SSC-N-174

Injection Aperture Comparison Between Super-ferric and Cos(Theta) Magnets

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Abstract

Linear apertures are obtained by particle tracking for super-ferric and cos(theta) magnet designs. Random multipoles anticipated in early SSC planning (SSC-7) and also those measured on early prototype magnets are used. Systematic multipole errors, assumed to be globally compensated, are ignored. The program TEAPOT is used for chromaticity compensation and particle tracking.

The most critical magnetic field uniformity requirement for the SSC concerns the values at injection time, when the needed aperture is greatest, and it is random, rather than systematic, errors which are most important.[1] Systematic field non-uniformity has a global influence which can be compensated inexpensively (relatively speaking) using correction elements. For this study we neglect them. Magnet-to-magnet random errors limit the linear aperture (defined below) and there is (at present) no known way to compensate for this remotely. It is possible to ameliorate their effects using sorting[2] based on pre-installation magnetic measurements, but we neglect this possibility since, for the TAC super-ferric magnets contemplated, the 2 in 1 design restricts the possibilities markedly relative to 1 in 1 designs. As a result it becomes a rather detailed matter to investigate the improvement to be expected from sorting.

Lattices having no IR's and consisting only of FODO cells are used, and the "linear aperture", found by tracking, is used as the main basis for comparison. This "linear aperture" is the transverse amplitude within which the fractional rms variation of the Courant-Snyder invariant (the "smear") does not exceed 10%. Within this aperture, beam manipulations are accurately predictable over hundreds of turns, and beam quality degradation can be controlled. It is still contraversial whether long-term stability is assured within this 10%-defined aperture or whether a smaller value, probably not less than 5%, is required. The aperture for long term stability rarely exceeds the 10%-defined linear aperture by more than a factor of 1.5. It is not the purpose of this note to pursue these questions, and, for comparative purposes, the 10% figure will be used.

The TAC group has favored 90° as the phase advance per cell in the regular arcs for the super-ferric design, while the CDG group has favored 60°. The linear aperture is not expected (or observed--see below) to have a strong dependence on this phase advance--it is closed orbit and systematic issues which favor one or the other. Nevertheless, in the interest of controlling the variables, tracking is done for both types of magnet, using both lattices.

The parameters of the lattices used are indicated in Table 1. In each case they are close to the regular arc designs for the option in question. In particular, the cos(theta) half-cells each contain 5 of the basic 17m dipole magnet units, and the super-ferric half-cells each contain 3 of the 34m magnets.

The assumed random multipoles are listed in Table 2. The standard units are used, namely parts per 10,000 at 1 cm. Entries labeled THEN, both in the table and in the figures refer to predictions by the Fisk committee[3] of the multipoles to be expected for the two magnet types. The label NOW refers to recent measurements[4,5] on prototype magnets, for which efforts were made to control random field errors. Though these are fractional error values based on short magnets, the same fractional values are assumed to apply to the integrated field multipoles of the full-length magnets to be used in the actual lattice. For the super-ferric design this is justified by the data of Table 3 which show the random variation measured in a longitudinal scan of a full-length magnet. Since the random variation is small compared to the measured random variation from magnet to magnet listed in Table 2, the short magnet values are appropriate. This is a kind of worst-case assumption, as the fractional magnet error in a long magnet cannot exceed the fractional error in any typical short portion of itself (on the average).

The program TEAPOT[6], starting with a random seed, assigns multipole values randomly to all of the dipole units in the ring. It then adjusts both horizontal and vertical chromaticity to zero using the two families of sextupoles present for that purpose. It is not necessary to decouple the horizontal and vertical motion as the multipoles a_1 and b_1 have been taken to be zero. In each case, a small number of seeds, indicated on the figures, was chosen to reduce fluctuations and to estimate the statistical precision of the results. In each of these randomly assigned lattices the program tracks particlesof various amplitudes, each for 256 turns. From the turn-by-turn coordinates the smear and also the tunes are extracted.

In Figure 1, values of smear are plotted for 60° lattices. The top two plots were obtained using the pre-construction predictions[3] for the multipole errors. The linear aperture is extracted at the

10% intersection. Values for the C design, super-ferric, and the D design, cos(theta), are approximately equal, as the transverse magnet dimensions were designed to give this result. The lower two figures give the results obtained using the measured multipoles. Figure 3 gives the results with 90° lattices using the same multipole errors listed in Table 2. Values obtained for the linear apertures of the various lattices are given in the figures.

