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LOCATION OF SEB DRIVE SEXTUPOLES

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
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AGS DIVISION TECHNICAL NOTE

No. 167

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D.A. Barge and J.W. Glenn

September 16, 1980

It has been determined that the H5 straight section, currently occupied by a third integral resonance[1] slow extraction drive sextupole, is an optimal location for an improved fast kicker for fast beam extraction. We wish to determine the feasibility of the simultaneous presence of FEB and SEB extraction components, and thus, in this note, we examine three alternative drive sextupole configurations, which do not use the H5 location, using program BEAM,[2] and compare these three configurations against the present arrangement.

For convenience, we label the existing drive sextupole configuration (-B5, +E5, -H5, +K5) as case A, (-B5, +E5, +K5) as case B, (-C13, +F13, -I13, +L13) as case C, and (-B5, +E5, -I13, +K5) as case D. Configuraton A has been studied before,[3] with slightly different parameters than used here. We reran this case as a consistency check, and obtained essential agreement with the previous results. Case C is suggested as an alternative to case A, since practically no separatrix rotation is expected when these sets of drive sextupoles are exchanged. The quantity ϕ, a strong measure of separatrix rotation,[4] increases by only 4°, in passing from case A to case C, using the approximation that $\psi \simeq N\ \pi\nu_0/120$, where ν_0 = 8-2/3, and N = no. of AGS magnets between a reference point of phase (ψ = 0) and the downstream sextupole. The center of the F5 straight section was taken to be the point of reference. Later, we discuss the reasons for interest in cases B and D.

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[1]M.Q. Barton and J. Faure, BNL Accelerator Department Internal Report AADD-131 (1967).
[2]G.H. Morgan, BNL Accelerator Department Internal Report GHM-1 (1966).
[3]L.R. Blumberg, notes from Accelerator Department Course Lecture No. 16, Jan. 15, 1979.
[4]M. Month, BNL Accelerator Department Internal Report AGSCD-17 (1967), Eq. (3.25).

In BEAM, we have increased the main magnet sextupole coefficients by a factor of 3, over their values at the used field option 2, according to the results of horizontal tune measurements at high field.[5] The integration steps in BEAM were always taken to be 1 inch.

We have attempted to provide BEAM with parameters representing current operating conditions for the AGS slow beam. We used readbacks from the MCR AGAST program, and shunt calibrations provided by the Electronics Support Group taken at a time period when the AGS was running smoothly with low extraction losses.*

It was found, and anticipated from previous work that the measured $3\lambda/2$ bump currents are incompatible with BEAM. The measured H bump current jams the 0.1π in.-mr. separatrix into the H20 septum, and the measured F bump current provides a very small (~0.2") horizontal spread (ΔY) at F5 in extracted emittance. To obtain reasonable spiral pitch at H20 and F5, it was necessary to reduce the H bump strength by a factor of 1.9 and the F bump strength by a factor of 1.5.**

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[5] M. Month, E.G. Gill, and E.C. Raka, Nucl. Inst. Meth. <u>93</u> (1971) 535.

*Readbacks were taken on 03/08/80, 0700. Calibrations were taken on 01/11/80. We determined parameters for BEAM from the relations $S_S = 17.15\ fI_S$, where S_S = sextupole drive strength in gauss/inch, I_S = sextupole current in amperes, and f = scale factor to field option 2 = 12.75/29.0; $S_{H,V} = 47.49\ fI_{H,V}$, where $S_{H,V}$ = horizontal quadrupole strength (no. 17 st. scns.) or vertical quadrupole strength (no. 3 st. scns.) in gauss, $I_{H,V}$ = horizontal or vertical quadrupole current in amperes; long magnet bump strength = $(\Delta p/p)_L = \pm 3I_B/(8\ I_m)$, short magnet bump strength = $(\Delta p/p)_S = 6(\Delta p/p)_L/5$, where I_B = current in backleg windings in amperes, I_m = main magnet current in amperes, determined to be 5080 amp. at 29.0 GeV/c, from E.D. Courant, "Field, Energy, Current vs. Time," BNL Accelerator Department Report, Dec. 19, 1960. The plus sign is used for an outward kick, the minus sign for inward. Septum locations, relative to the socket lines were also determined from MCR AGAST readbacks of 03/08/80. For the purposes of this note, we have ignored the relatively small difference between the socket line coordinate systems and the BEAM coordinate systems in the straight sections.

**In this respect, PUE data taken just before extraction begins (PUE's sampled at 625 ms, switch three off at 660 ms after t_0) indicate that the beam is oscillating with a strong 9th harmonic component, such that large inside excursions are observed at H20 ($Y \simeq -0.9$ in.) and F5 ($Y \simeq -0.6$ in.). This effect has been observed to persist, over long running periods of SEB. If these excursions remain, throughout the spill time, then it is possible that we have found the reason for the large bump strengths, relative to BEAM. It is also true that backleg excitation is not as effective as gap excitation. We have not evaluated this effect.

The H bump adjustment required to allow the extraction process to occur, with BEAM, was initially made assuming that the extracted emittance width at H20 would be about 30% smaller than the field region of H20 (1 cm.). The F bump was similarly treated; the field region at F5 being 1.5" wide.*** The septum locations were taken from AGAST readbacks and known calibrations, but in effect, due to the above mentioned difficulty, no real use was made of the F5 septum location in BEAM.

Subsequent to the greater portions of this work, measurements were made of extracted beam horizontal spot sizes at H20, F5, and F10, with flags. The horizontal beam size at H20 was found to be 0.264" wide, a value considerably smaller than originally assumed. Rather than repeat the somewhat tedious work of separatrix searches, we chose to move the H20 septum in BEAM (about 0.1 inch), to produce a ΔY (extracted emittance width) of 0.264," for all 4 cases A, B, C, and D. Thus the Figures (1,4,6), (7,10,12), (13,16,18) show two extracted emittance areas, associated, respectively, with the measured septum location, and the adjusted septum location. Case D used only the ΔY as measured at H20.

The drive sextupole strengths, for cases B, C and D were derived from case A (measured strength) by using BEAM to determine the effective sextupole drive strength[6] E for case A, and then iterating[†] cases B, C, and D to yield the same value of E (within 0.01%) as in case A. Iteration was necessary since the horizontal β function and ψ $[= {}_0\int^s d\rho/\beta_H(\rho)]$ are dependent on drive sextupole strength. Usually two iterations were required to produce the

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***The F bump strengths chosen were, for magnet no. (129), -0.0126; (86,87,128), -0.0106; (114,115), +0.0106; (100, 101), +0.0126. The H bump strengths used were (139, 180, 181), -0.0220; (138), -0.0184; (152, 153, 166, 167), +0.0184. These strengths were used for all four cases A, B, C, and D.

[6]Reference 4, Eq. (3.27).

[†]Special DATREP subroutines were written to perform the above mentioned iteration. Each iteration consisted of three steps: i) a determination the momentum (p) of the equilibrium orbit with ν_H = 8-2/3 (horizontal tune), ii) a determination of α_H and β_H for this value of p at an arbitrarily chosen reference point (taken to be F5) in the AGS, by allowing beam to compute transfer matrices for one revolution, and iii) determination of β_H and ψ at the sextupole locations, using the results of ii), transfer matrices from F5 to a desired sextupole location, and the transformation, Eq. (8) appearing in Blumberg, et. al., Accelerator Department Internal Report AGS Div. 69-12. Separatrix searches were performed with a DATREP supplied by L.R. Blumberg. A listing of this routine appears in reference 3.

above mentioned agreement, which, in effect, determined the drive sextupole strengths of cases B and C to 4 significant figures. It was determined by the above procedure that the current required for the drive sextupoles for cases B and C is about 20% higher than the current for case A (see Table I). We estimate an increase in power dissipation from 0.47 kW for case A to 0.73 kW for case C for dc operation. The reason for the increase in current is the perturbation of the symmetric lattice of the AGS by the bumps, and the drive sextupoles themselves.

The kick strength at H20 was chosen to maximize the separation at F5, as calculated by BEAM. See Table I for values used. The kick strength at F5 was held at 1.0773 mr for all four cases A, B, C, and D.

TABLE I

	Measured	Calculated			
	A	A	B	C	D
Extracted emittance width, H20 (in.)	0.264	0.264	0.263	0.264	0.264
Extracted emittance width, F5 (in.)	0.741	0.583	0.647	0.683	0.675
Extracted emittance width, F10 (in.)	0.660	0.590	0.656	0.626	0.661
Maximum clearance at F5 (in.)		0.051	0.027	0.055	0.036
Clearance at F10 (in.)		0.733	0.661	0.749	0.680
Kick at H20 (mr.)		0.419	0.293	0.503	0.335
Sextupole current, 29 GeV/c (amperes)	224	224	298	278	235
Sextupole strength, field option 2 (gauss/inch)		1691.2	2250.6	2096.1	1775.3
ϕ from BEAM (degrees)++		99.795	98.090	97.179	98.427
ϕ from $\psi \tilde{-} N\pi\nu_0/120$ (degrees)++		100.000	100.000	104.000	103.526

++We use the convention $2\pi > \phi \geq 0$.

It appears, from Table I that case B is the worst of the three proposed sextupole arrangements, in view of the insufficient clearance at F5 (F5 septum is 0.030 inch wide). Also, for case B, the extracted emittance width has increased by 11% over that of case A, whereas case C has increased by only 6%. However, in view of the simple physical change required in the AGS to implement case B we plan to examine it, as well as case C during the next SEB run, in order to gain further insight as to the adequacy of the AGS model provided by the BEAM program. We propose to measure clearances at F5 versus H20 voltage and beam sizes at H20, F5 and F10.

Because of the relative difficulty of wiring up the sextupoles for case D, we consider this case, at this moment, as a "backup" configuration. In the event measurements, in progress, indicate excessive power dissipation in the sextupoles for cases B and C, then, of course, case D becomes of interest.

Aside from the above mentioned difficulty using measured bump strengths in BEAM, there exists another area of difficulty between BEAM and the AGS. We have used BEAM to study cases A and C where, instead of increasing the main magnet sextupole coefficients by a factor of 3 over their values at field option 2, we employed multipole constants as determined at 29.0 GeV/c from curves of multipole constants versus momentum.[8] We have examined cases A and C with these constants, and, as before, we used measured quadrupole and sextupole currents for case A, decreased bump strengths, and adjusted H20 septum location to yield an extracted ΔY at H20 of 0.264 inches. As a result of these calculations, we found that the clearance at F5 had dropped to $\sim$0.007 inches for both cases A and C, a clearance insufficient for all the particles to miss the F5 septum.

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[8] H. Weisberg, AGS Division Technical Note No. 155 (1979), p.4. Using the notation of that report, the values of the multipole coefficients were taken to be:

$$b_1^A = 0.1046 \qquad b_2^A = -0.0006 \qquad b_3^A = -0.000058 \qquad b_4^A = 0.0$$
$$b_1^B = 0.1038 \qquad b_2^B = -0.0007 \qquad b_3^B = -0.000025 \qquad b_4^B = 0.0$$
$$b_1^C = 0.1035 \qquad b_2^C = -0.0006 \qquad b_3^C = -0.000033 \qquad b_4^C = -0.000012$$

The algebraic signs of b_1^C, b_3^C must be reversed for use in BEAM, and BEAM must be used in the mode where the field is computed from the polynomial expansion, for $|Y| < 4"$. See comments on p.3 of this reference, as to difficulties with this procedure.

However, for realistic H20 voltages, only a small fraction ($\sim$ 1%) of the extracted phase area at F5 is intercepted by that septum. The area intercepted by the F5 septum is associated with the high momentum particles (at some instant during the slow spill), and thus, extraction losses at F5, to be calculated, would depend on assumptions concerning the distribution of the particles within the stable beam emittance area of 0.1 πin.-mr. At this point only the obvious can be said, namely, it seems absurd to use the slow beam extraction process to measure the characteristics of the main magnets of the AGS.

