SOME NOTES ON TUNING THE NSNS RING LATTICE

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1 Introduction

The four-fold symmetric lattice designed by Y.Y. Lee for the NSNS ring is described in Refs. [1, 2]. We consider here the ways in which the lattice quadrupoles can be tuned to achieve the desired betatron tunes while keeping distortions of the betatron functions and the periodic dispersion to a minimum. The effects of systematic and random quadrupole errors are also investigated.

2 The Ideal Lattice

The ideal lattice consists of four superperiods, each containing a 90° arc and a long straight section. In order to make the periodic dispersion zero in the long straight sections, the horizontal transfer matrix for each arc must be equal to the unit matrix **I** as discussed in Ref. [3]. We also require that the vertical transfer matrix for each arc be equal to **I**. To satisfy these requirements, the arcs consist of four identical FODO cells, each cell having a betatron phase advance of $\pi/2$ in both planes. Using AC to denote the Arc Cell, we write, in the notation of the MAD program [4],

AC: Line = (QF, OO, BND, O, QD, QD, OO, BND, O, QF)

where QF and QD are horizontal focusing and defocusing half-quadrupoles of length 0.25 meters, OO is a drift of length 1.55 meters, BND is a 11.25° bend of length 1.5 meters, and O is a drift of length 0.45 meters. Each arc cell is therefore 8 meters long and bends the beam 22.5°. We shall use KF and KD to denote the field gradients in quadrupoles QF and QD. The total 90° arc, consisting of 4 cells, is given by

$$\text{ARC: Line} = (\text{AC, AC, AC, AC}).$$

Two identical FODO cells without a dipole form each long straight section. We use EC to denote these Empty Cells and write

$$\text{EC: Line} = (\text{QFS, LL, LL, QDS, QDS, LL, LL, QFS})$$

where QFS and QDS are horizontal focusing and defocusing half-quadrupoles of length 0.25 meters and LL is a drift of length 2.6465 meters. Each empty cell is therefore 11.586 meters long. We shall use KFS and KDS to denote the field gradients in quadrupoles QFS and QDS. Each superperiod, starting from the center of one long straight section and going to the center of the next, is then given by

$$\text{SP: Line} = (\text{EC, ARC, EC}).$$

We use $\mu_x(AC)$ and $\mu_y(AC)$ to denote the horizontal and vertical betatron phase advances for the arc cell AC; the horizontal and vertical tunes for the entire ring are denoted by Q_x and Q_y. To obtain the values of KF and KD required to make $\mu_x(AC) = \mu_y(AC) = \pi/2$ in both planes, we apply the Match module [5] of the MAD code to the arc cell AC with the constraints $\mu_x(AC) = \mu_y(AC) = \pi/2$. The resulting values (Tesla/meter) of KF and KD are

$$\text{KF} = 3.882808, \quad \text{KD} = -4.123195. \tag{1}$$

With these values, the transfer matrix for the entire arc (ARC) will be **I** in both planes. The corresponding lattice parameters for the matched arc cell are shown in Figure (1) where the solid line is the horizontal beta function β_x, the dashed line is the vertical beta function β_y, and the dotted line is the horizontal dispersion D_x. To obtain the desired tunes for the ring, we keep KF and KD fixed at the values given by (1) and adjust KFS and KDS. Applying the Match module to the superperiod SP, we find that the values (Tesla/meter) of KFS and KDS required to give the nominal tunes, $Q_x = 5.82$ and $Q_y = 5.80$, are

$$\text{KFS} = 2.633147, \quad \text{KDS} = -2.617792. \tag{2}$$

The corresponding lattice parameters for the superperiod are shown in Figure (2). Here the maximum values (meters) of β_x, β_y, and D_x are 19.130, 19.225, and 4.101 respectively. The values (Tesla/meter) of KFS and KDS required to give various tunes are listed in Table I along with the maximum values of β_x and β_y.

Table I: Ideal Lattice Parameters

KFS	KDS	Q_x	Q_y	β_x	β_y
2.633147	−2.617792	5.820	5.800	19.130	19.225
2.323119	−2.546390	5.500	5.800	20.338	18.303
2.802707	−2.654130	5.992	5.800	19.014	19.731
2.633147	−2.617792	5.820	5.800	19.130	19.225
2.567355	−2.328728	5.820	5.500	18.272	20.404
2.673089	−2.806309	5.820	5.992	19.691	19.069
2.633147	−2.617792	5.820	5.800	19.130	19.225
2.235635	−2.235635	5.500	5.500	19.351	19.351
2.375463	−2.747311	5.500	5.992	20.978	18.194
2.747312	−2.375463	5.992	5.500	18.195	20.978
2.836559	−2.836559	5.992	5.992	19.552	19.551

3 The Actual Lattice

In the Ideal Lattice described above, the half-quadrupoles QF at the ends of the arcs are joined with the half-quadrupoles QFS at the ends of the long straight sections thereby making full-length quadrupoles having a gradient of KF for one half of the quad and KFS for the other half. Since such quadrupoles can not be made in practice, we must modify the ideal lattice so that the two halves of the end quadrupoles have the same gradient. This will amount to a small perturbation of the ideal lattice which, as we shall see, requires some careful attention as the tunes approach six. Let us define the superperiod of the actual lattice as follows:

$$\text{SP: Line} = (\text{EL, ARC, ER}).$$

where

$$\text{EL: Line} = (\text{QHC, LL, LL, QVS, QVS, LL, LL, QHE}),$$

$$\text{ER: Line} = (\text{QHE, LL, LL, QVS, QVS, LL, LL, QHC}),$$

ARC: Line = (AL, AC, AC, AR),

and

AL: Line = (QHE, OO, BND, O, QVA, QVA, OO, BND, O, QHA),

AC: Line = (QHA, OO, BND, O, QVA, QVA, OO, BND, O, QHA),

AR: Line = (QHA, OO, BND, O, QVA, QVA, OO, BND, O, QHE).

Here EL and ER are the Empty cells to the Left and Right of the arc; AL and AR are the Arc cells on the Left and Right ends of the Arc. The drifts and bends are the same as those in the ideal lattice and each of the quadrupoles is a half-quadrupole of length 0.25 meters. In the labeling of the quadrupoles, QH and QV denote horizontal and vertical focusing quadrupoles, and the additional letters A, E, S, C denote quadrupoles located in the Arcs, at the Ends of the arcs, in the long Straight sections, and at the Center of the long straight sections. With the lattice superperiod defined in this way, the half-quads QHE at the ends of the arcs are joined with the same half-quads at the ends of the long straight sections.