The term "linear aperture" has usually also been taken to include a requirement on the dependence of tune on amplitude, with an acceptable tune shift of 0.005 defined. For the 60° lattices, dependence of tune on amplitude is given for the two magnet types.

Only on-momentum behaviour has been investigated for this note.

References

1. R. Talman, Proc. of the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider. Snowmass, 1984. p. 349.
2. S. Ohnuma and R. Gluckstern, IEEE Trans. on Nucl. Sc., NS-32 1985, p. 2314; and L. Schachinger, SSC-N-123, Dynamic and Linear Apertures in the SSC Clustered-IR Test Lattice With Dipole Sorting.
3. E. Fisk et al., SSC-7, Magnetic Errors in the SSC. Also SSC-SR-1013.
4. TAC note MSIM, 4/8-9/86, and Longitudinal variation of multipoles in the 28m dipole STEX1.
5. SSC-SR-2020, Conceptual Design of the Superconducting Super Collider, 1986, p. 127.
6. L. Schachinger and R. Talman, TEAPOT, A Thin Element Program for Optics and Tracking, SSC-52, 1985.

Table 1.

LATTICE PARAMETERS FOR COS(THETA), SUPER-FERRIC COMPARISON

SYMBOL	QUANTITY	Unit	60° LATTICES C super-ferric	60° LATTICES D cos (theta)	90° LATTICES C super-ferric	90° LATTICES D cos (theta)
B_o	dipole field	Tesla	3.0	6.0	3.0	6.6
n	# of ½cells		1370	818	1330	748
l	length of ½cell	m	110.3	94.3	116.7	95.3
C	circumference	km	151.1	77.1	155.2	71.3
ν_x	horz. tune		114.265	68.265	166.265	93.265
ν_y	vert. tune		114.285	68.285	166.265	93.285
$\hat{\beta}$	max. beta	m	379.1	323.4	391.2	323.7
$\check{\beta}$	min. beta	m	128.2	109.7	69.5	53.8
l_D	dipole length	m	102.0	85.4	105.2	84.9
n_D	units/½cell		3	5	3	5
l_D/n_D	unit length	m	34	17	35	17

Table 2.
Non-vanishing multipoles (standard deviations in "units").

	C,THEN	C,NOW	D,THEN	D,NOW
a_2	1.1	2.0	0.63	0.22
a_3	1.3	1.3	0.69	0.29
a_4	0.8	0.2	0.14	0.12
a_5	0.7	0.3	0.16	0.11
a_6	0.7	0.3	0.034	0.03
a_7		0.6	0.030	0.08
a_8		0.3	0.0064	0.01
a_9			0.0056	0.01
b_2	1.0	2.4	2.15	1.24
b_3	0.8	0.4	0.35	0.15
b_4	0.4	1.1	0.59	0.30
b_5	0.4	0.3	0.059	0.03
b_6	0.5	0.5	0.076	0.06
b_7		0.5	0.016	0.05
b_8		0.4	0.021	0.01
b_9			0.0030	0.00

Table 3. (Copied from ref. 4.)*

Longitudinal variation of multipoles (x.0001) in the 28m dipole STEX1

Z(feet)	B0(Tesla)	b2	a2
4	1.543	-0.3	0.0
8	1.551	-0.4	-0.4
12	1.543	-1.0	0.8
16	1.549	-1.2	0.4
20	1.546	-1.4	-1.1
24	1.548	-0.4	-0.2
28	1.536	-0.9	-0.3
32	1.536	-1.0	0.0
36	1.531	-0.8	0.2
40	1.545	-0.2	-0.3
.			
.			
.			
76	1.550	-0.9	-0.5
80	1.552	-0.7	-0.1
84	1.548	-0.1	-0.6
88	1.546	-0.7	-1.4
<>	1.545	-0.7	-0.3
sigma	0.006	0.4	0.6

(The gap in this table was due to bad splices in the warm finger obstructing the probe. These will be corrected for our next measurements.)

This magnet is of an earlier design of conducter placement. The currents were roughly adjusted to zero the sextupole in the first position. The decapole could also have been zeroed, but would have taken longer. The other points were measured using the same currents as used for the first point.