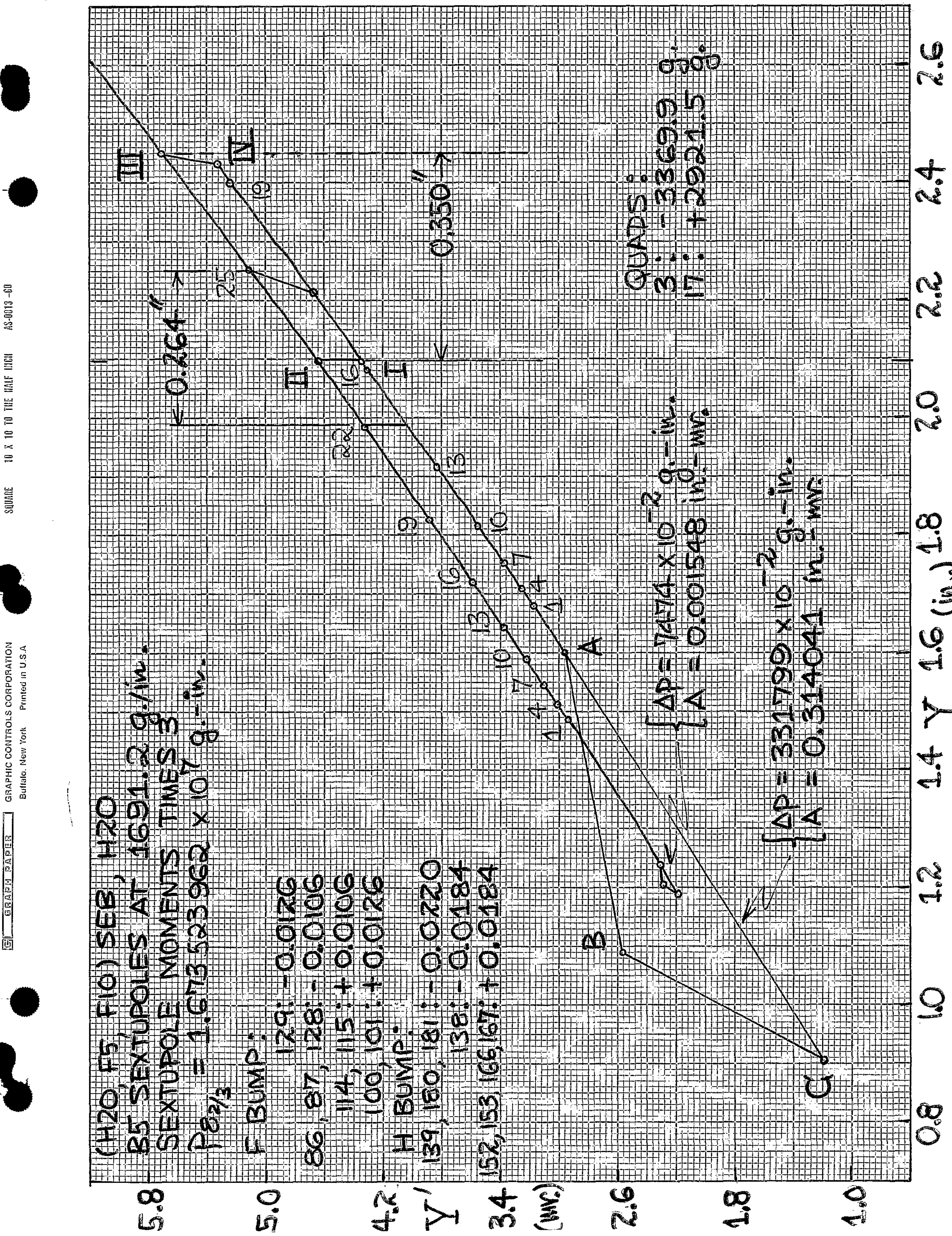
The distinct curvature of the unstable trajectories predicted by BEAM is only partially understood.[+++] It is this curvature that avoids possible interference at F10. The unstable "A" trajectories (see Figs. 5, 11, 17) are curved up and away from the F10 septum. We have been able to reduce this curvature, but not eliminate it all together, by setting main magnet sextupole (and all higher orders) coefficients to zero. Further understanding of this behavior is desirable.

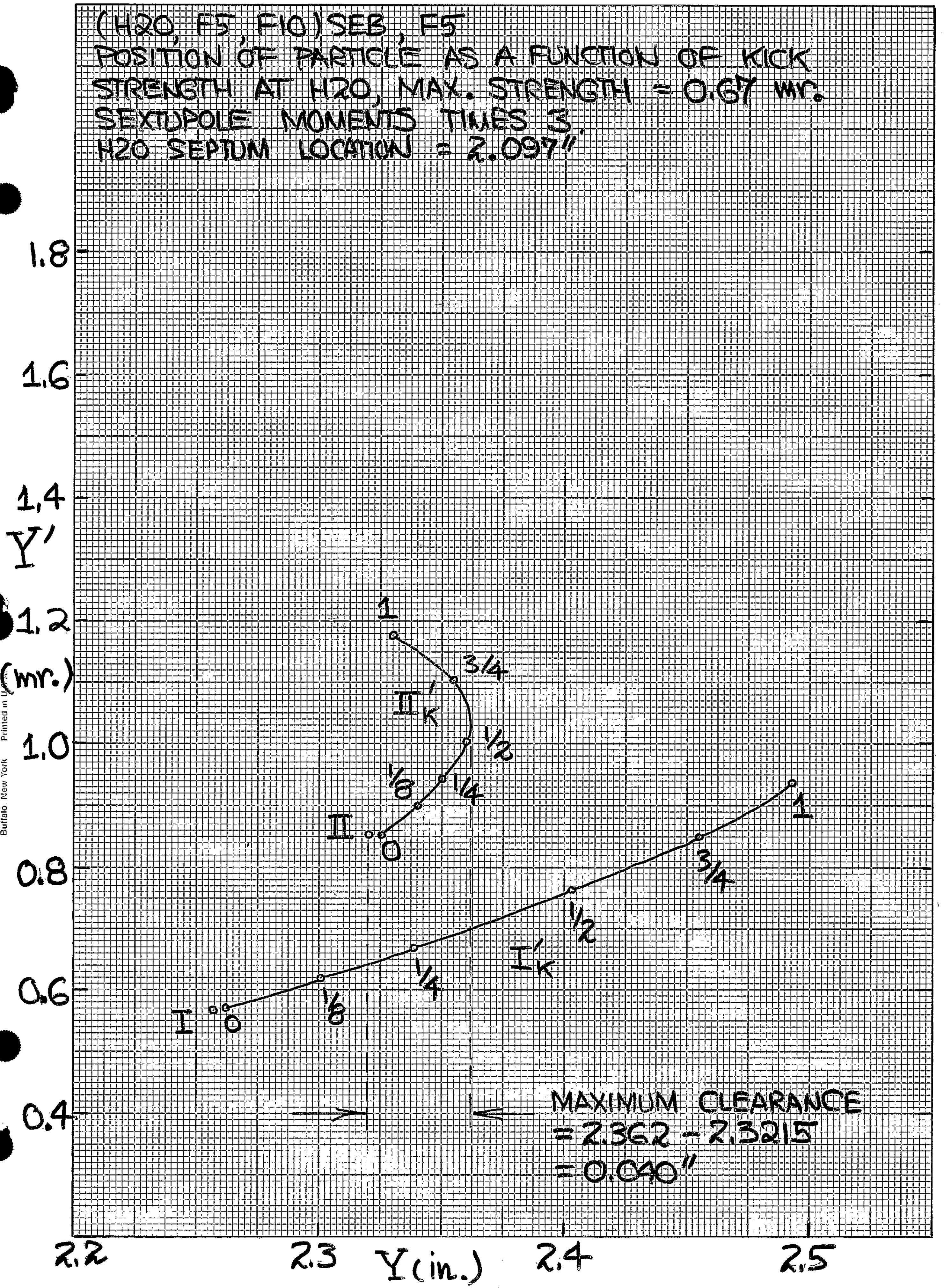
Using the perturbation theory,[4] to calculate currents, we have been able to induce separatrix rotation in BEAM by powering two sets of 4 sextupoles each, separated by one superperiod. Assuming a desired rotation of -15°, and then using the perturbation theory to calculate sextupole strengths for BEAM, we found that BEAM predicted a rotation of -13.8°, in essential agreement. We hope to explore this phenomenon further, to improve the extraction process.

We wish to thank H. Weisberg and Zhang Chuaug for their continued interest and discussions, and R. Noble and J. Funaro for calibration data.

[+++] Indications are that either errors propagated thru the step by step integrations of the 4th order Runge-Kutta in BEAM, or computer round off errors, or both, cause observable shifts in the unstable trajectories, somewhere around the 30th turn.

Fig. 1
Case A


(H20, F5, F10) SEB, H20
85 SEXTUPOLES AT 1691.2 g./in.
SEXTUPOLE MOMENTS TIMES 3
Pβ2/3 = 1.67352396 2 x 10^7 g.-in.
F BUMP:
129: -0.0126
86, 87, 128: -0.0106
114, 115: +0.0106
100, 101: +0.0126
H BUMP:
139, 180, 181: -0.0220
138: -0.0184
152, 153, 166, 167: +0.0184
ΔP = 7474 x 10^-2 g.-in.
A = 0.001548 in.-mr.
ΔP = 331799 x 10^-2 g.-in.
A = 0.314041 in.-mr.
QUADS:
3: -3369.9 g.
17: +2921.5 g.
0.264"
0.350"
I
II
III
IV
A
B
C
Y (in.)
Y' (mr.)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
1.0
1.8
2.6
3.4
4.2
5.0
5.8


(H20, F5, F10) SEB, F5
POSITION OF PARTICLE AS A FUNCTION OF KICK
STRENGTH AT H20, MAX. STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS TIMES 3.
H20 SEPTUM LOCATION = 2.097"
Y' (mr.)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Y (in.)
2.2
2.3
2.4
2.5
MAXIMUM CLEARANCE
= 2.362 - 2.3215
= 0.040"

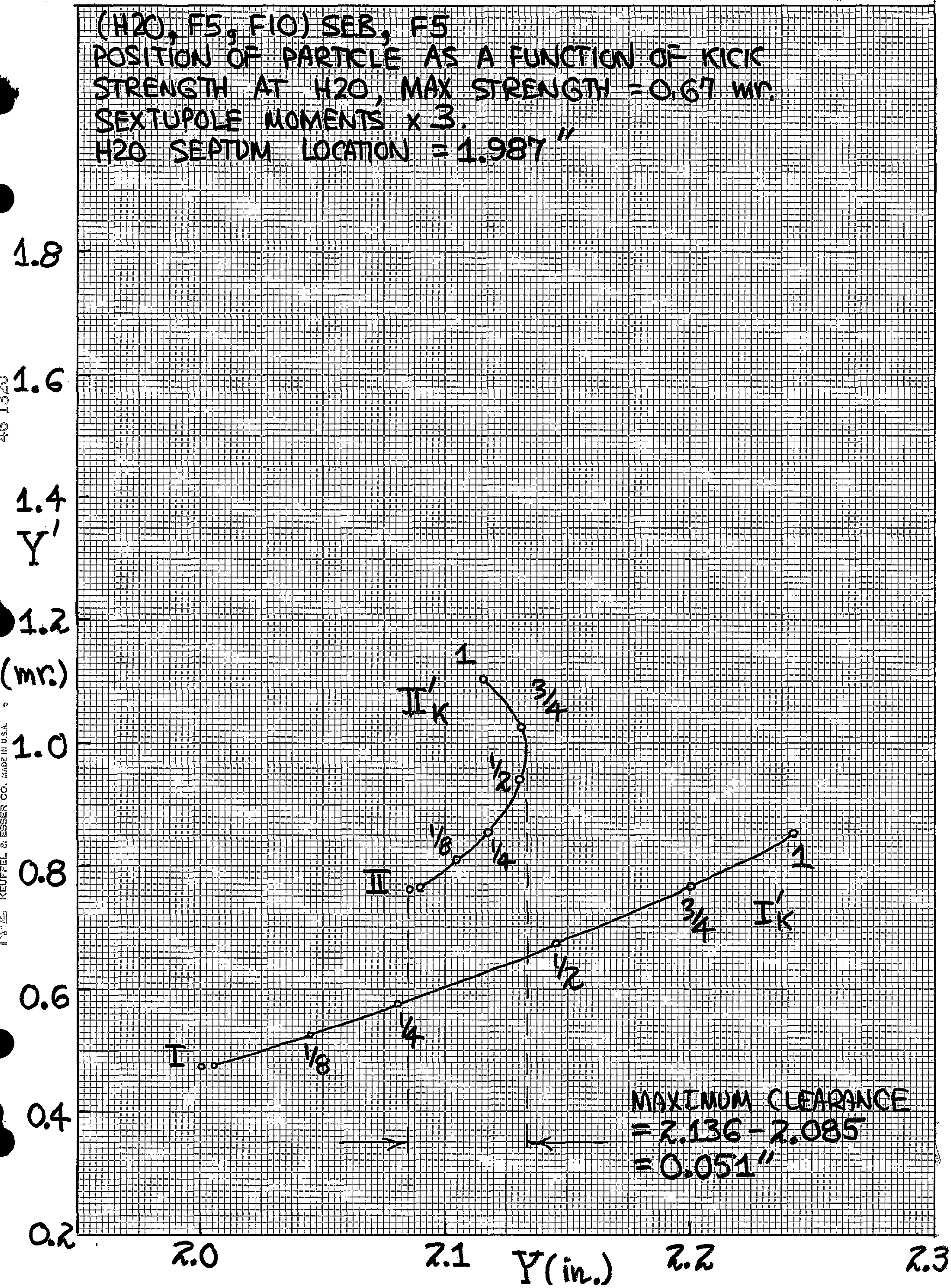

(H20, F5, F10) SEB, F5
POSITION OF PARTICLE AS A FUNCTION OF KICK STRENGTH AT H20, MAX STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS x 3.
H20 SEPTUM LOCATION = 1.987"
1.8
1.6
1.4
Y'
1.2
(mr.)
1.0
0.8
0.6
0.4
0.2
2.0
2.1
Y (in.)
2.2
2.3
II'K
1
3/4
1/2
1/8
1/4
II
I
1/8
1/4
1/2
3/4
1
I'K
MAXIMUM CLEARANCE
= 2.136 - 2.085
= 0.051"
46 1320
K&E 10 X 10 TO 1/2 INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