We use KHA, KVA, KHE, KHC, KVS to denote the field gradients in quadrupoles QHA, QVA, QHE, QHC, QVS. To ensure that the dispersion is zero in the long straight sections of the actual lattice, it is sufficient to set the gradients of quadrupoles QHA and QVA equal to those of the corresponding quadrupoles of the ideal lattice. Thus we have

$$\mathrm{KHA} = \mathrm{KF} = 3.882808, \quad \mathrm{KVA} = \mathrm{KD} = -4.123195. \tag{3}$$

As a first approximation for the settings of the end quadrupoles (QHE) and the straight section quadrupoles (QHC and QVS) we set

$$\mathrm{KHE} = \frac{1}{2}(\mathrm{KF} + \mathrm{KFS}), \quad \mathrm{KHC} = \mathrm{KFS}, \quad \mathrm{KVS} = \mathrm{KDS}. \tag{4}$$

The actual lattice is then the same as the ideal lattice except for the values of the gradients in the end quads. Because of the four-fold symmetry of the ring, these quads introduce a 12th harmonic quadrupole perturbation that can excite the $2Q_x = 12$ and $2Q_y = 12$ resonances. As the tunes approach six, we therefore expect some beta function distortion. To correct for this effect, we apply a small correction, KE, to KHE and adjust its value to minimize the beta function distortion. At the same time we apply a correction −2∗KE to the center quads QHC so that there is no change in the tunes (to first order). Thus we have

$$\mathrm{KHE} = \frac{1}{2}(\mathrm{KF} + \mathrm{KFS}) + \mathrm{KE}, \quad \mathrm{KHC} = \mathrm{KFS} - 2{*}\mathrm{KE}. \tag{5}$$

Using the Match module of the MAD code with appropriate constraints on the beta function we obtain the values (Tesla/meter) of KFS, KDS, and KE required to give various tunes while keeping the beta function distortion to a minimum. The results are listed in Table II along with the maximum values of β_x and β_y (meters).

Table II: Actual Lattice Parameters						
KFS	KDS	KE $\times 10^3$	Q_x	Q_y	β_x	β_y
2.630007	−2.616449	−1.135565	5.820	5.800	19.062	19.207
2.318054	−2.544043	−1.259121	5.500	5.800	20.247	18.275
2.800399	−2.653185	−1.052921	5.992	5.800	18.955	19.718
2.630007	−2.616449	−1.135565	5.820	5.800	19.062	19.207
2.563762	−2.326891	−1.258435	5.820	5.500	18.202	20.383
2.670187	−2.805179	−1.063944	5.820	5.992	19.624	19.194
2.630007	−2.616449	−1.135565	5.820	5.800	19.062	19.207
2.229719	−2.232356	−1.394014	5.500	5.500	19.256	19.316
2.370821	−2.745334	−1.180672	5.500	5.992	20.890	18.441
2.744694	−2.374182	−1.164053	5.992	5.500	18.135	20.962
2.834419	−2.835763	−0.987781	5.992	5.992	19.494	19.633

Comparing these numbers with those listed in Table I we see that with the appropriate correction KE we get similar values for the maximum of the beta function. Figures (3) and (4) show the effect of the correction for the case in which $Q_x = 5.992$ and $Q_y = 5.80$. Here we see that without the correction, the maximum value of β_x is 25 meters; this is reduced to 19 meters with the appropriate correction. Figures (5) and (6) show the effect of the correction for the case in which the tunes are set at the nominal operating point ($Q_x = 5.82$, $Q_y = 5.80$). Here the effect is small because the tunes are sufficiently far from six. The effect of the correction for the case in which $Q_x = 5.82$, $Q_y = 5.992$ is shown in Figures (7) and (8). Here we see that even with the vertical tune close to six, the distortion of the vertical beta function is small. This is because the end quads are located at vertical beta minima and therefore do not significantly perturb the vertical lattice parameters.

4 Quadrupole Strings

To provide sufficient tuning flexibility, the lattice quadrupoles will have main and trim windings that will be wired together to form several different series strings. To facilitate the description of the strings we label the four superperiods of the ring A, B, C, and D which we take to run along the beam direction from the beginning of one arc to the next. The order of magnets in each superperiod X is DHX1, QVX1, DHX2, QHX2, ..., DHX8, QHX8, QVX9, QHX10, QVX11, and QHX12, where D and Q denote Dipoles and Quadrupoles and H and V refer to the Horizontal and Vertical planes. The long straight section in superperiod X runs from QHX8 through QHX12. In terms of the half-quadrupoles defined in Section 3 we have

QVX1: Line = (QVA, QVA), QHX2: Line = (QHA, QHA)

QVX3: Line = (QVA, QVA), QHX4: Line = (QHA, QHA)

QVX5: Line = (QVA, QVA), QHX6: Line = (QHA, QHA)

QVX7: Line = (QVA, QVA), QHX8: Line = (QHE, QHE)

QVX9: Line = (QVS, QVS), QHX10: Line = (QHC, QHC)

QVX11: Line = (QVS, QVS), QHX12: Line = (QHE, QHE).

In the actual ring, the lengths of quadrupoles QHX2, QHX4, and QHX6 will be adjusted so that with the main windings of all 28 arc quadrupoles (QVX1, QHX2, ..., QVX7) connected in a series string to one power supply, the current in the string can be adjusted to give zero dispersion in the long straight sections. We use PSA to denote this string and its power supply (here A stands for Arc). The main windings of the 12 Horizontal quads (QHX8, QHX10 and QHX12) in the long straight sections will be connected in a series string PSH powered by a supply with the same name; the main windings of the 8 Vertical quads (QVX9 and QVX11) will be connected in a series string PSV. Thus we write

$$\mathrm{PSA} = \mathrm{QVX1} + \mathrm{QHX2} + \cdots + \mathrm{QVX7},$$

$$\mathrm{PSH} = \mathrm{QHX8} + \mathrm{QHX10} + \mathrm{QHX12}, \qquad \mathrm{PSV} = \mathrm{QVX9} + \mathrm{QVX11}$$

where X indicates that the quadrupoles from all four superperiods A, B, C, D are included in the string. Power supplies PSH and PSV will be used to adjust the tunes of the ring.

To correct for any systematic errors in the relative strengths of the horizontal and vertical quads in the arcs, quads QHX2, QHX4, and QHX6 will have trim windings that are connected together to form two series strings TRMA and TRMB. Thus

$$\mathrm{TRMA} = \mathrm{QHX2} + \mathrm{QHX6}, \qquad \mathrm{TRMB} = \mathrm{QHX4}.$$

To allow for independent adjustment of the Center and End quads in the long straight sections, quads QHX8, QHX10, and QHX12 will have trim windings that are connected together to form two series strings TRMC and TRME. Thus

$$\mathrm{TRMC} = \mathrm{QHX10}, \qquad \mathrm{TRME} = \mathrm{QHX8} + \mathrm{QHX12}.$$

These strings allow one to apply the correction KE discussed in the previous section. To correct distortions of the vertical beta function, quads QVX9 and QVX11 will have trim windings that are connected together to form string TRMV. Thus

$$\mathrm{TRMV} = \mathrm{QVX9} - \mathrm{QVX11}.$$

Here the $-$ sign indicates that trim winding of QVX11 is connected in the string with polarity opposite that of QVX9. This ensures that the string does not alter the tunes (to first order).