* Only values for a_2 and b_2 are copied since they are expected to dominate the linear aperture.[1]

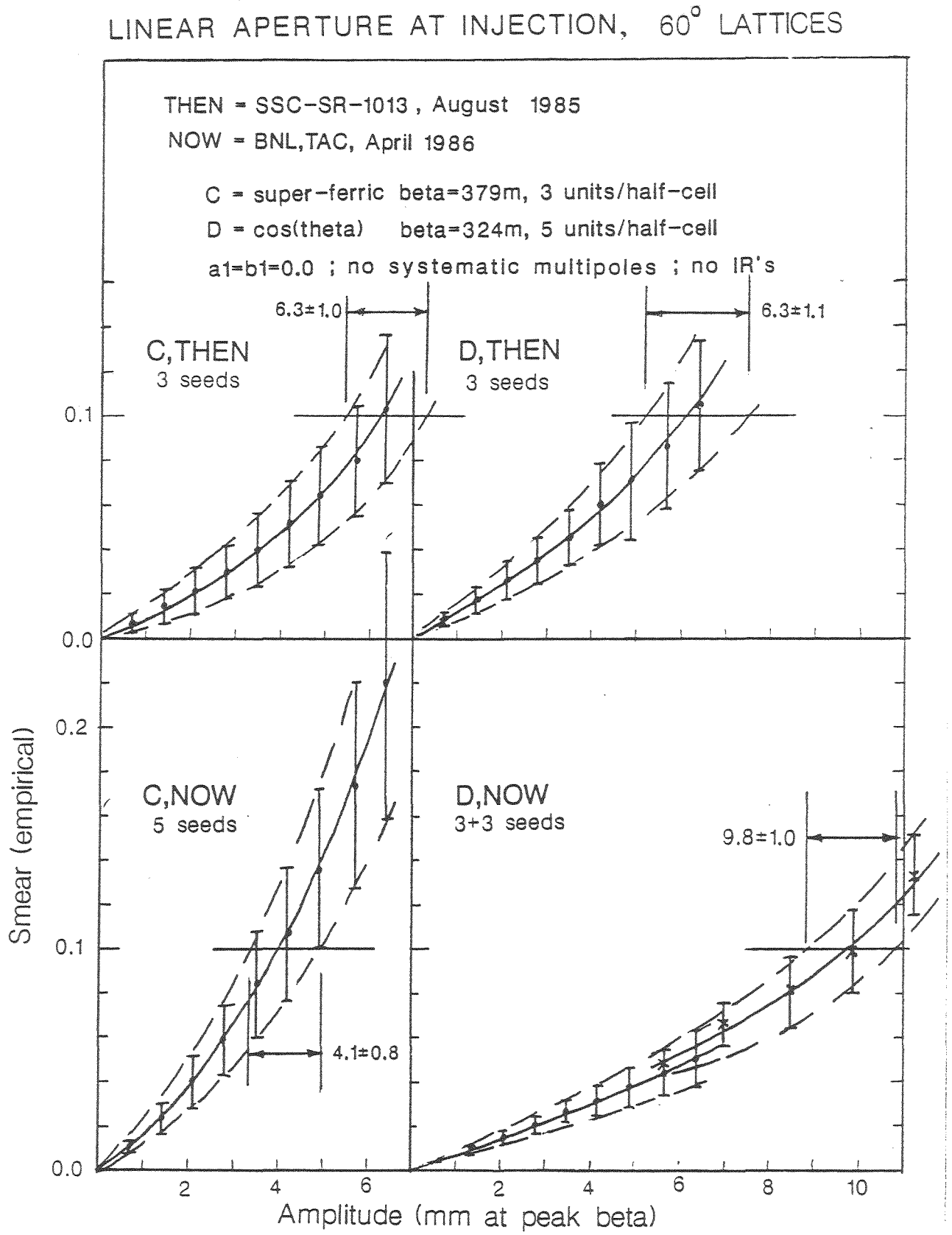
LINEAR APERTURE AT INJECTION, 60° LATTICES
THEN = SSC-SR-1013 , August 1985
NOW = BNL,TAC, April 1986
C = super-ferric beta=379m, 3 units/half-cell
D = cos(theta) beta=324m, 5 units/half-cell
a1=b1=0.0 ; no systematic multipoles ; no IR's
6.3±1.0
C,THEN
3 seeds
6.3±1.1
D,THEN
3 seeds
C,NOW
5 seeds
4.1±0.8
D,NOW
3+3 seeds
9.8±1.0
Smear (empirical)
0.0
0.1
0.2
2
4
6
8
10
Amplitude (mm at peak beta)

Figure 1.