Fig. 4
Case A

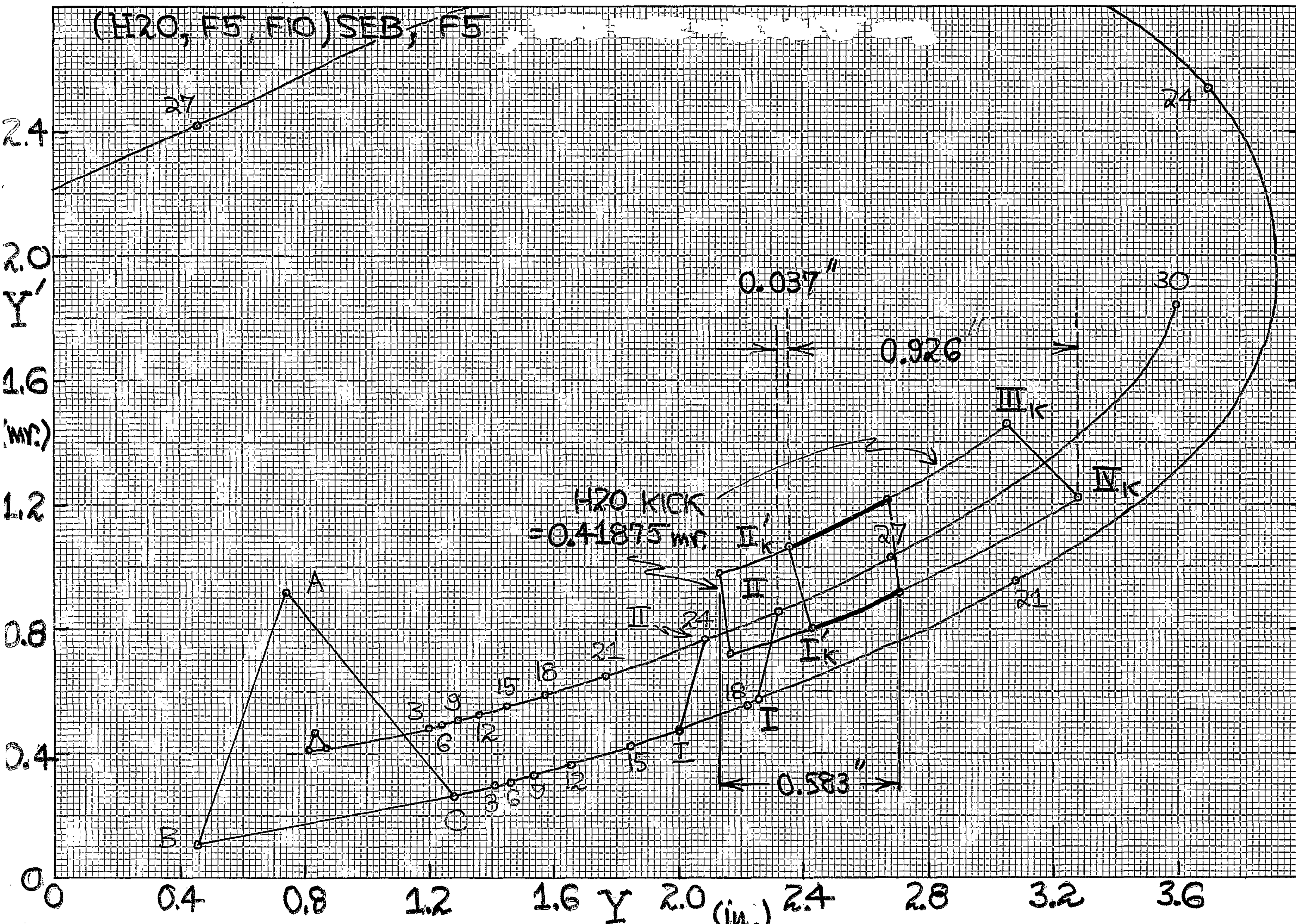


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Fig. 5
Case A

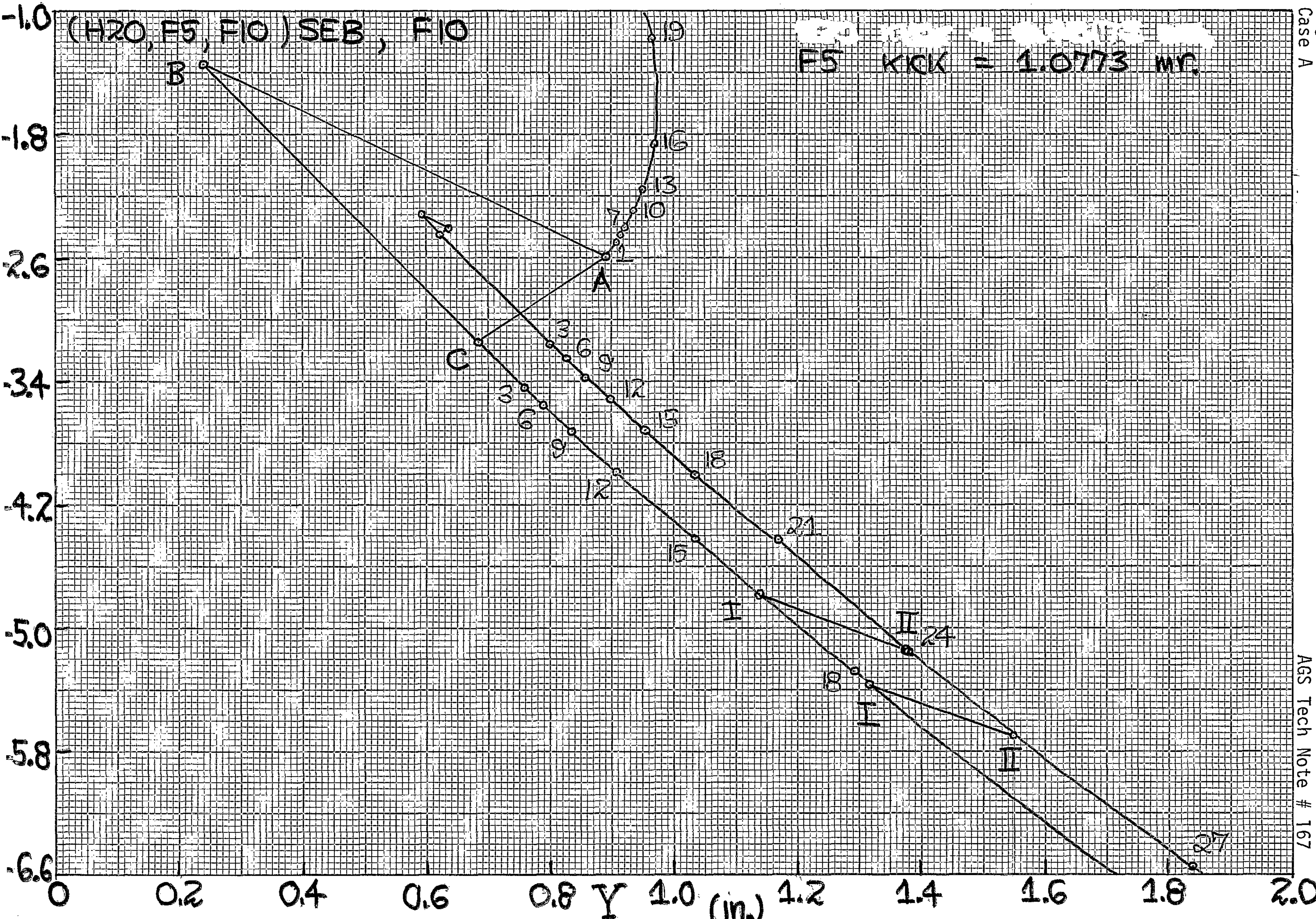

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Fig. 6
Case A

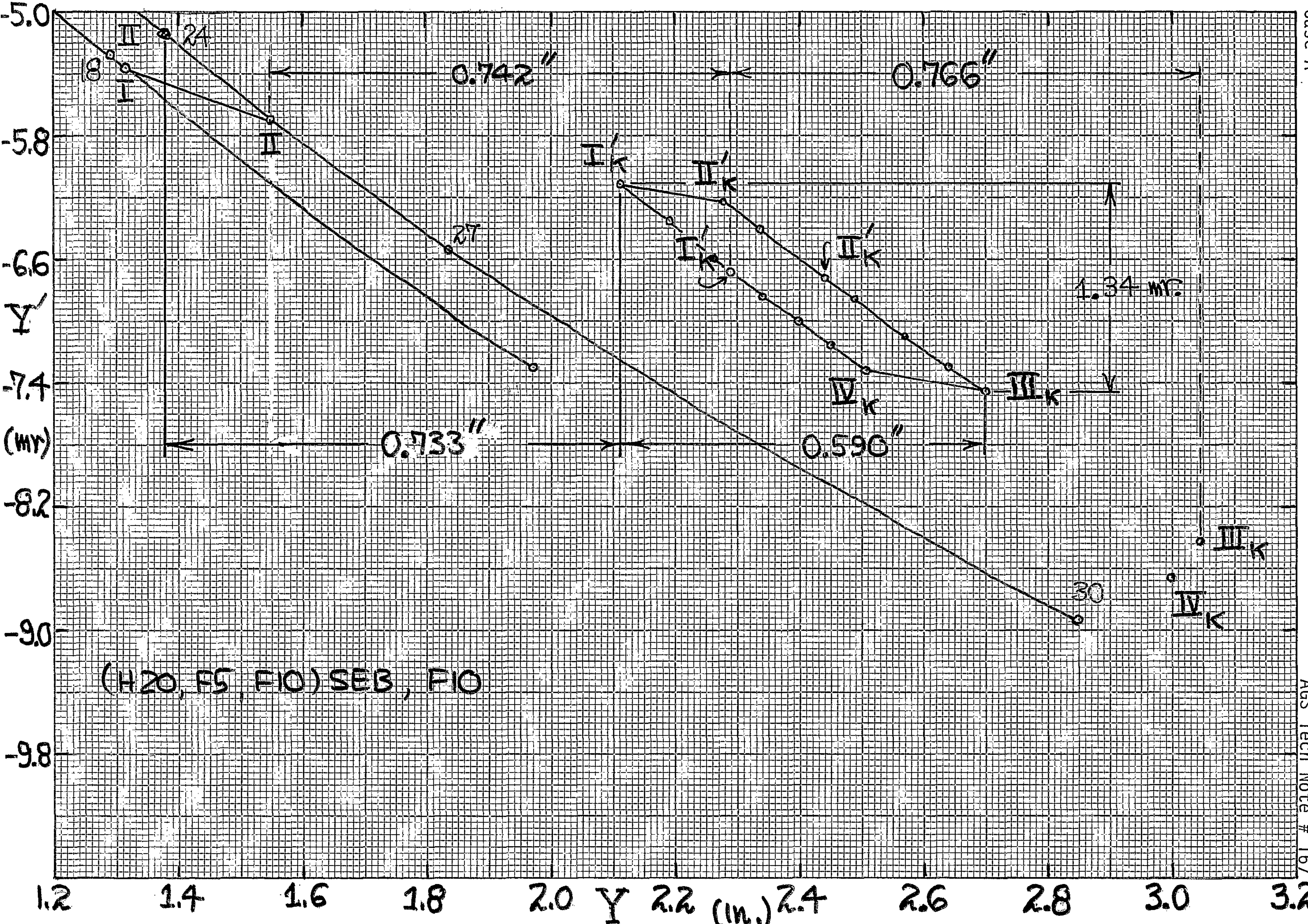

-5.0
-5.8
-6.6
-7.4
-8.2
-9.0
-9.8
Y'
(mr)
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
Y (in.)
0.742"
0.766"
0.733"
0.590"
1.34 mr.
18
24
27
30
(H20, F5, F10) SEB, F10