Each of the eight strings (PSA, PSH, PSV, TRMA, TRMB, TRMC, TRME, TRMV) defined above maintains the four-fold symmetry of the ring, and, except for TRMV, they are the same as those originally proposed by Y.Y. Lee. For the correction of random quadrupole errors it is necessary to have an additional set of trim windings connected together in strings that break the four-fold symmetry. We define these as follows:

$$\mathrm{XTRMA} = \mathrm{QHA2} - \mathrm{QHB2} + \mathrm{QHC2} - \mathrm{QHD2}$$

$$- \mathrm{QHA6} + \mathrm{QHB6} - \mathrm{QHC6} + \mathrm{QHD6},$$

$$\mathrm{XTRMB} = \mathrm{QHA4} - \mathrm{QHB4} + \mathrm{QHC4} - \mathrm{QHD4},$$

$$\mathrm{XTRM1} = \mathrm{QHA10} - \mathrm{QHC10}, \quad \mathrm{XTRM2} = \mathrm{QHB10} - \mathrm{QHD10}$$

$$\mathrm{XTRM3} = \mathrm{QVA11} - \mathrm{QVC11}, \quad \mathrm{XTRM4} = \mathrm{QVB11} - \mathrm{QVD11}.$$

Here XTRM stands for eXtra TRiM, and the + and − signs indicate the relative polarities of the quadrupoles in each string. In the XTRMA and XTRMB strings, quadrupoles separated by an azimuthal angle of $\pi/2$ are excited with opposite polatities and therefore produce only azimuthal harmonics 2, 6, 10, 14, and so on. Similarly, in the XTRM1, XTRM2, XTRM3, and XTRM4 strings, quadrupoles separated by an azimuthal angle of π are excited with opposite polarities and therefore produce only harmonics 1, 3, 5, 7, 9, 11, and so on. The use of these strings will be discussed in the next sections.

5 Distortions of Dispersion and Beta

If the arc quadrupoles, QHA and QVA, do not have the gradients given by (3), then the periodic dispersion may not be zero in the long straight sections. Let us assume that

$$\mathrm{KHA} = \mathrm{KF}(1 + \Delta_{\mathrm{F}}), \quad \mathrm{KVA} = \mathrm{KD}(1 + \Delta_{\mathrm{D}}) \tag{6}$$

where KF and KD are the nominal gradients required to give zero dispersion. The lattice parameters obtained for various values of Δ_{F} and Δ_{D} are listed in Table III. Here the straight section quadrupoles have been adjusted to give the indicated tunes, and D_{A} and D_{S} are the resulting extreme values (in meters) of the periodic dispersion in the Arcs and Straight sections respectively. The maximum values (meters) of β_x and β_y are also given.

Table III: Effect of Arc Quad Variations							
Δ_F (%)	Δ_D (%)	Q_x	Q_y	β_x	β_y	D_A	D_S
+1	+1	5.820	5.800	19.214	18.881	4.028	+0.104
−1	−1	5.820	5.800	19.566	19.672	4.174	−0.108
+1	0	5.820	5.800	19.518	19.102	3.994	+0.132
−1	0	5.820	5.800	19.311	19.314	4.208	−0.137
0	+1	5.820	5.800	19.103	18.985	4.135	−0.028
0	−1	5.820	5.800	19.663	19.550	4.067	+0.029
+1	+1	5.992	5.800	19.800	19.387	4.041	+0.102
−1	−1	5.992	5.800	20.250	20.158	4.159	−0.107
+1	0	5.992	5.800	20.513	19.607	4.012	+0.130
−1	0	5.992	5.800	20.494	19.827	4.190	−0.135
0	+1	5.992	5.800	19.057	19.493	4.131	−0.028
0	−1	5.992	5.800	19.547	20.031	4.071	+0.028

Figures (9) and (10) show the lattice parameters obtained for the case in which $\Delta_F = \pm 1\%$ with tunes $Q_x = 5.992$, $Q_y = 5.80$. Here, and in the Table, we see that even with the horizontal tune close to six, the distortion of the dispersion in the straight sections is at most ± 0.14 meters. The reason for the relatively small distortion is that the quadrupole perturbation introduced by KHA does not have any sixth harmonic component. Only if the four-fold symmetry of the arc quadrupoles is broken will there be a sixth harmonic component that can produce significant distortion of the dispersion.

Let us suppose, then, that the gradient KHA of the horizontal quadrupole in the center of one of the arcs, say QHA4, is just 0.1 percent higher than the nominal value given by (3). The resulting lattice parameters for the case in which $Q_x = 5.992$ and $Q_y = 5.80$ are shown in Figure (11). Here we see a significantly larger distortion of the dispersion for a much smaller quadrupole perturbation. To compensate for this kind of perturbation we need to produce a sixth harmonic which cancels that produced by the perturbation. This can be done with the quadrupole strings XTRMA and XTRMB defined in the previous section. Using the Match module of the MAD code with appropriate constraints on the dispersion, we find that we can correct the dispersion distortion with the gradients in string XTRMA set to zero and those in string XTRMB set to -9.71×10^{-4} Tesla/meter. This is just what we expect for the error of 0.001×3.882808 in the setting of QHA4. Figure (12) shows the corrected lattice parameters.

As a further test of the ability of strings XTRMA and XTRMB to correct distortions of the dispersion, we use the Efield command [6] of the MAD code to generate Gaussian distributions of quadrupole errors in the ring. We take the RMS deviation of the distributions to be 0.1 percent of the nominal quadrupole gradients and impose a cutoff of 2.5 standard deviations. Figure (13) shows the lattice parameters obtained from an error distribution with a seed of 7777. Here the tunes have been adjusted to be $Q_x = Q_y = 5.992$ after the errors have been generated, but no further corrections have been applied. Because the tunes are close to six, we see significant distortion of the dispersion and the beta functions. Using the Match module with appropriate constraints on the dispersion, we find that we can correct the dispersion distortion with the gradients in string XTRMA set to 2.644×10^{-3} and those in string XTRMB set to 1.366×10^{-3} Tesla/meter. Using the Match module again with appropriate constraints on the beta functions we find that we can minimize the beta function distortion with KE set to -1.518×10^{-3} and the gradients of the quads in string TRMV set to 0.236×10^{-3} Tesla/meter. Figure (14) shows the resulting lattice parameters with these corrections. The results of carrying out the analysis with several different seeds are summarized in Table IV.

Table IV: Beta and Dispersion Corrections
$Q_x = Q_y = 5.992$ (Gradients in units of 10^{-3} T/m)

Seed	KFS	KDS	KE	TRMV	XTRMA	XTRMB
7777	2835.144	−2831.689	−1.518	+0.236	+2.644	+1.366
6777	2836.492	−2837.919	+0.043	−0.393	−0.324	+1.505
5777	2830.878	−2838.450	−1.837	−3.400	−1.397	−2.327
4777	2834.847	−2836.694	−0.794	−0.369	−1.996	−0.476
3777	2834.964	−2834.670	−0.227	+0.596	+0.487	+0.425
2777	2835.790	−2837.040	−0.850	−0.689	+1.819	+0.002
1777	2835.752	−2833.118	−0.516	−1.729	+1.715	+1.164

6 $2Q_x = 11$ and $2Q_y = 11$ Resonance Correction

If the tunes are near either the $2Q_x = 11$ or the $2Q_y = 11$ resonance, then quadrupole errors that have an azimuthal 11th harmonic can excite the resonance and produce significant distortions of the beta function. To cancel the 11th harmonic components of the quadrupole errors, we use the strings XTRM1, 2, 3, 4 defined in Section 4. To test the ability of the strings to correct the resonances, we again use the Efield command of the MAD code to generate Gaussian distributions of quadrupole errors in the ring. We take the RMS deviation of the distributions to be 0.1 percent of the nominal quadrupole gradients and impose a cutoff of 2.5 standard deviations. Figure (15) shows the lattice parameters obtained from an error distribution with a seed of 7777. Here the tunes have been adjusted to be $Q_x = Q_y = 5.508$ after the errors have been generated, but no further corrections have been applied. (Actually, the dispersion has been corrected here too, but the effect of this correction with $Q_x = Q_y = 5.508$ is very small.) Using the Match module with appropriate constraints on the beta functions we find that we can minimize the beta function distortion with the gradients of the quads in strings XTRM1, 2, 3, 4 set to −2.333, −5.951, −3.428, and 11.82 $\times 10^{-3}$ Tesla/meter respectively. Figure (16) shows the resulting lattice parameters with these corrections. The results of carrying out the analysis with several different seeds are summarized in Table V.

