BNL-104463-2014-TECH

AGS/AD/Tech Note No. 22;BNL-104463-2014-IR

BEAM MEASUREMENT WITH THE FAST KICKER

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June 1966

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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AGS DIVISION TECHNICAL NOTE

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June 16, 1966

BEAM MEASUREMENT WITH THE FAST KICKER

To use the fast kicker as a beam measuring tool it is necessary to know the beam transport characteristics of the magnets and vacuum piping located downstream from this magnet. Knowledge of the beam trajectories and oscillations, both when "Kicked" and undisturbed, is also needed so that partial beam stoppers and detection devices may be positioned to advantage. This report describes how the information was obtained using the "Beam" computer program.

The Undisturbed Beam

The undisturbed beam was considered to be limited in horizontal phase space by the 5 3/4-in. straight sections following the number 5 magnets in each of the superperiods. Vertical phase space was taken to be limited by the 2 1/2-in. vertical opening of the fast kicker scheduled for installation at L10. Using the "Beam" program (EDC-36), as modified by M. Barton and H. Reich (Memorandum November 24, 1965), an injected particle momentum of $.4040 \times 10^6$ gauss inches was found to have its equilibrium orbit passing very near the center of the No. 5 straight sections. Horizontal betatron oscillations are then allowed to have their greatest amplitudes at this momentum, and this was the momentum used for computations.

The transformation matrices calculated and printed out by "Beam" when searching for equilibrium orbits were used to obtain values for α and β at the straight section locations. These values were in turn used to construct beam ellipses about the equilibrium orbit positions at each of the straight sections. When the results in the horizontal plane were tested with four test particles in the "Beam" program there was close agreement in the results. This indicates, along with computational consistency, that the machine may be considered linear for the dimensions involved.

<u>The Deflected Beam</u>

The kicked beam was taken as at present where we have the old injection system piping fitted in at L10 to L12. The centerline of the deflected beam pipe is approximately 8 in. from the undisturbed beam pipe at L12. The deflected beam pipe is not quite 4 in. in diameter and extends from the center of the L12 magnet to the straight section after L13.

As the beam size is a maximum right at injection before betatron oscillation amplitudes are reduced with increasing energy, this is the condition for which to plan. Using "Beam" an angular deflection of .02496 radians when added to the equilibrium orbit at L10 was found to trace a suitable path down the pipe. Making use of the transformation matrices produced by the program α and β were transformed to L11, L12, and to L13. Again ellipses were constructed about the midpoint path. This time, when test particles were launched through the program to check results, the agreement was good through L12 straight section. At L13 the non-linearity of the fringe field is evident but there is still good agreement for particles with small radial deviation from the central path.

ν Value

For these calculations the "Beam" program was used without quadrupole or sextupole fields. This yields a mathematically "Natural" machine with a νH of 8.65 and νv of 8.73. Actual machine operation is generally with quadrupole fields such that νH is about 8.3 and νv about 8.7.

The effect of this reduction in horizontal ν value is to decrease the machine acceptance by an amount approximately equal to the decrease in ν value.

From EDC-28

$$\beta \cong \beta n \frac{\nu n}{\nu}$$

$$\text{then } W = \frac{\alpha^2}{\beta} \cong \frac{\alpha^2}{\beta n} \; \frac{\nu}{\nu n} = Wn \frac{\nu}{\nu n}$$

The actual beam envelope is then somewhat smaller than described. All beam clearances should certainly still be valid and transformation matrices from L10 to L13 are unchanged.

Observations

Referring to the beam ellipses:

The horizontal beam envelope at L12-L13 is greater than the 4 in. allowed by the vacuum pipe. To obtain complete transmission at injection energy through to L13 the pipe would have to be widened to 7 in.

The L11 straight section is a good location for a beam collimating device. The undisturbed beam has a maximum horizontal betatron oscillation amplitude of but 1.8 in. As the deflected beam is displaced 4 in. from the undisturbed beam, there is more than 1/4 in. free for a support. A support so positioned would not interfere with the beam before, or after, the "Kick".