Fig. 7
Case B

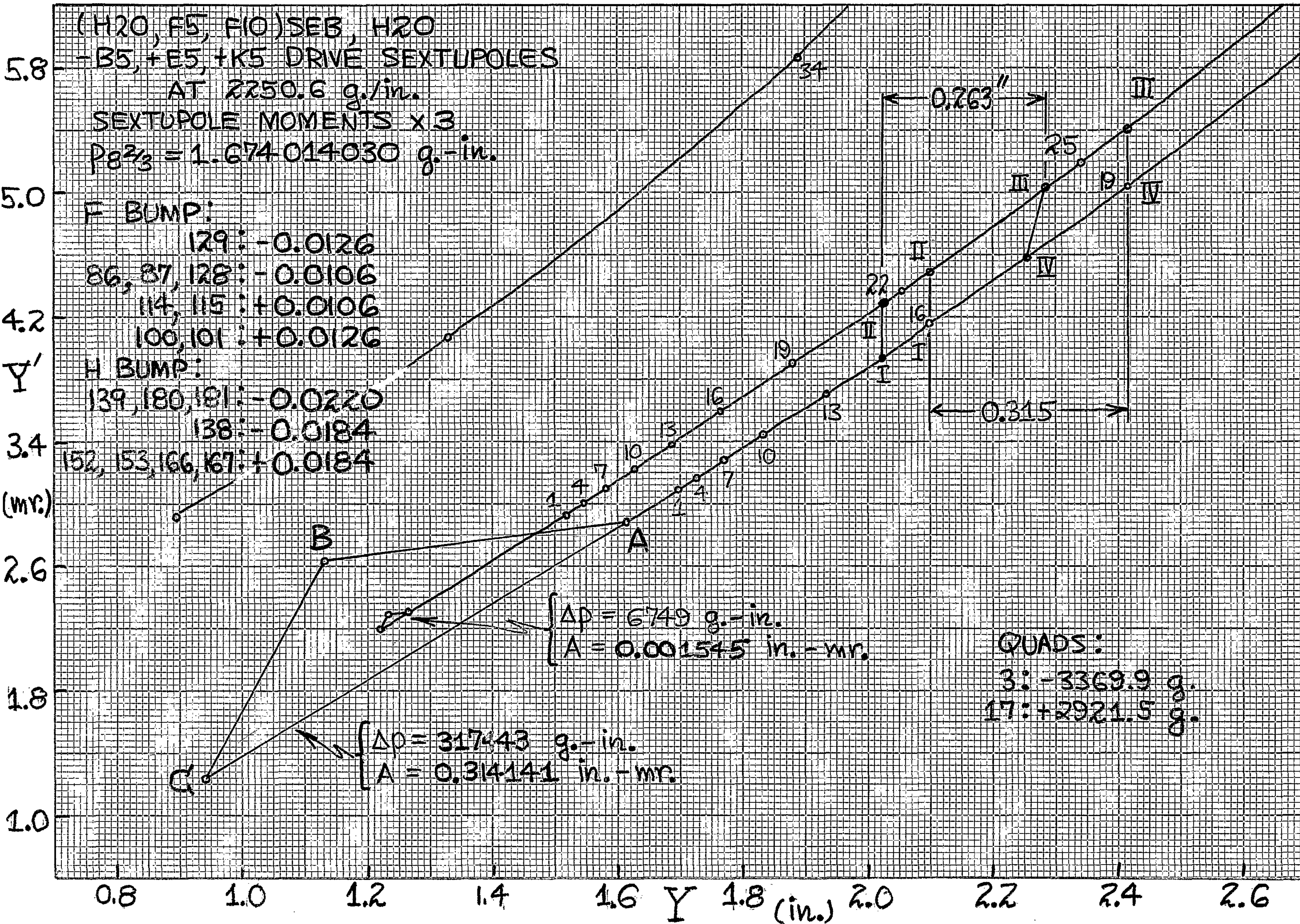
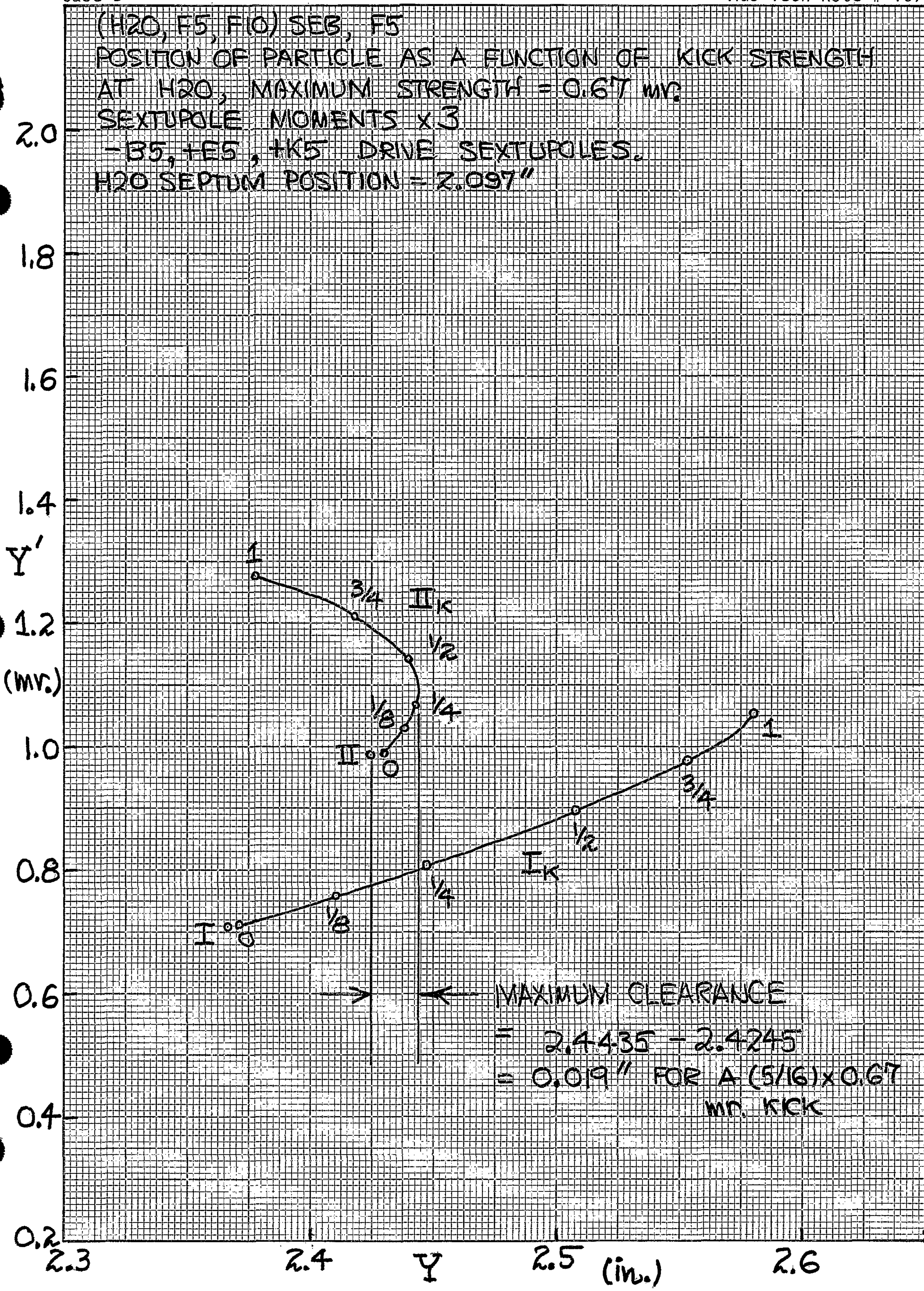
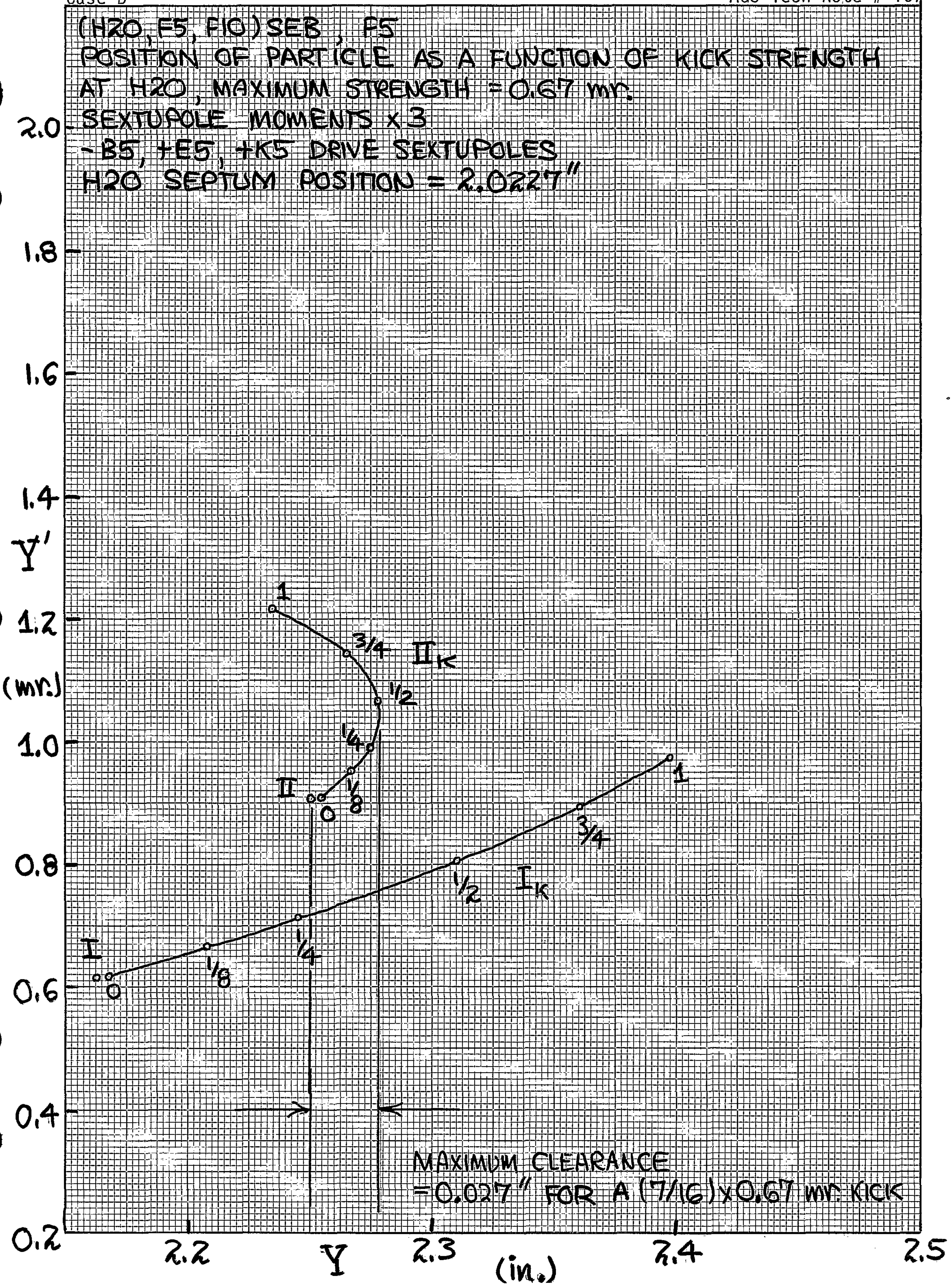

(H20, F5, F10)SEB, H20
-B5, +E5, +K5 DRIVE SEXTUPOLES
AT 2250.6 g./in.
SEXTUPOLE MOMENTS x 3
Pδ2/3 = 1.674014030 g.-in.
F BUMP:
129 : -0.0126
86, 87, 128 : -0.0106
114, 115 : +0.0106
100, 101 : +0.0126
H BUMP:
139, 180, 181 : -0.0220
138 : -0.0184
152, 153, 166, 167 : +0.0184
Δp = 6749 g.-in.
A = 0.001545 in.-mr.
Δp = 317443 g.-in.
A = 0.314141 in.-mr.
QUADS:
3 : -3369.9 g.
17 : +2921.5 g.
0.263″
0.315
A
B
C
Y′ (mr.)
Y (in.)
5.8
5.0
4.2
3.4
2.6
1.8
1.0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6

Fig. 8
Case B


(H20, F5, F10) SEB, F5
POSITION OF PARTICLE AS A FUNCTION OF KICK STRENGTH
AT H20, MAXIMUM STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS x 3
-I35, +E5, +K5 DRIVE SEXTUPOLES.
H20 SEPTUM POSITION = 2.097"
Y'
(mr.)
Y
(in.)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
2.3
2.4
2.5
2.6
II_K
I_K
II
I
0
1/8
1/4
1/2
3/4
1
MAXIMUM CLEARANCE
= 2.4435 - 2.4245
= 0.019" FOR A (5/16) x 0.67
mr. KICK


(H20, F5, F10) SEB, F5
POSITION OF PARTICLE AS A FUNCTION OF KICK STRENGTH
AT H20, MAXIMUM STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS x 3
-B5, +E5, +K5 DRIVE SEXTUPOLES
H20 SEPTUM POSITION = 2.0227"
2.0
1.8
1.6
1.4
Y'
1.2
(mr.)
1.0
0.8
0.6
0.4
0.2
2.2
Y
2.3
(in.)
2.4
2.5
1
3/4
II_K
1/2
1/4
II
1/8
0
1
3/4
1/2
I_K
1/4
I
1/8
0
MAXIMUM CLEARANCE
=0.027" FOR A (7/16)x0.67 mr. KICK

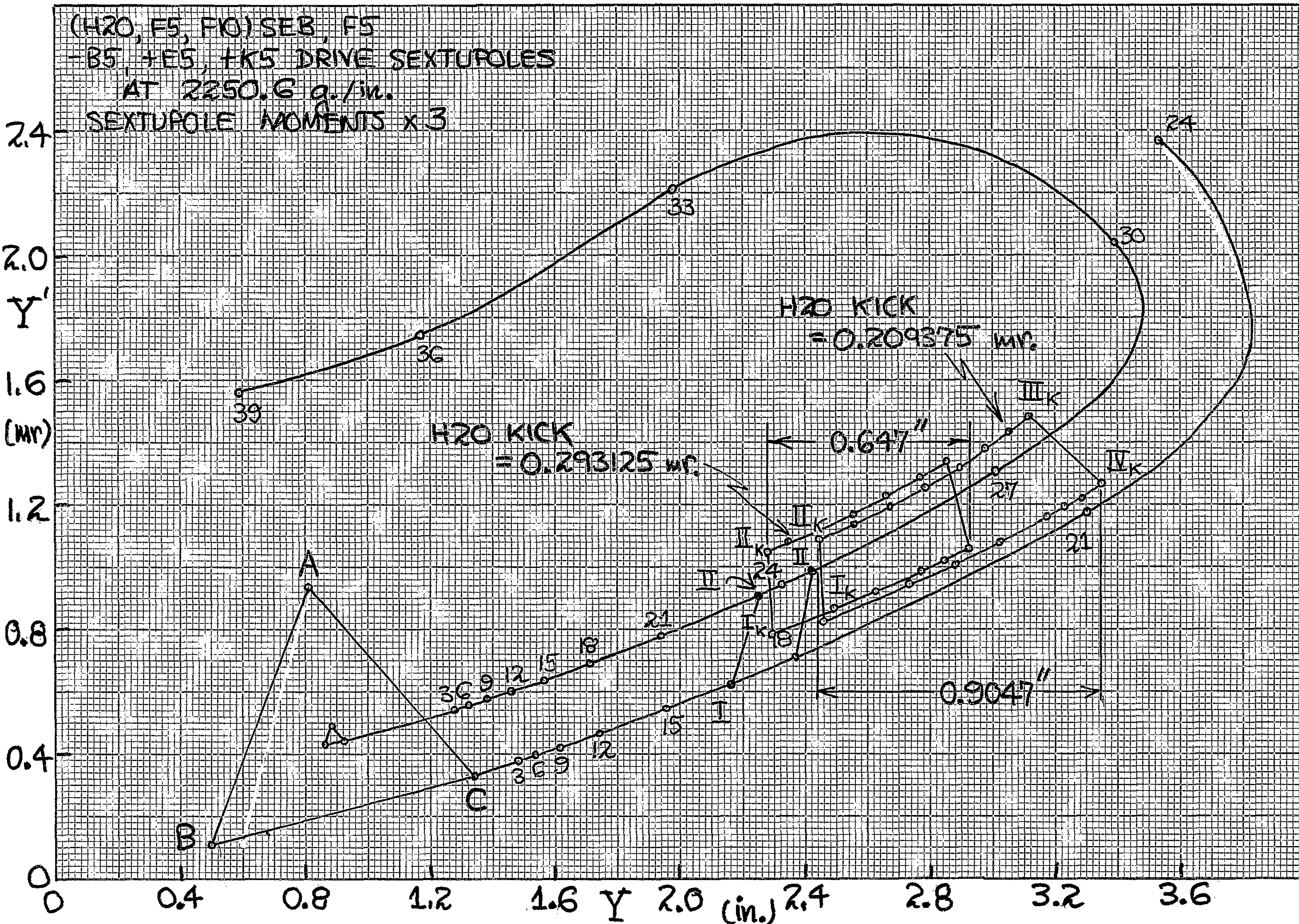

(H20, F5, F10) SEB, F5
-B5, +E5, +K5 DRIVE SEXTUPOLES
AT 2250.6 g./in.
SEXTUPOLE MOMENTS x 3
H20 KICK
= 0.209375 mr.
H20 KICK
= 0.293125 mr.
0.647"
0.9047"
A
B
C
Y'
(mr)
Y
(in.)
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
24
30
33
36
39
27
21
18
15
12
9
6
3
I
II
III
I_K
II_K
III_K
IV_K