Table V: Correction of the $2Q_x = 11$ and $2Q_y = 11$ Resonances $Q_x = Q_y = 5.508$ (Gradients in units of 10^{-3} T/m)						
Seed	KFS	KDS	XTRM1	XTRM2	XTRM3	XTRM4
7777	2240.269	−2238.156	−2.333	−5.951	−3.428	+11.82
6777	2242.873	−2245.721	−1.831	+2.253	−8.032	+3.578
4777	2240.784	−2243.997	+2.428	−4.375	−2.608	+9.933
3777	2240.893	−2242.070	+5.567	−4.035	+0.228	+4.895
2777	2241.911	−2244.586	+2.558	+5.028	−3.388	−1.980
1777	2241.216	−2240.044	−1.368	+1.173	−7.458	+3.448
0777	2239.480	−2240.771	−1.561	+0.266	+4.648	−9.778

7 Acknowledgement

I would like to thank Jim Niederer for his help and advice in using the MAD code. The calculations carried out here would not have been possible without his most recent version of the code [5, 6].

8 References

1. Y.Y. Lee, "The 4 Fold Symmetric Lattice for the NSNS Accumulator Ring", BNL/NSNS Tech. Note No. 026, February 19, 1997.

2. C.J. Gardner, Y.Y. Lee, and A.U. Luccio, "Accumulator Ring Lattice for the National Spallation Neutron Source", Proceedings of the 1997 Particle Accelerator Conf., Vancouver, B.C., Canada, May 12–16, 1997.

3. K.L. Brown and R.V. Servranckx, "First and Second-Order Charged Particle Optics", Physics of High Energy Particle Accelerators, AIP Conf. Proceedings No. 127, American Institute of Physics, New York, 1985, p. 134.