Detection equipment can be located anywhere up to the L12 straight section before beam is lost on the vacuum chamber walls.

Linear transformation of beam characteristics should certainly be adequate for measurements made up to L12. To so transform measurements made at L13 would introduce an error depending on the particles' radial position.

Distribution: AGS Staff
M. Barton
J. Herrera

ARW/pam

Transformation Matrices from "BEAM" May 66

Injection field $P = .4040 \times 10^6$ gaussinches

$\nu H = 8.657$
$\nu V = 8.726$

$$\begin{pmatrix} X_2 \\ X_2' \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} X_1 \\ X_1' \end{pmatrix}$$

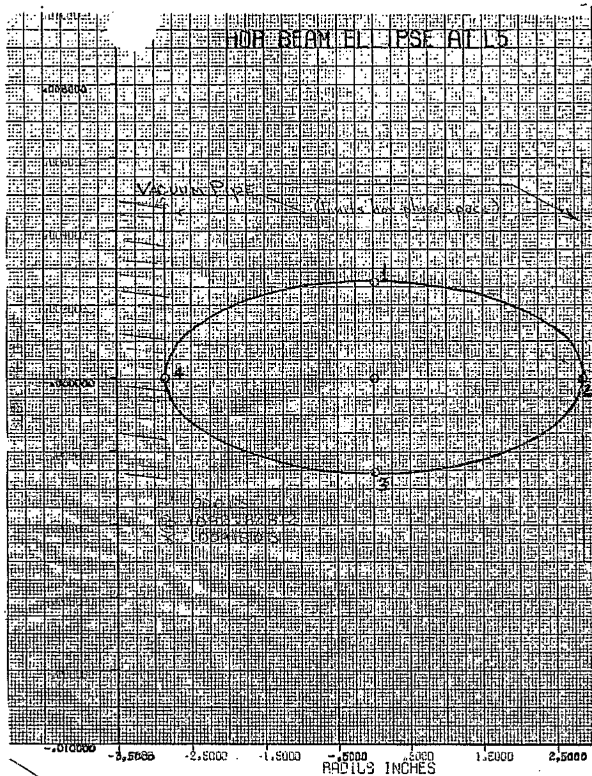
a_{11} unitless
a_{12} Killoinch
a_{21} Millirad /inch
a_{22} unitless

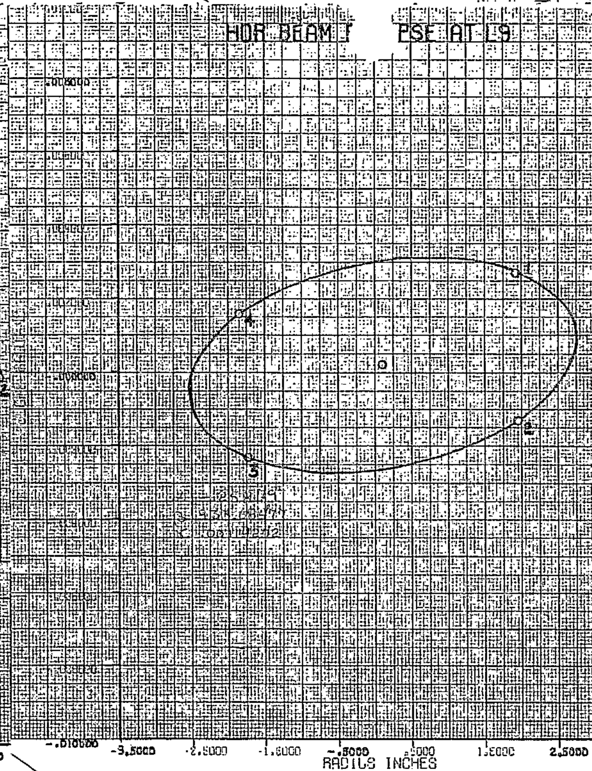
From Center S+Section	To Center St Section	Horizontal a_{11}	a_{12}	a_{21}	a_{22}	Vertical a_{11}	a_{12}	a_{21}	a_{22}
L5	L9	.66982	.72033	-.49654	.95894	.60641	.32139	-2.55747	.29676
L9	L10	.76475	.14004	-2.3487	.87750	1.24696	.162308	2.49773	1.12706
L10	L11	1.12795	.16237	2.51574	1.24870	.87671	.13998	-2.3632	.76328
L11	L12	1.12796	.10823	2.51585	1.12795	.87670	.097903	-2.3633	.87671
L12	L13	.77458	.12475	-2.8850	.82635	1.24013	.147.728	3.1646	1.18334