Fig. 10
Case B

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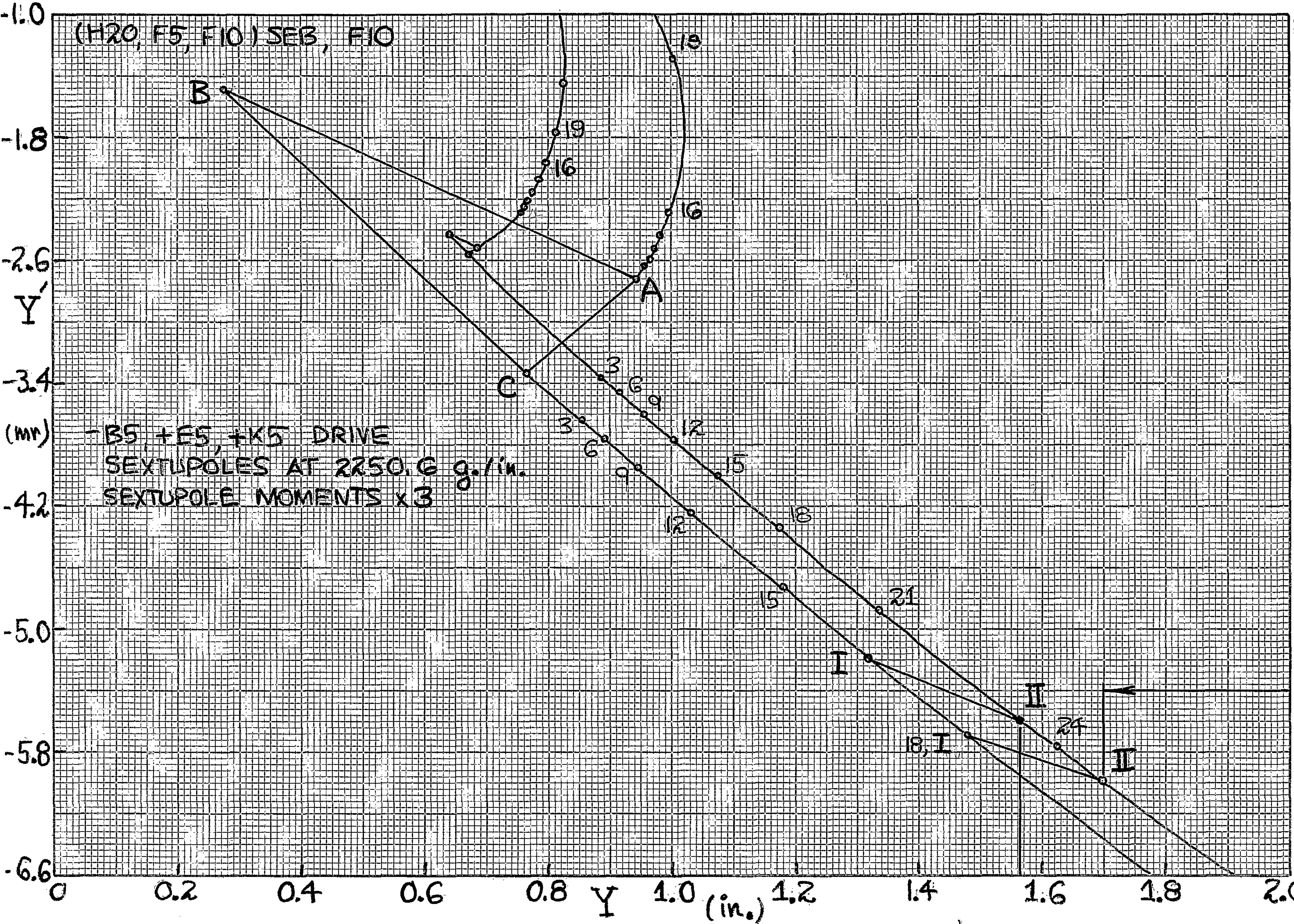

Fig. 11
Case B

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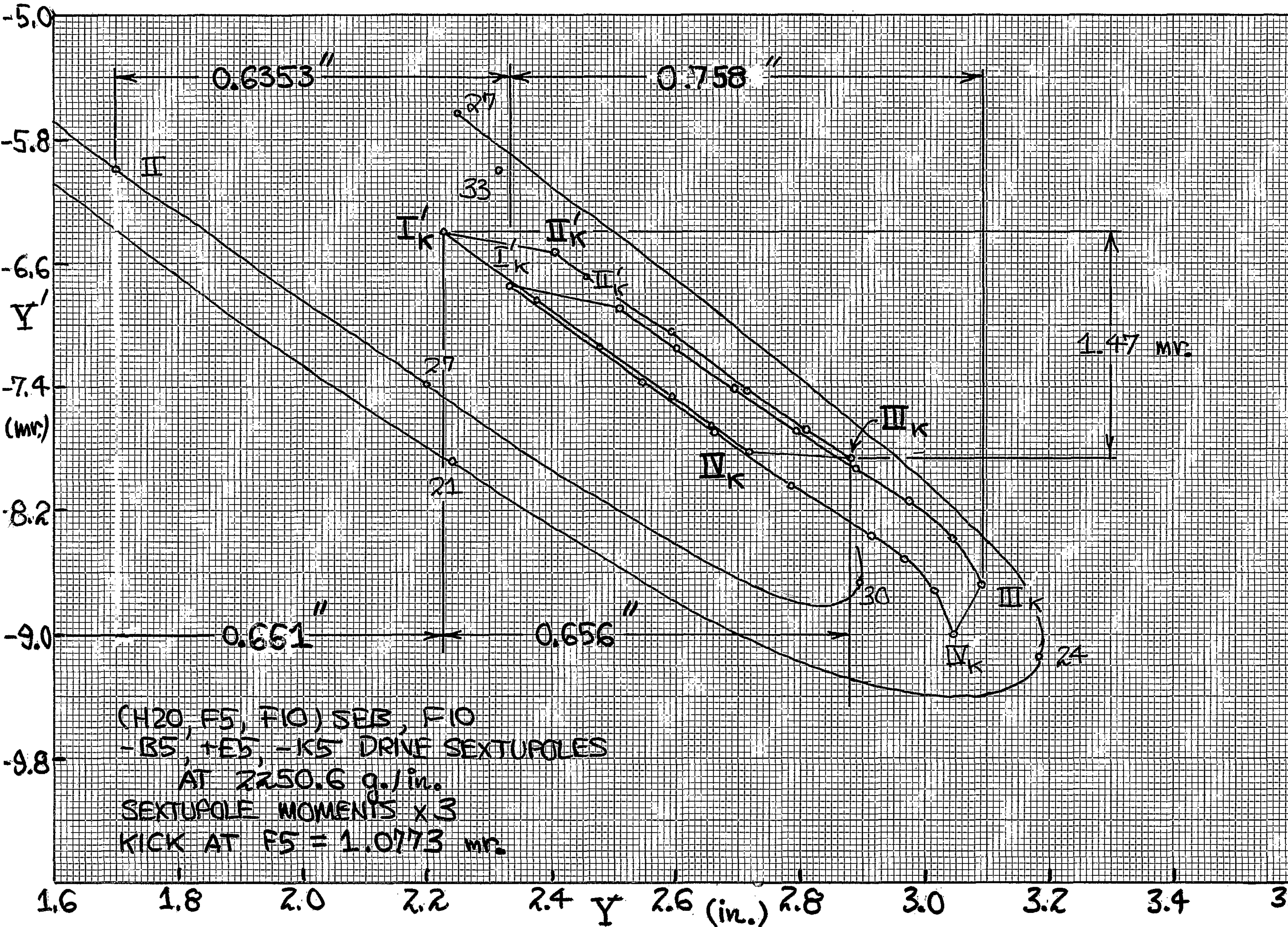

Fig. 12
Case B

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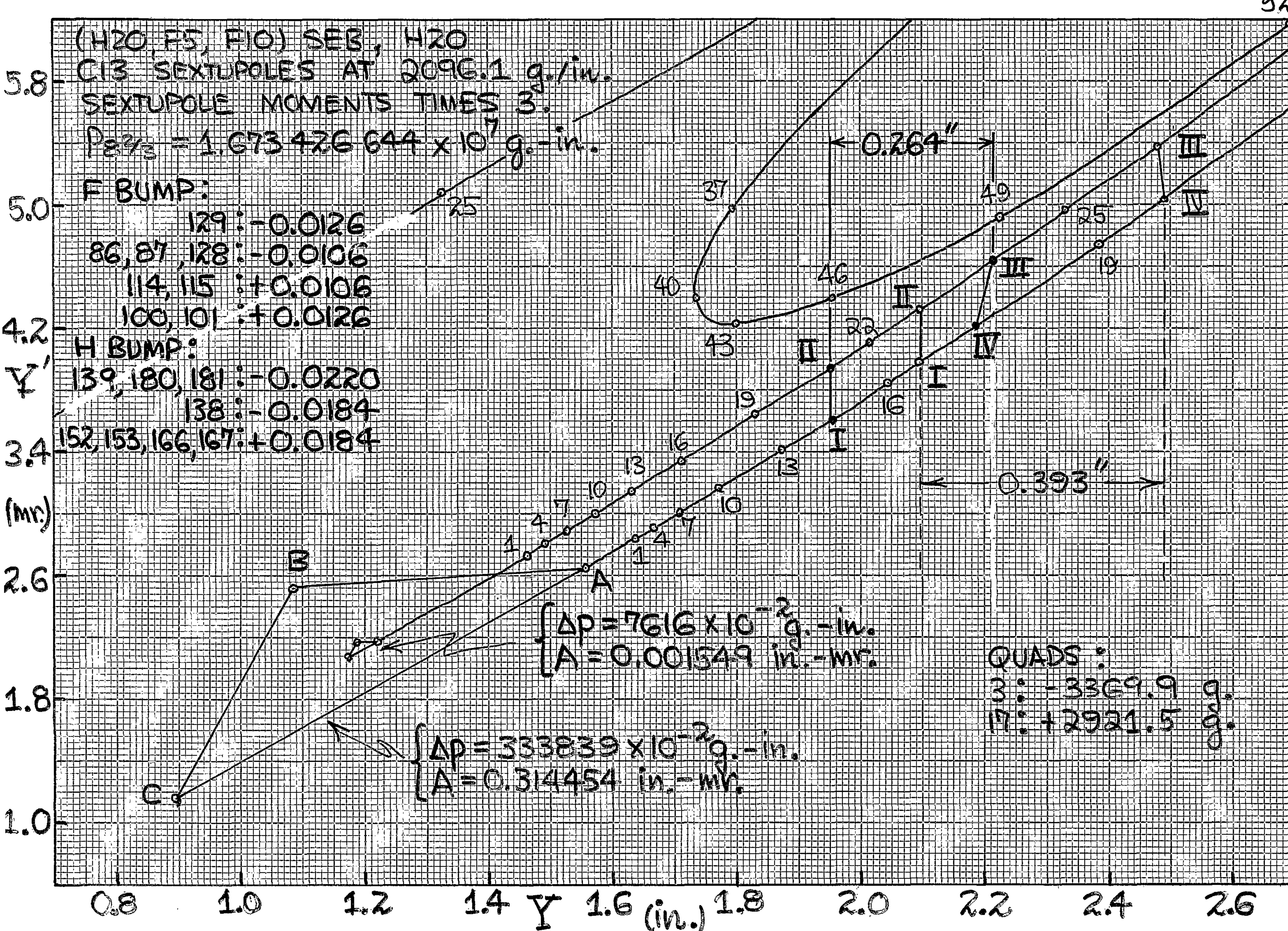
Fig. 13
Case C