4. H. Grote and F.C. Iselin, "The MAD Program Version 8.4 User's Reference Manual", CERN/SL/90–13 (AP), 27 August 1991.

5. J. Niederer, "BNL MAD Program Notes—Fmatch: Enhanced Matching Commands", AGS/AD/Tech. Note No. 436, June 3, 1996.

6. J. Niederer, "BNL MAD Program Notes—Upgrade to Version 7C", AGS/AD/Tech. Note No. 463, July 14, 1997.

Figure 1: Arc Cell (AC) Lattice Parameters

Matched with Mux = Muy = pi/2

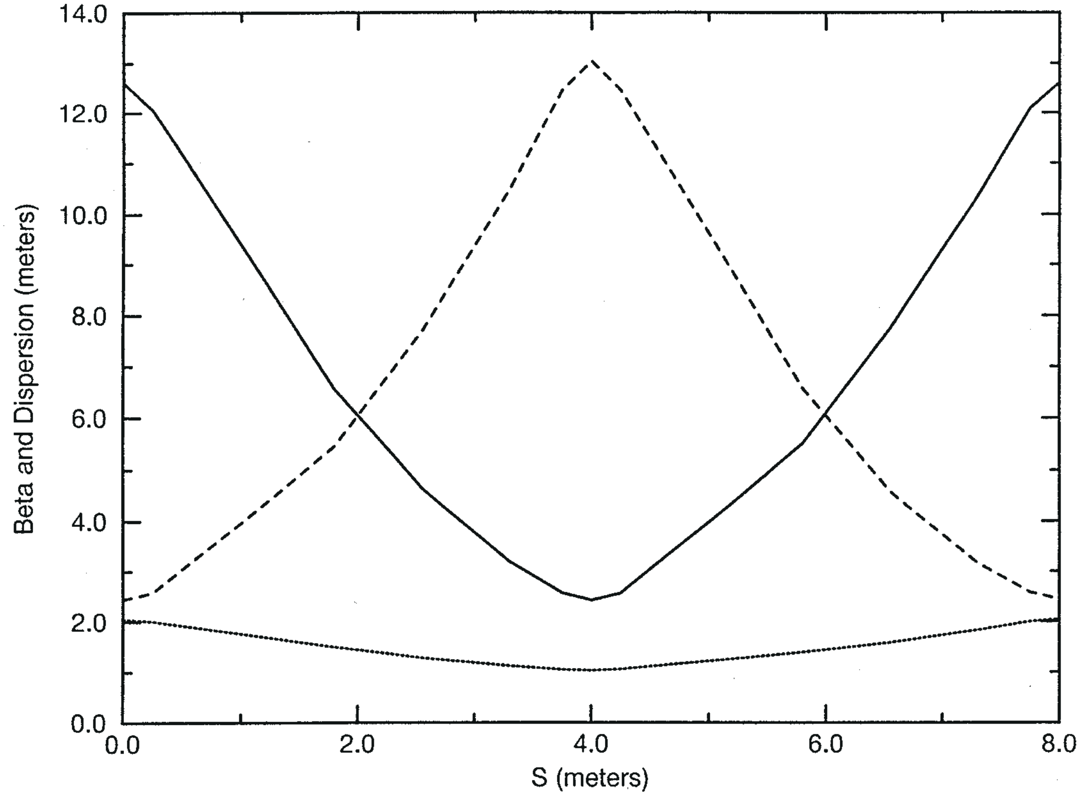


Figure 2: Ideal Superperiod (SP) Lattice Parameters

Qx = 5.82, Qy = 5.80

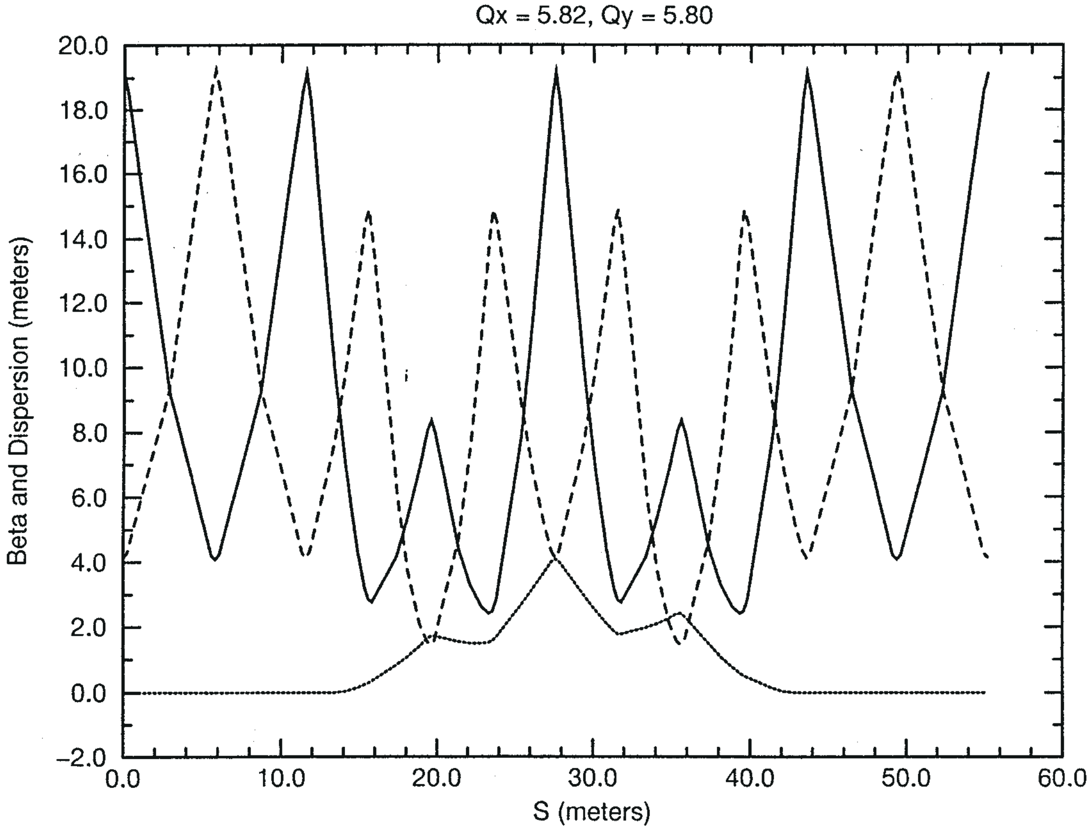


Figure 3: Actual Lattice Parameters

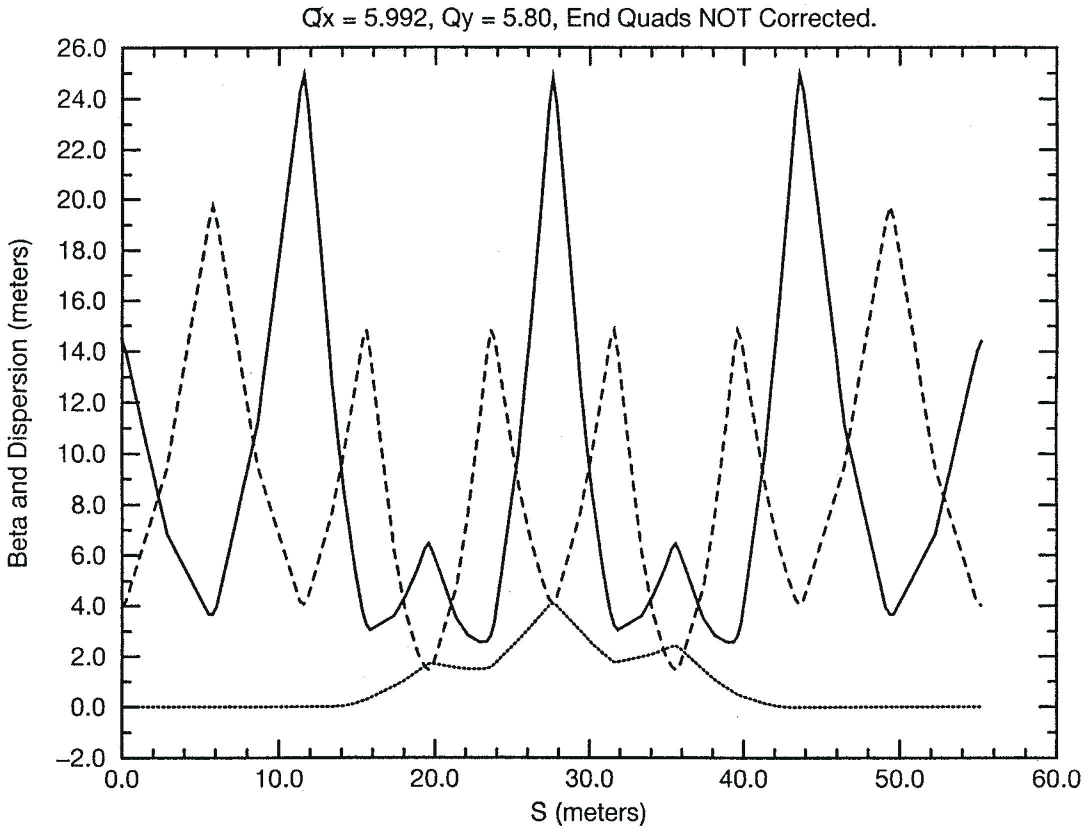


Figure 4: Actual Lattice Parameters

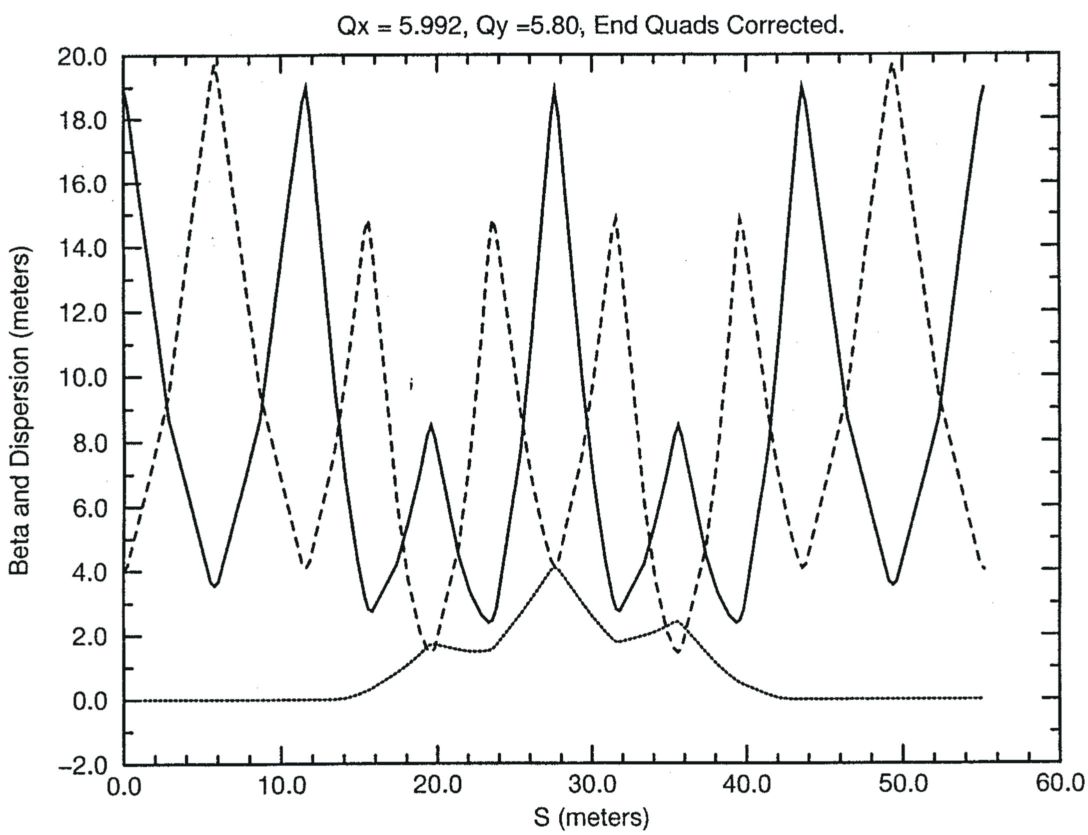


Figure 5: Actual Lattice Parameters

Qx = 5.82, Qy = 5.80, End Quads NOT Corrected.