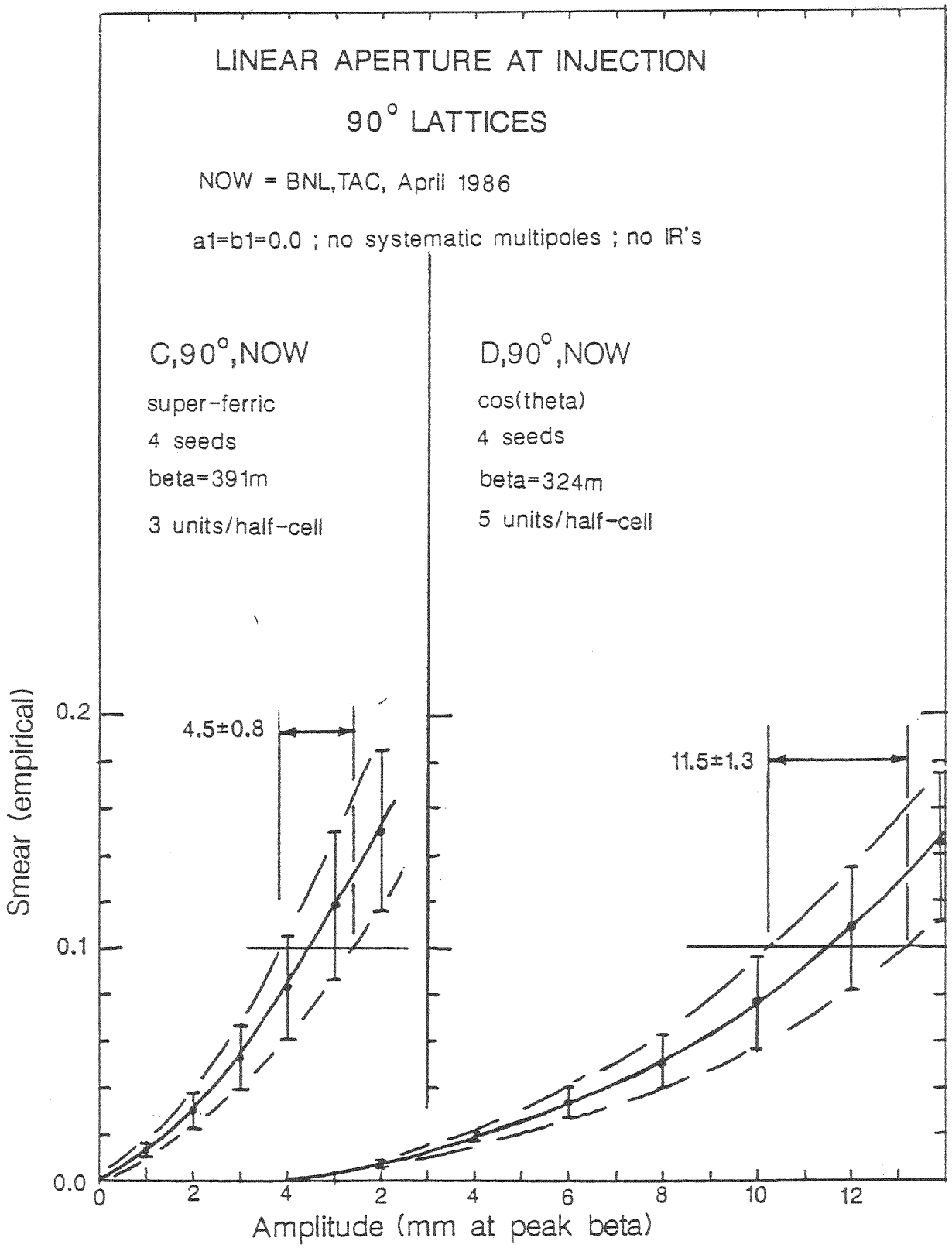
LINEAR APERTURE AT INJECTION
90° LATTICES
NOW = BNL,TAC, April 1986
a1=b1=0.0 ; no systematic multipoles ; no IR's
C,90°,NOW
super-ferric
4 seeds
beta=391m
3 units/half-cell
D,90°,NOW
cos(theta)
4 seeds
beta=324m
5 units/half-cell
4.5±0.8
11.5±1.3
Smear (empirical)
0.2
0.1
0.0
0
2
4
2
4
6
8
10
12
Amplitude (mm at peak beta)

Figure 2.