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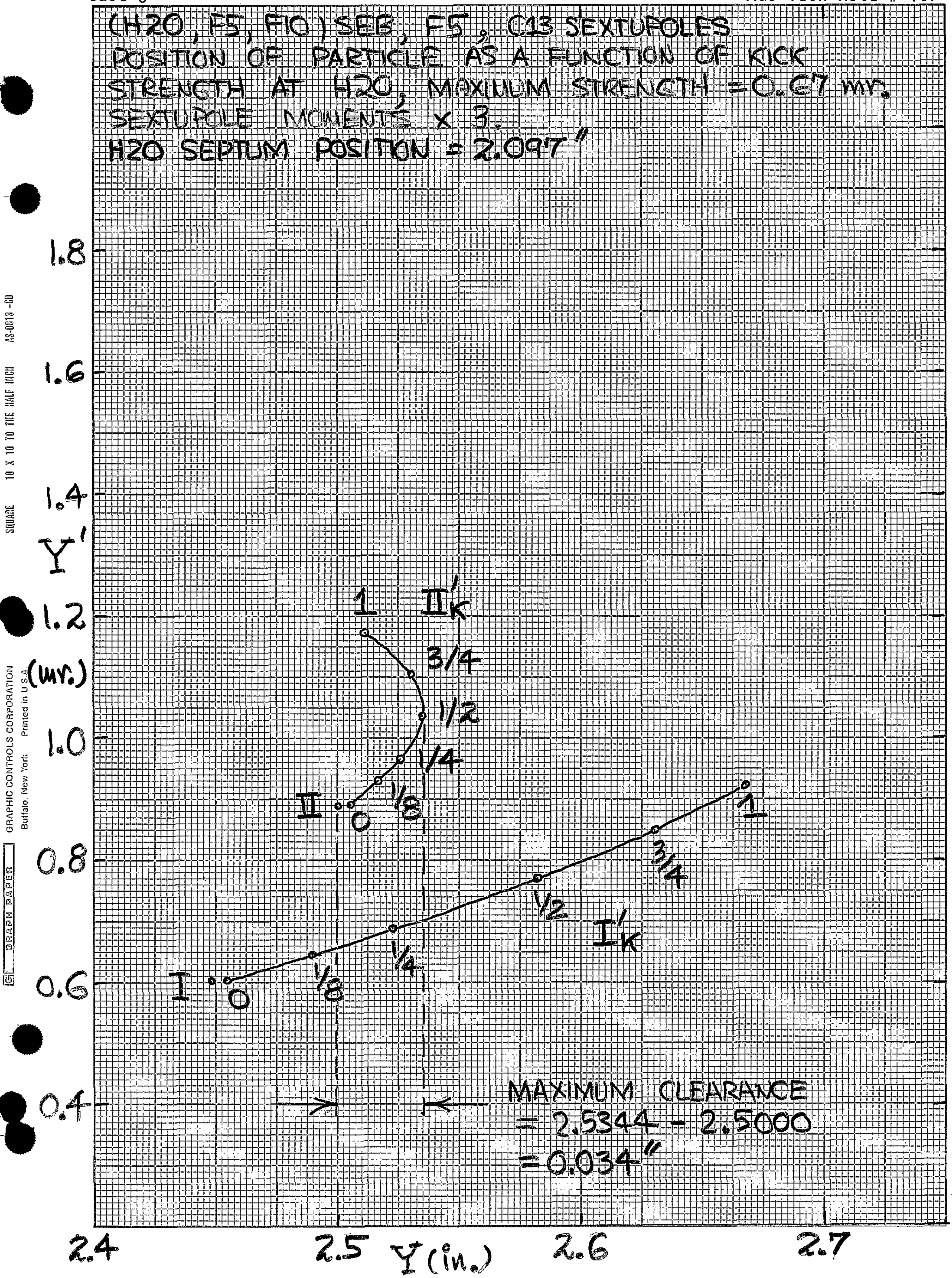
(H20, F5, F10) SEB, F5, C13 SEXTUPOLES
POSITION OF PARTICLE AS A FUNCTION OF KICK STRENGTH AT H20, MAXIMUM STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS x 3.
H20 SEPTUM POSITION = 2.097"
Y' (mr.)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Y (in.)
2.4
2.5
2.6
2.7
I
II
II'_K
I'_K
0
1/8
1/4
1/2
3/4
1
MAXIMUM CLEARANCE
= 2.5344 - 2.5000
= 0.034"
SQUARE 10 X 10 TO THE HALF INCH AS-0013-GD
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GRAPH PAPER

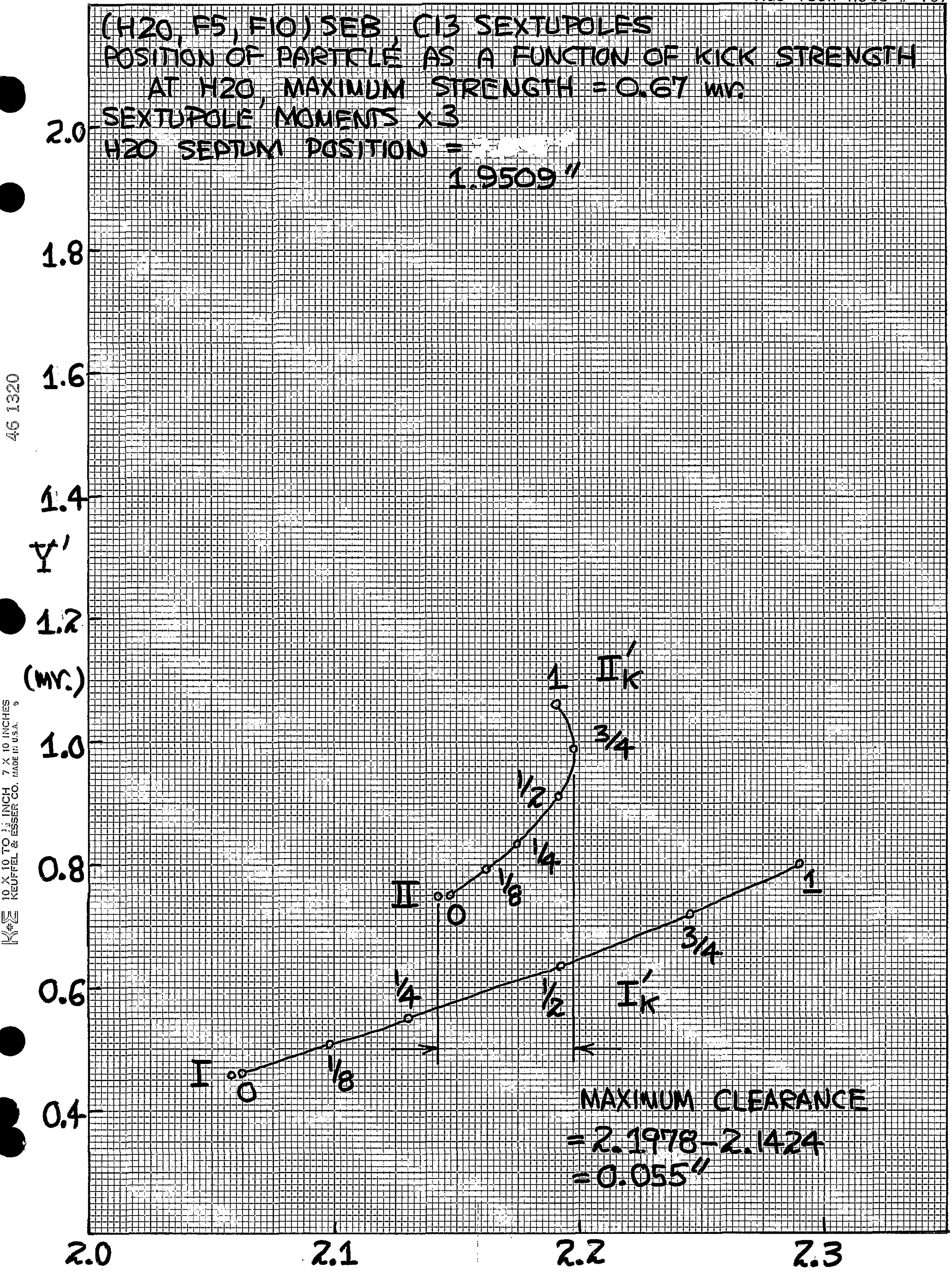
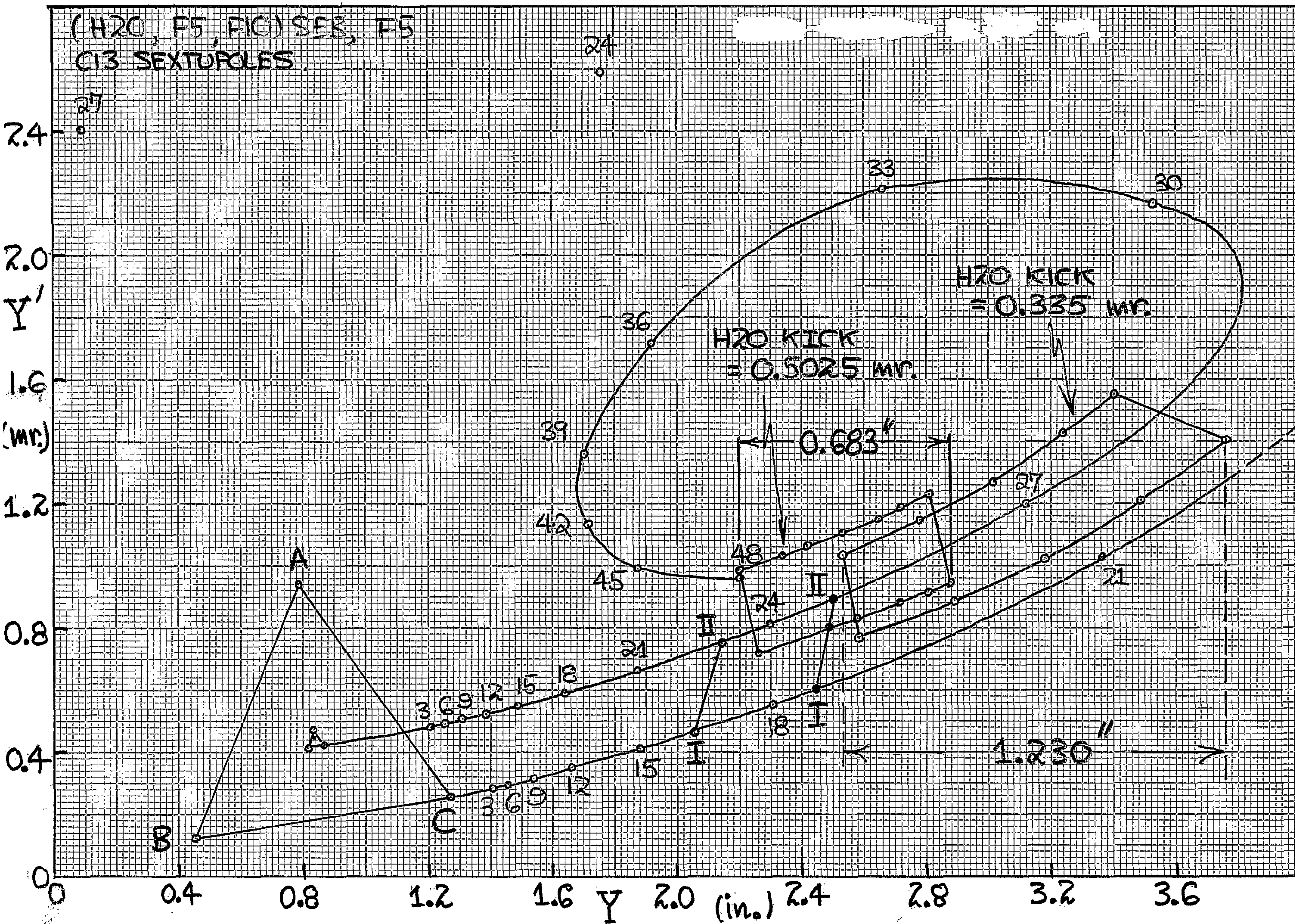

(H20, F5, F10) SEB, C13 SEXTUPOLES
POSITION OF PARTICLE AS A FUNCTION OF KICK STRENGTH AT H20, MAXIMUM STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS x 3
H20 SEPTUM POSITION = 1.9509"
Y' (mr.)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
I
0
1/8
1/4
1/2
3/4
1
I'K
II
0
1/8
1/4
1/2
3/4
1
II'K
MAXIMUM CLEARANCE
= 2.1978 - 2.1424
= 0.055"
2.0
2.1
2.2
2.3