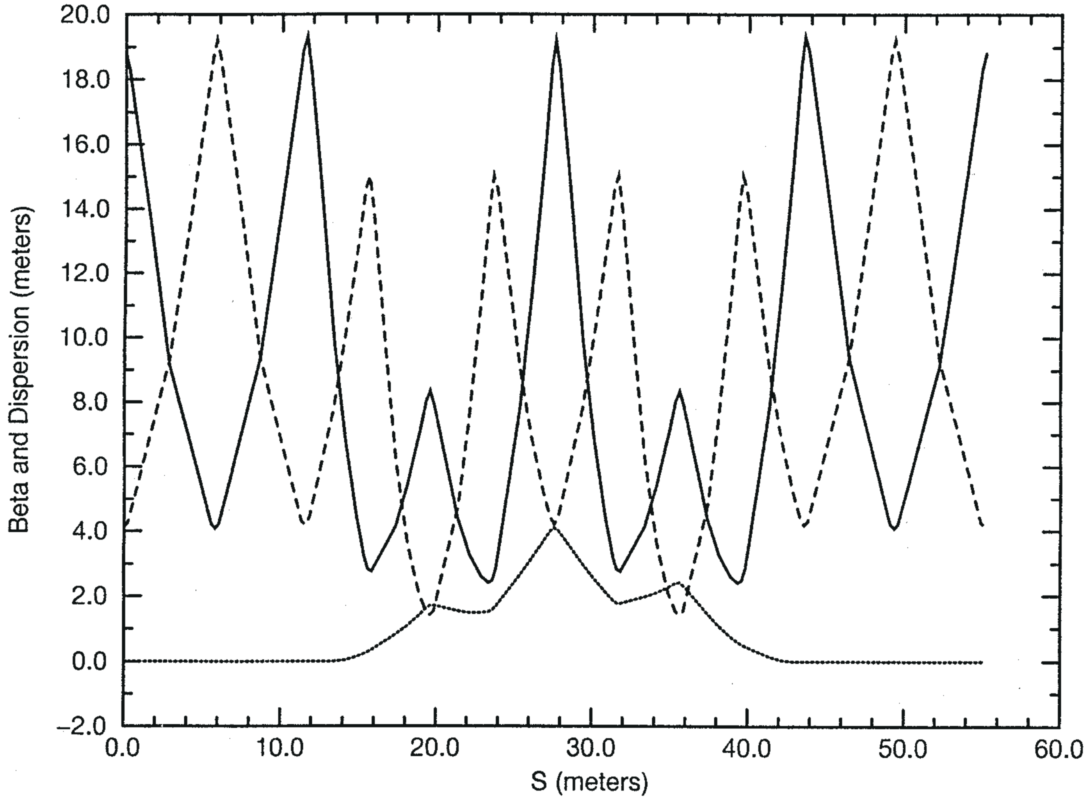


Figure 6: Actual Lattice Parameters

Qx = 5.82, Qy = 5.80, End Quads Corrected.

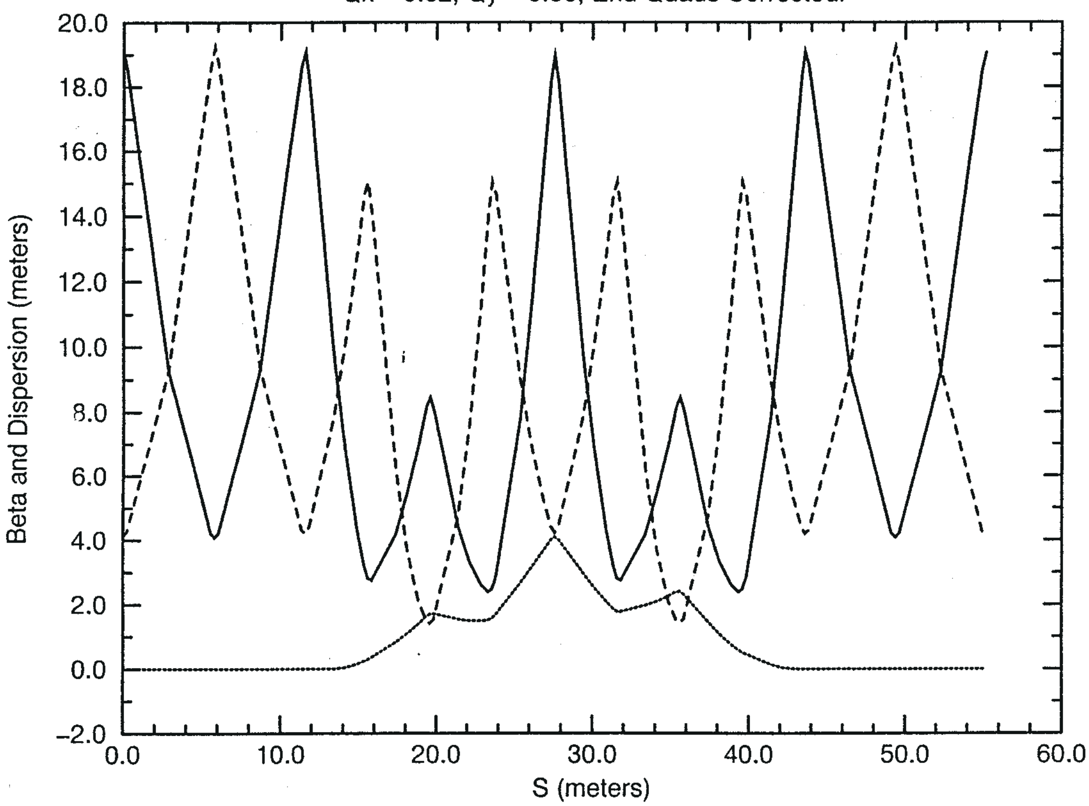


Figure 7: Actual Lattice Parameters

Qx = 5.82, Qy =5.992, End Quads NOT Corrected.