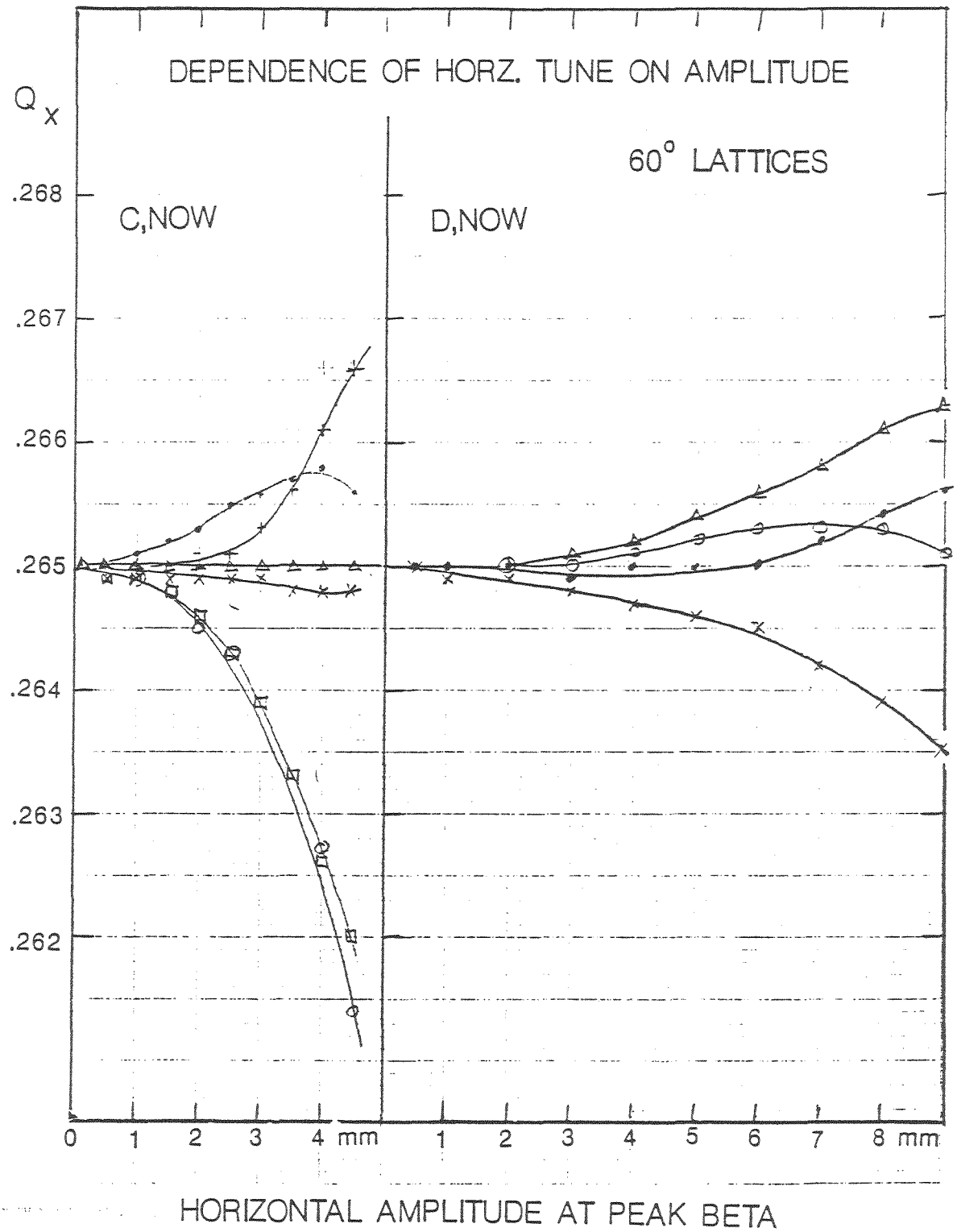
DEPENDENCE OF HORZ. TUNE ON AMPLITUDE
Q_x
60° LATTICES
C,NOW
D,NOW
.268
.267
.266
.265
.264
.263
.262
0
1
2
3
4 mm
1
2
3
4
5
6
7
8 mm
HORIZONTAL AMPLITUDE AT PEAK BETA

Figure 3.