Fig. 16
Case C



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Case C

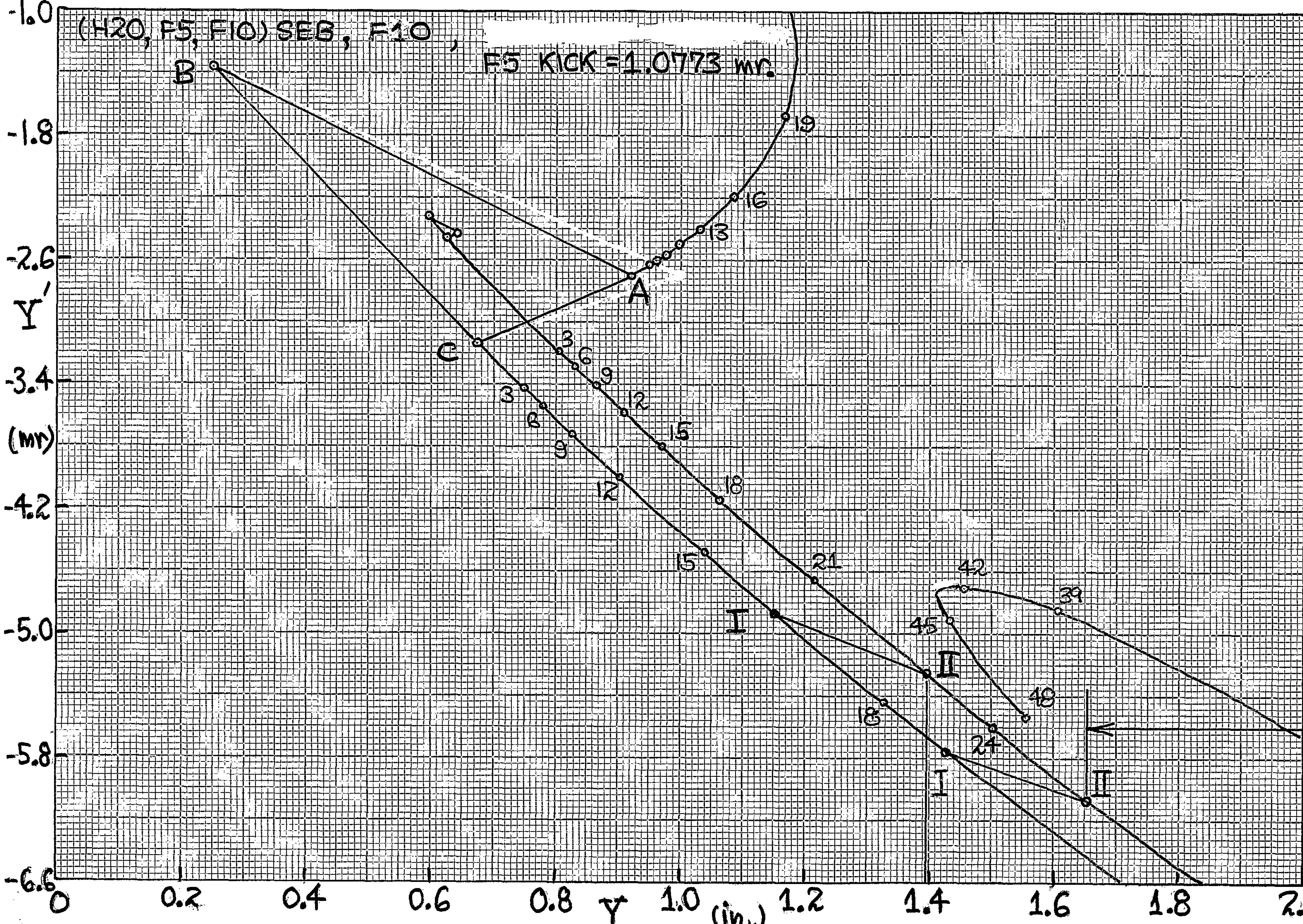
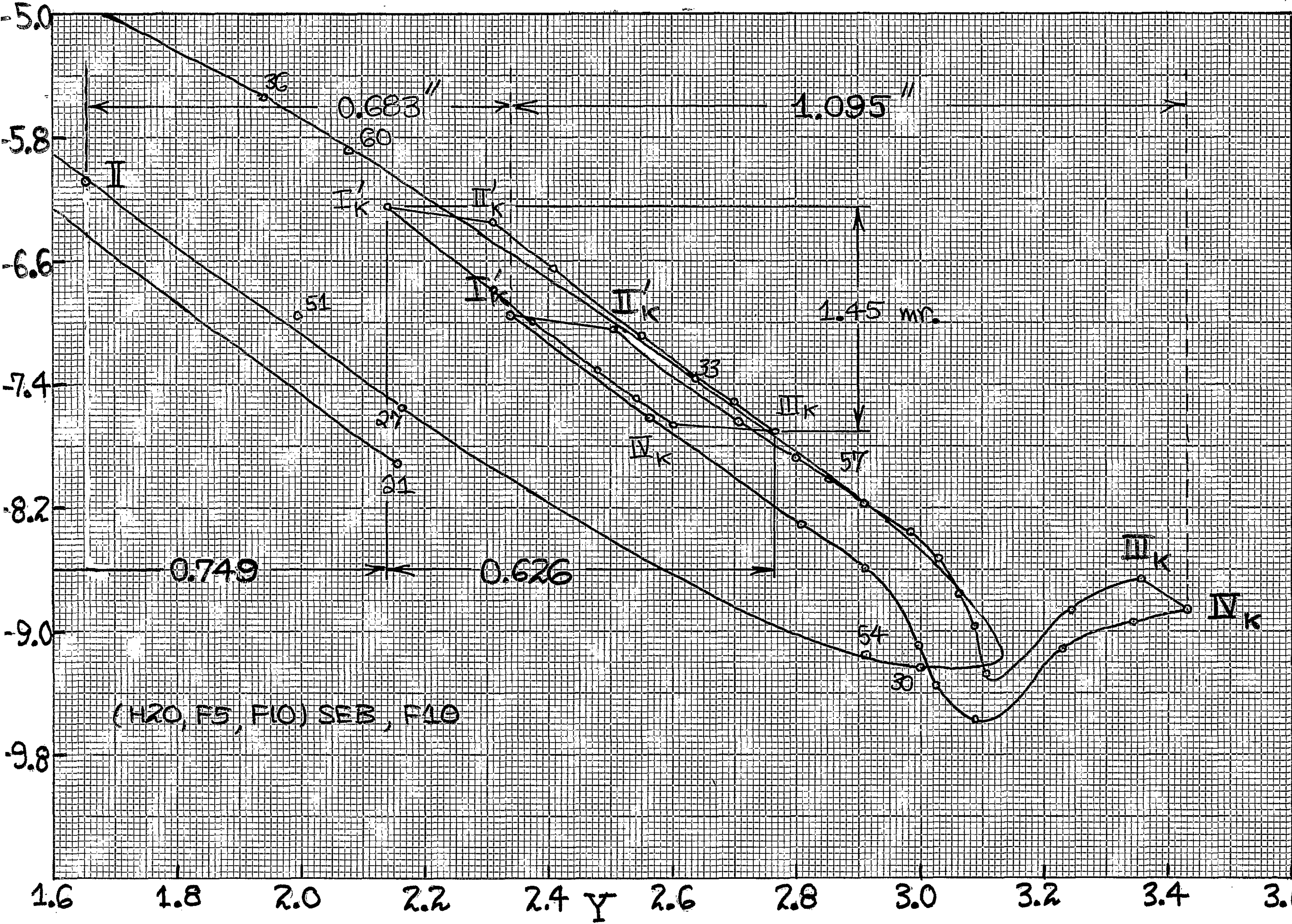

(H20, F5, F10) SEB, F10,
F5 KICK = 1.0773 mr.
Y′ (mr)
Y (in.)
A
B
C
I
II
-1.0
-1.8
-2.6
-3.4
-4.2
-5.0
-5.8
-6.6
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
3
6
9
12
15
18
21
24
13
16
19
39
42
45
48

Fig. 18
Case C



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46 1320

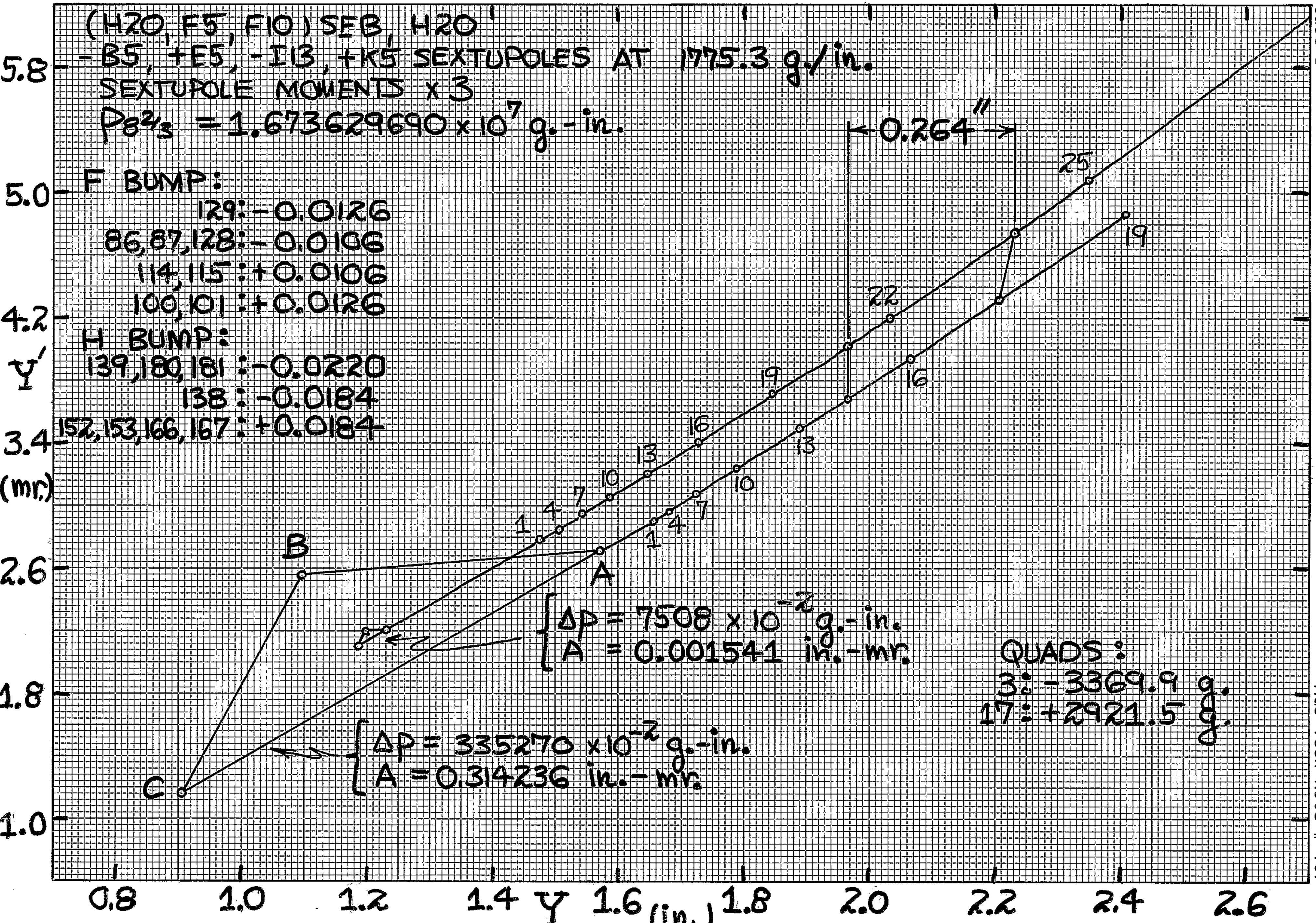

Fig. 19
Case D

Fig. 20
Case D

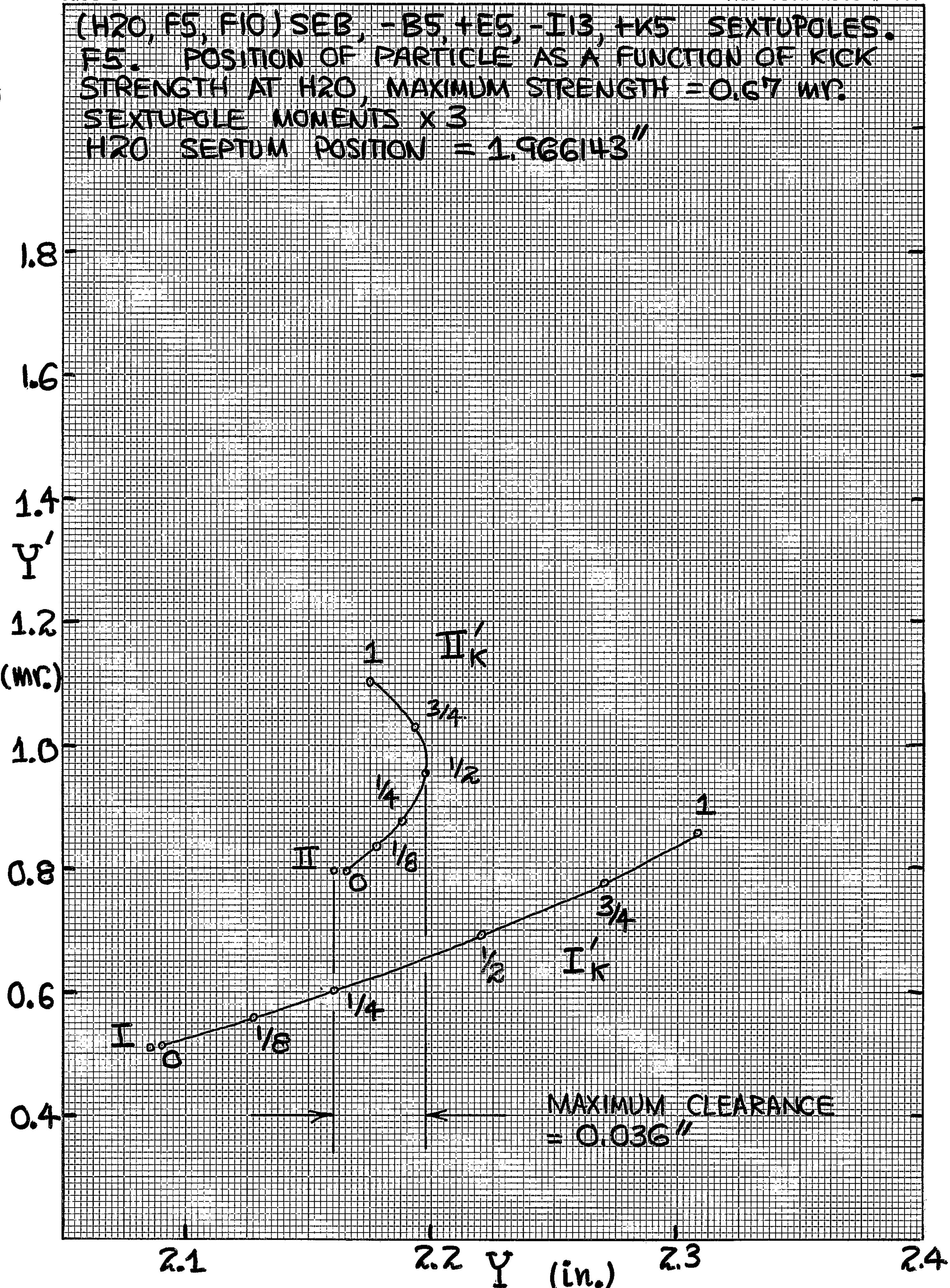
(H20, F5, F10) SEB, -B5, +E5, -I13, +K5 SEXTUPOLES.
F5. POSITION OF PARTICLE AS A FUNCTION OF KICK STRENGTH AT H20, MAXIMUM STRENGTH = 0.67 mr.
SEXTUPOLE MOMENTS x 3
H20 SEPTUM POSITION = 1.966143″
1.8
1.6
1.4
Y′
1.2
(mr.)
1.0
0.8
0.6
0.4
1
II'_K
3/4
1/2
1/4
1/8
II
0
1
3/4
1/2
I'_K
1/4
I
1/8
0
MAXIMUM CLEARANCE = 0.036″
2.1
2.2
Y (in.)
2.3
2.4