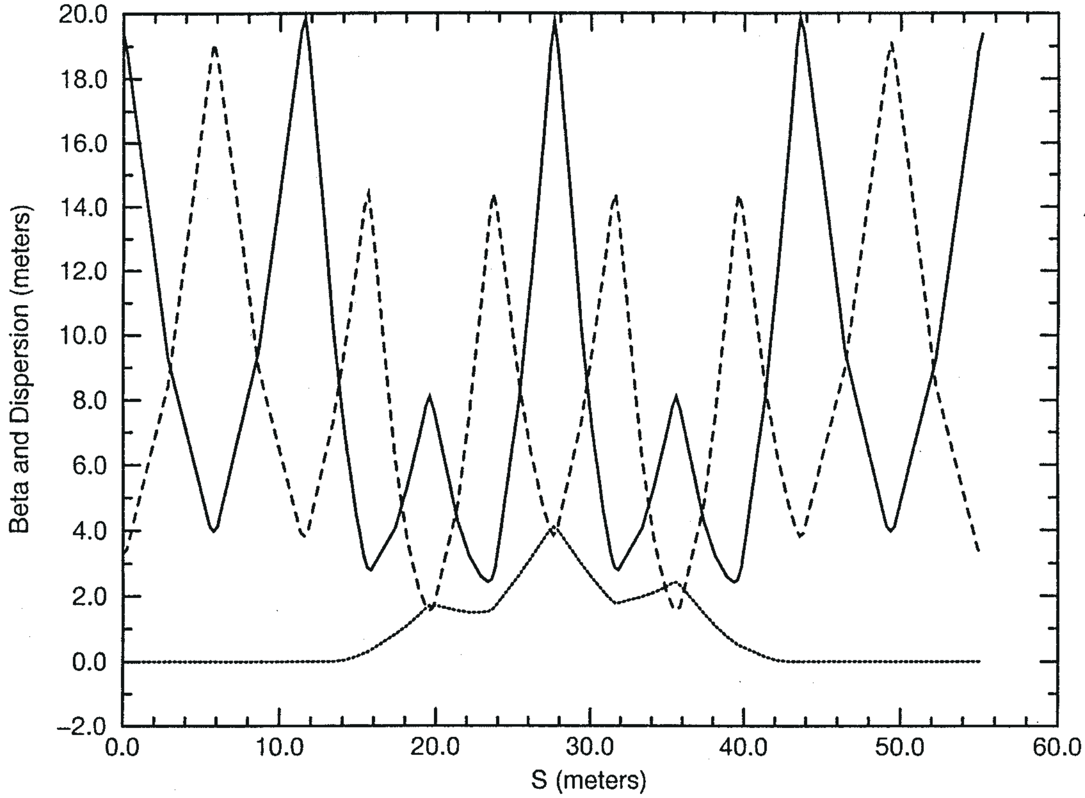
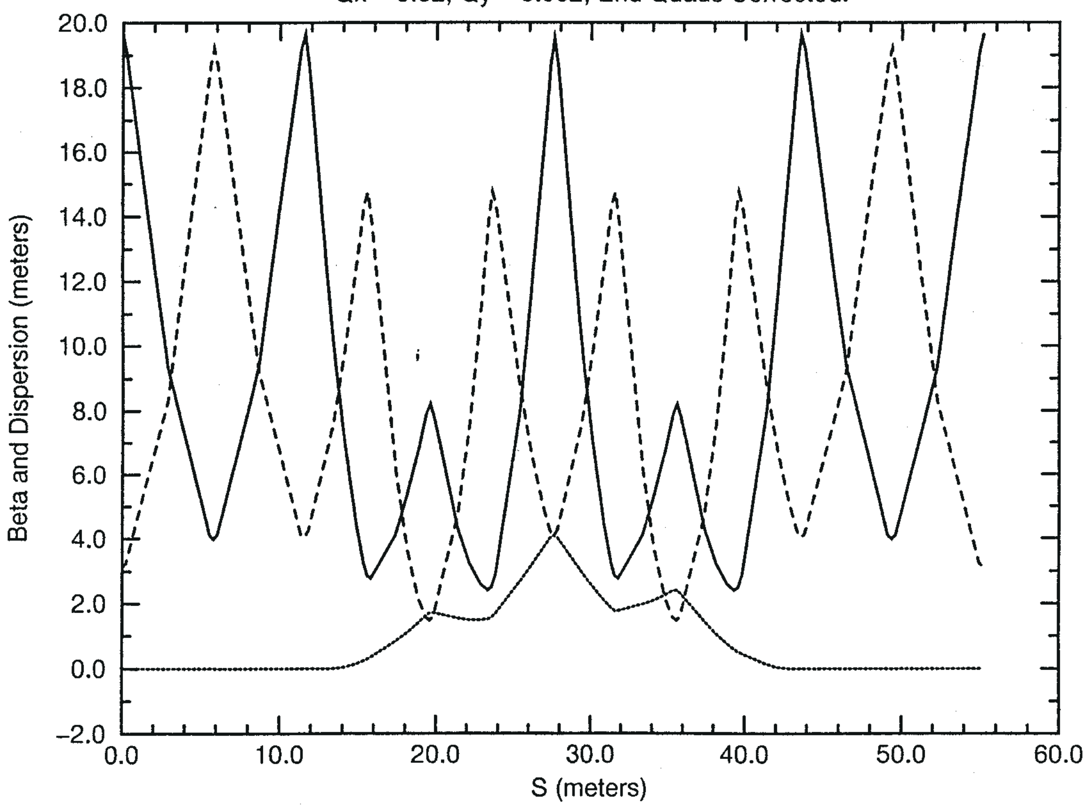


Figure 8: Actual Lattice Parameters

Qx = 5.82, Qy = 5.992, End Quads Corrected.



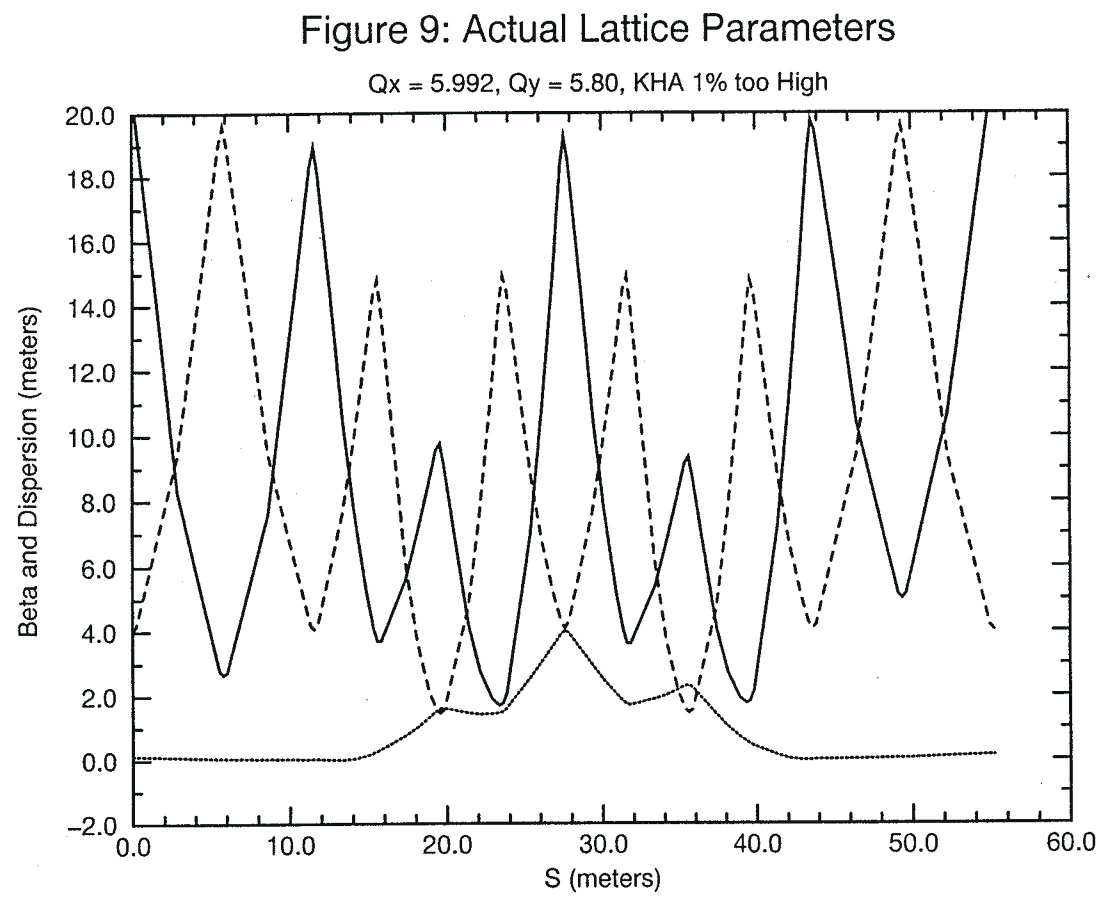


Figure 9: Actual Lattice Parameters
Qx = 5.992, Qy = 5.80, KHA 1% too High
Beta and Dispersion (meters)
S (meters)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0

