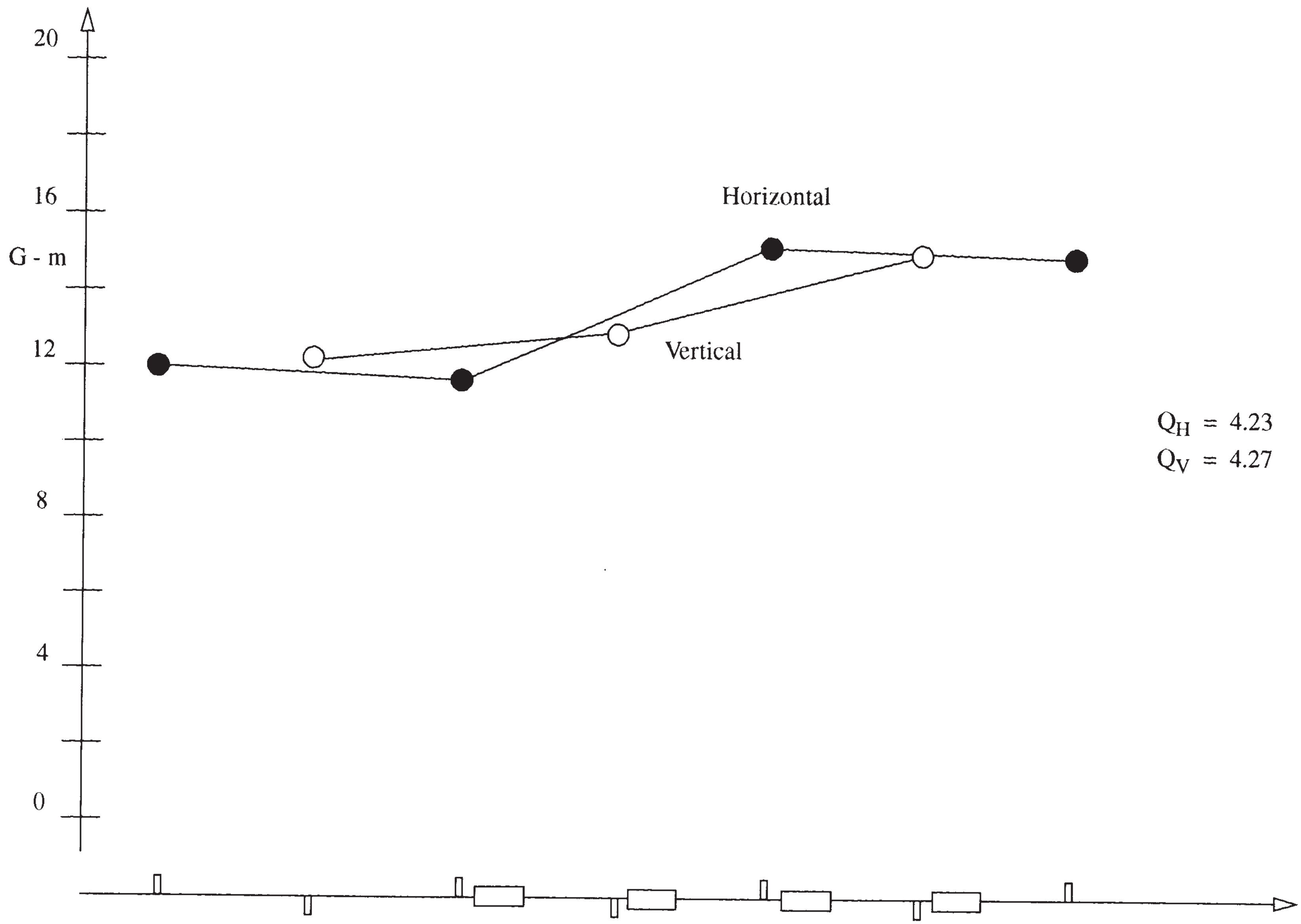

Figure 10. Maximum Corrector Strength in Half-Period. High-Tune Lattice.