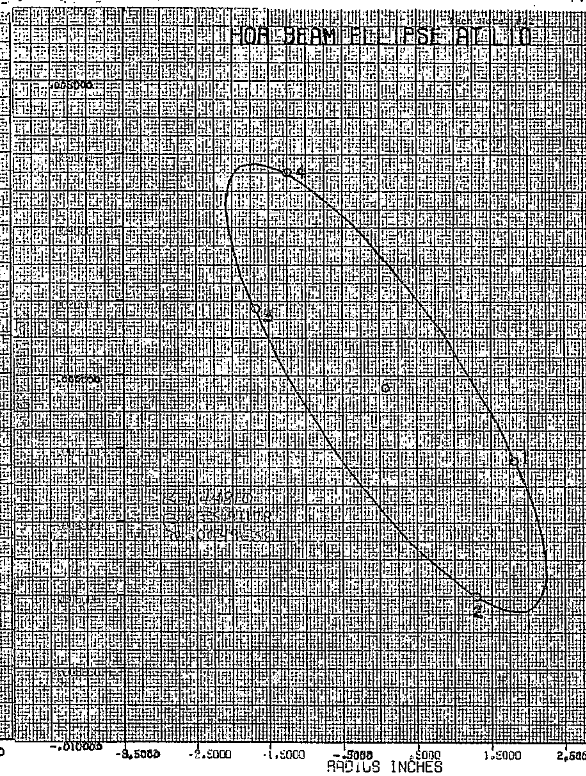
WITH Kick at L10

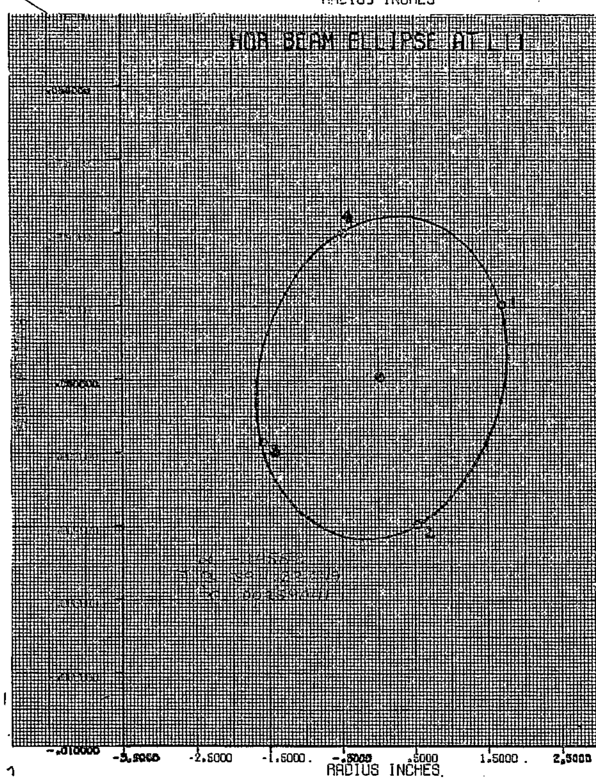
L10	L11	1.13170	.16280	2.5842	1.25538	.87339	.13978	-2.4205	.75755
L11	L12	1.11635	.10773	2.16387	1.10460	.88748	.098754	-2.04813	.89887
L12	L13	1.17244	.143303	1.94610	1.09078	.834096	.124964	-1.83993	.91224