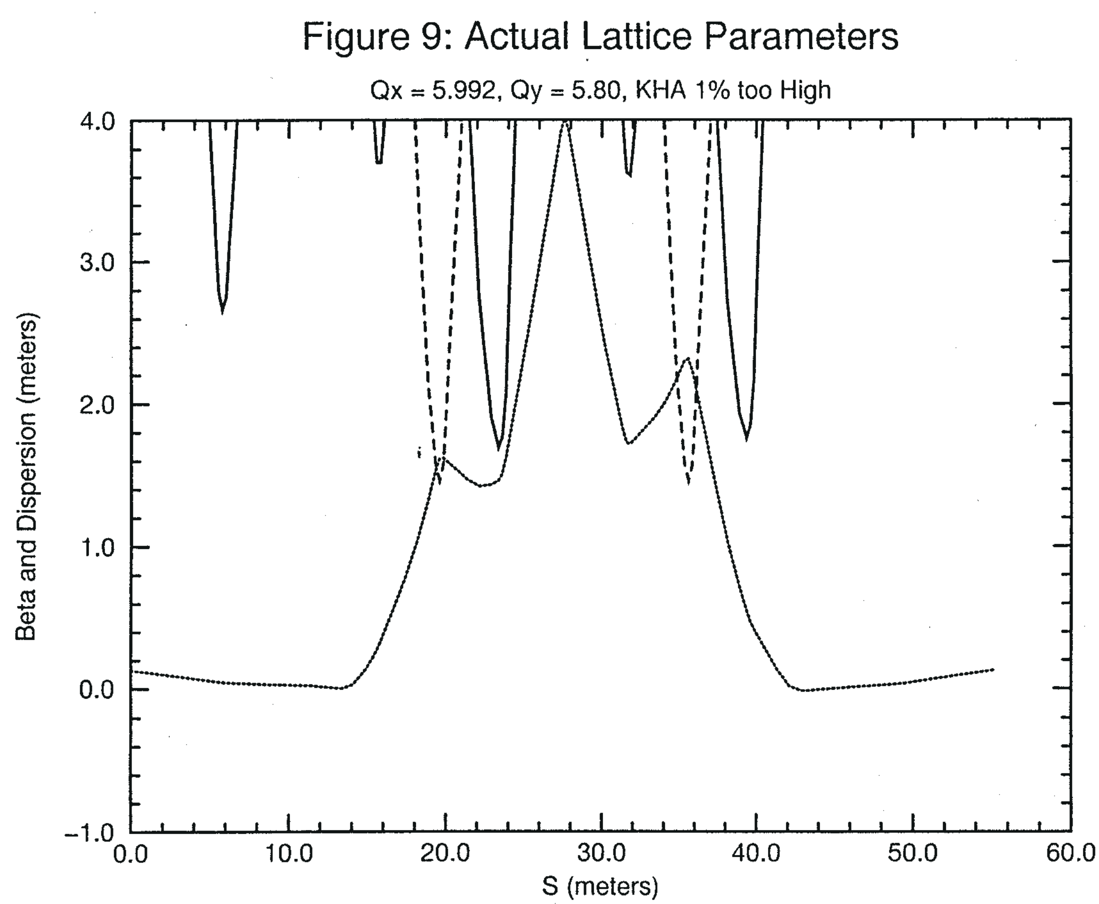


Figure 9: Actual Lattice Parameters
Qx = 5.992, Qy = 5.80, KHA 1% too High
Beta and Dispersion (meters)
S (meters)
4.0
3.0
2.0
1.0
0.0
-1.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0

Figure 10: Actual Lattice Parameters

Qx = 5.992, Qy = 5.80, KHA 1% too Low

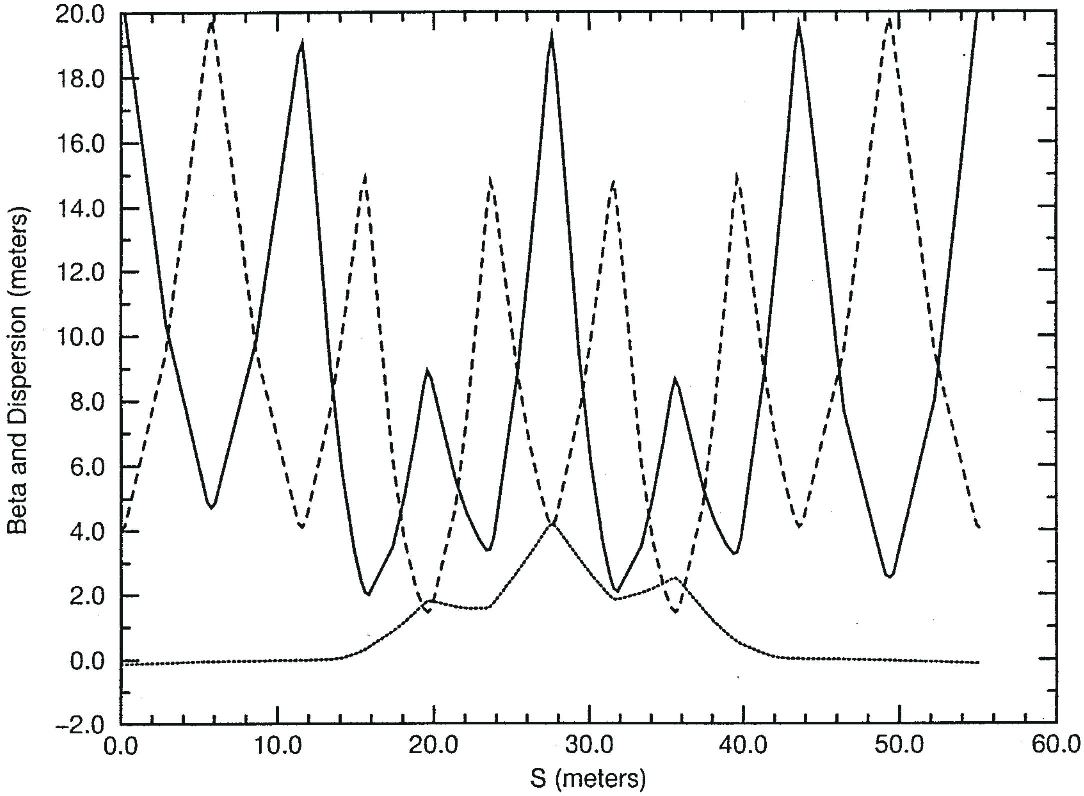


Figure 10: Actual Lattice Parameters

Qx = 5.992, Qy = 5.80, KHA 1% too Low