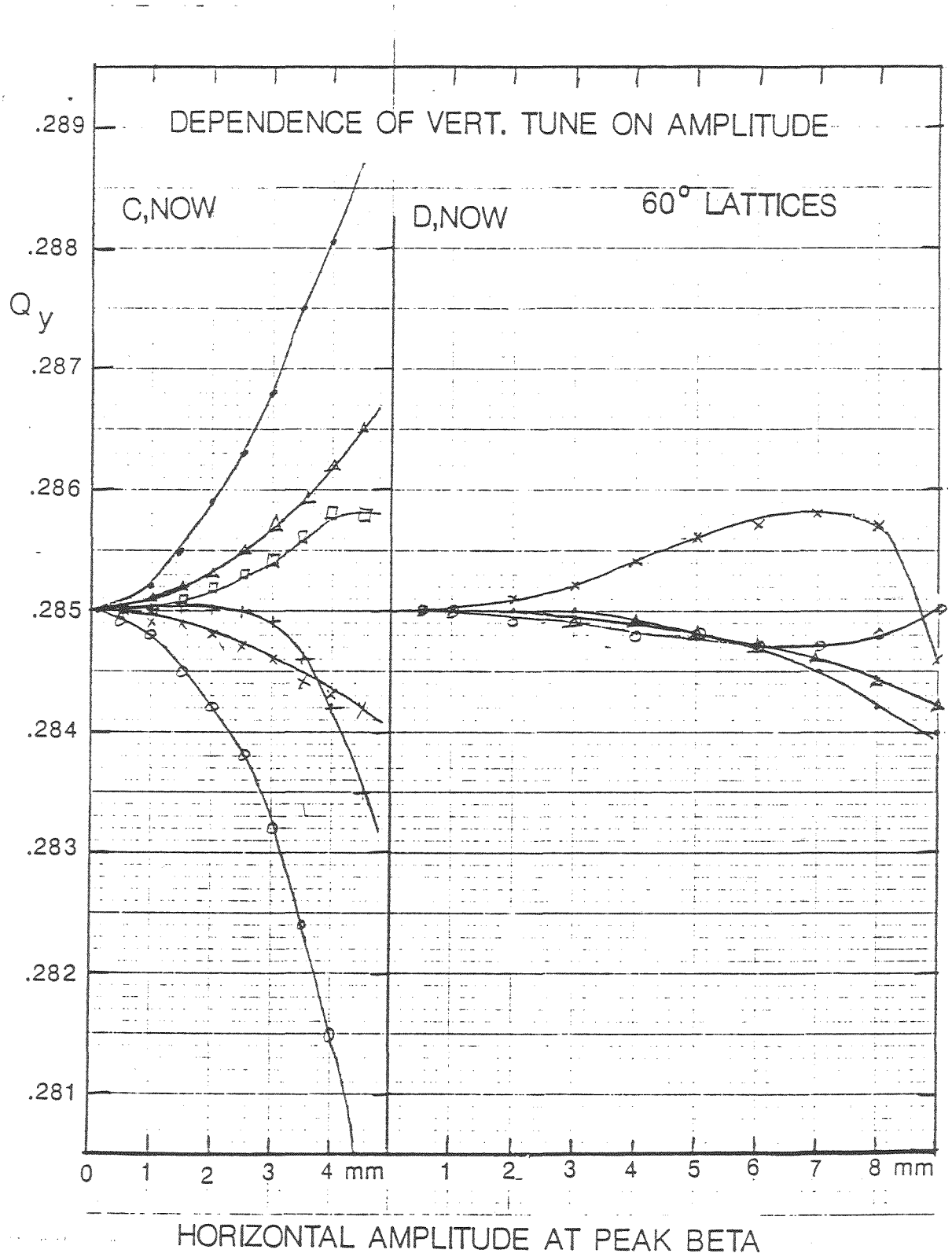
DEPENDENCE OF VERT. TUNE ON AMPLITUDE
C,NOW
D,NOW
60° LATTICES
Q y
.289
.288
.287
.286
.285
.284
.283
.282
.281
0
1
2
3
4 mm
1
2
3
4
5
6
7
8 mm
HORIZONTAL AMPLITUDE AT PEAK BETA

Figure 4.