Fig. 21
Case D

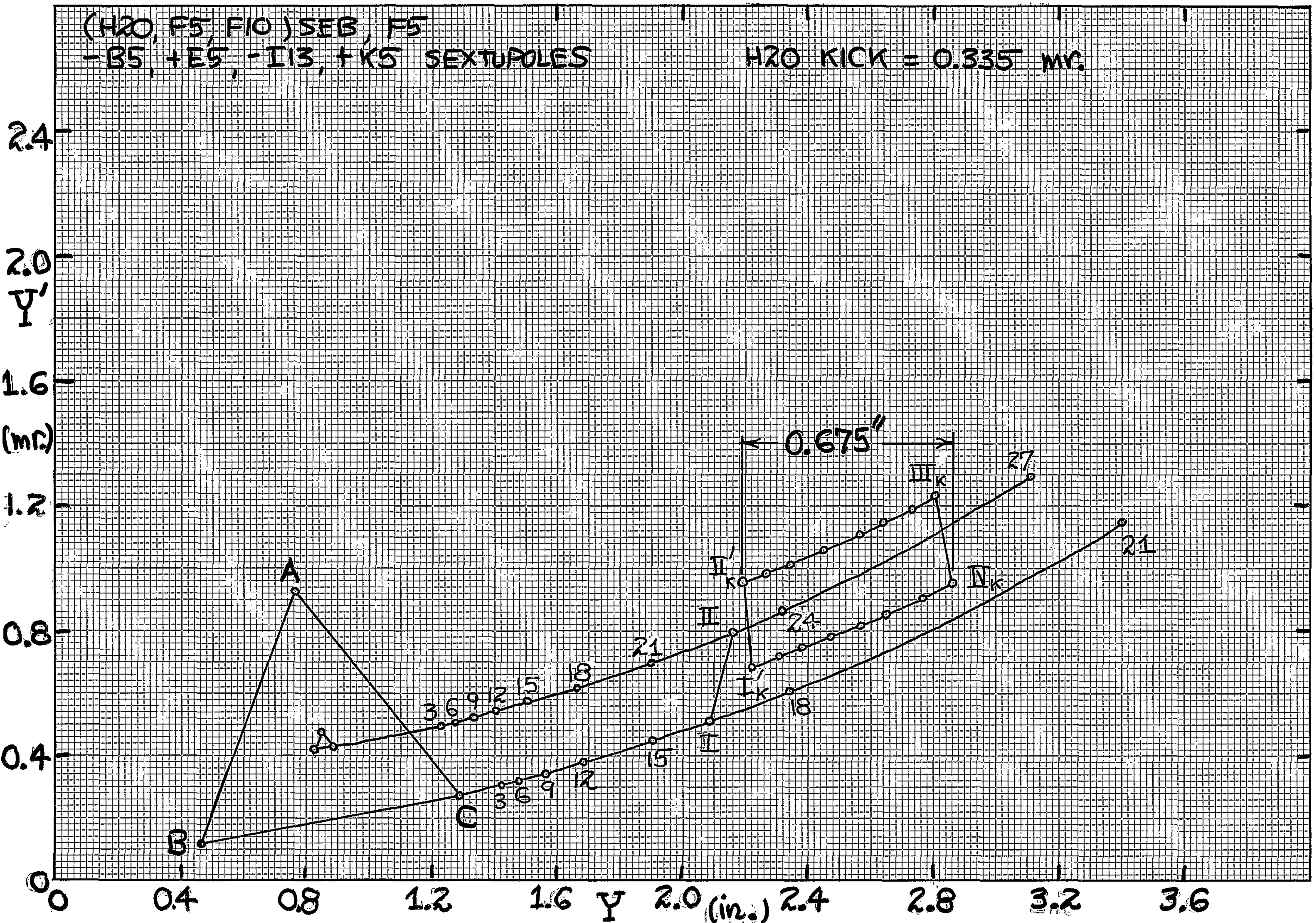

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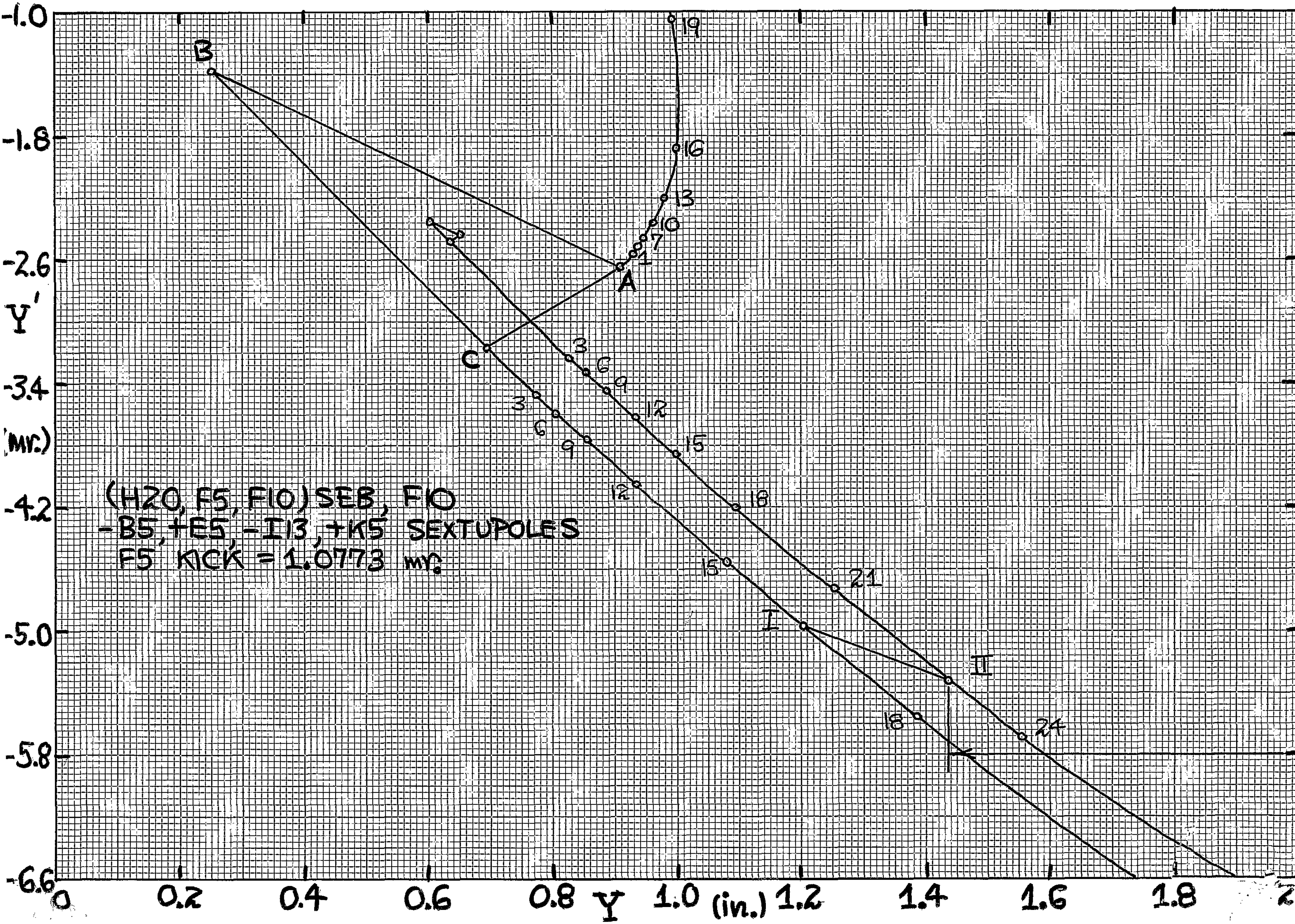
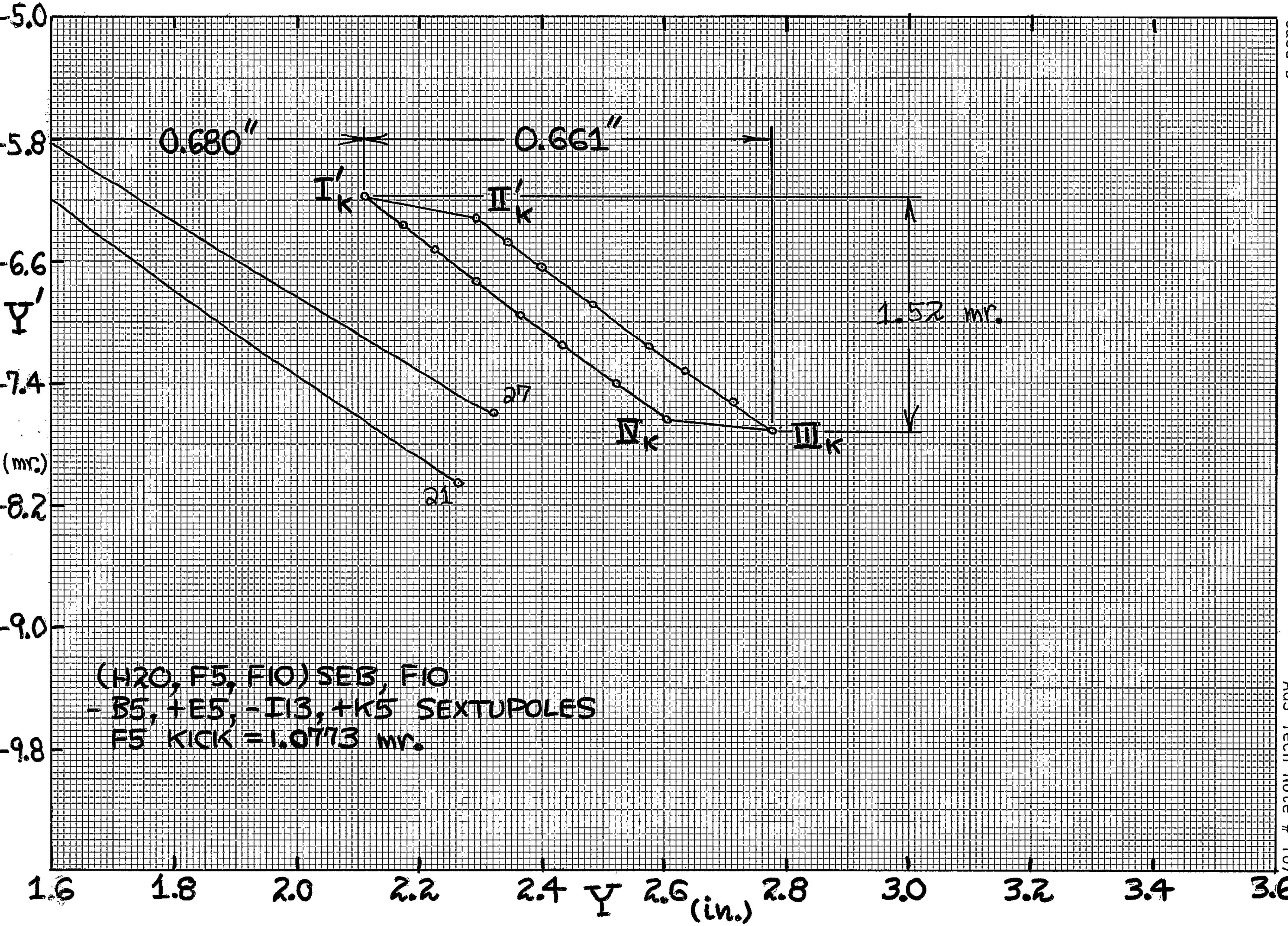
Fig. 22
Case D


(H20, F5, F10) SEB, F10
-B5, +E5, -I13, +K5 SEXTUPOLES
F5 KICK = 1.0773 mr.
Y'
(mr.)
Y (in.)
-1.0
-1.8
-2.6
-3.4
-4.2
-5.0
-5.8
-6.6
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
A
B
C
I
II
1
4
7
10
13
16
19
3
6
9
12
15
18
21
24



-5.0
-5.8
-6.6
-7.4
-8.2
-9.0
-9.8
Y'
(mr.)
1.6
1.8
2.0
2.2
2.4
Y
2.6
(in.)
2.8
3.0
3.2
3.4
3.6
0.680"
0.661"
I'k
II'k
IIIk
IVk
1.52 mr.
27
21
(H20, F5, F10) SEB, F10
- B5, +E5, -I13, +K5 SEXTUPOLES
F5 KICK = 1.0773 mr.

Fig. 23
Case D