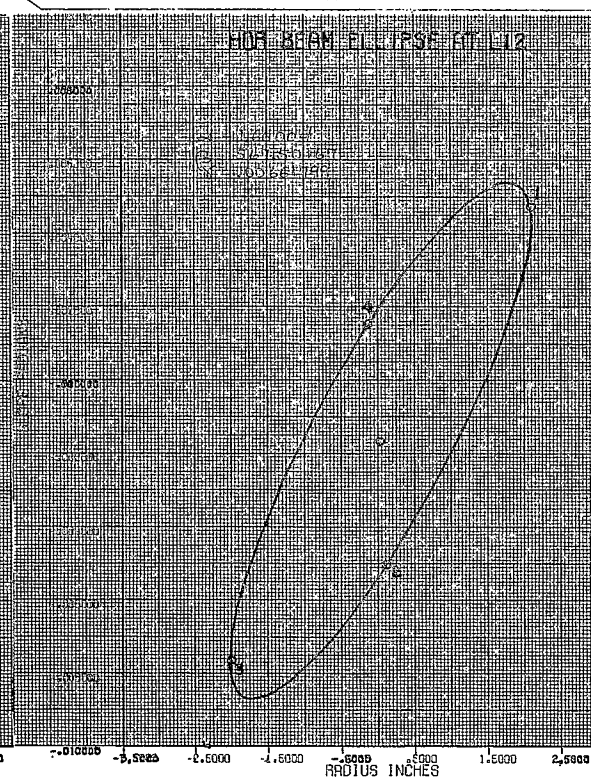
Center St Section	Undisturbed Beam (equilibrium orbit) X	X prime	Kicked Beam (beamcenter path) X	X prime
L5	.002230	.000007		
L9	.093995	.000177		
L10	.066890	-.000362	.066890	.024599
L11	.033001	.000039	4.092789	.031290
L12	.028325	-.001667	7.998246	.043691
L13	.023858	-.000017	15.864964	.068029

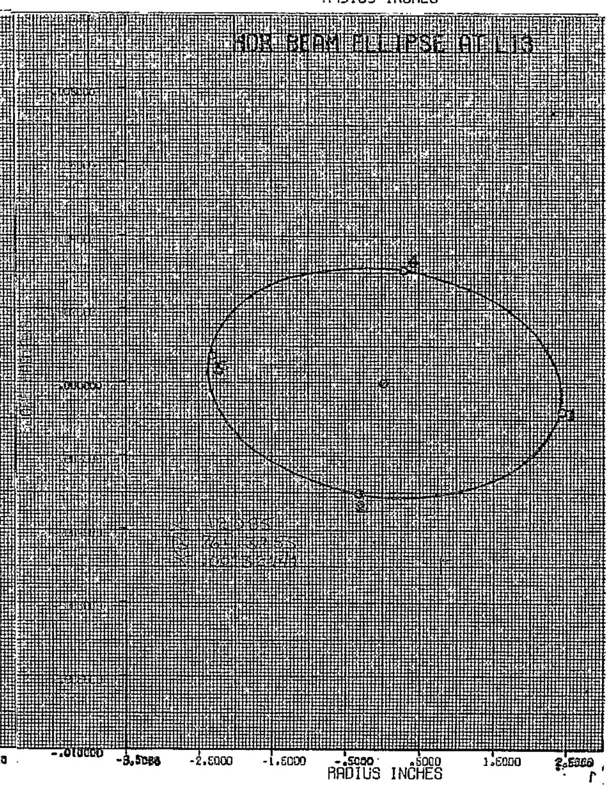

HOR BEAM ELLIPSE AT L5
Vacuum Pipe
-.010000 -3.5000 -2.5000 -1.5000 -.5000 .5000 1.5000 2.5000
RADIUS INCHES

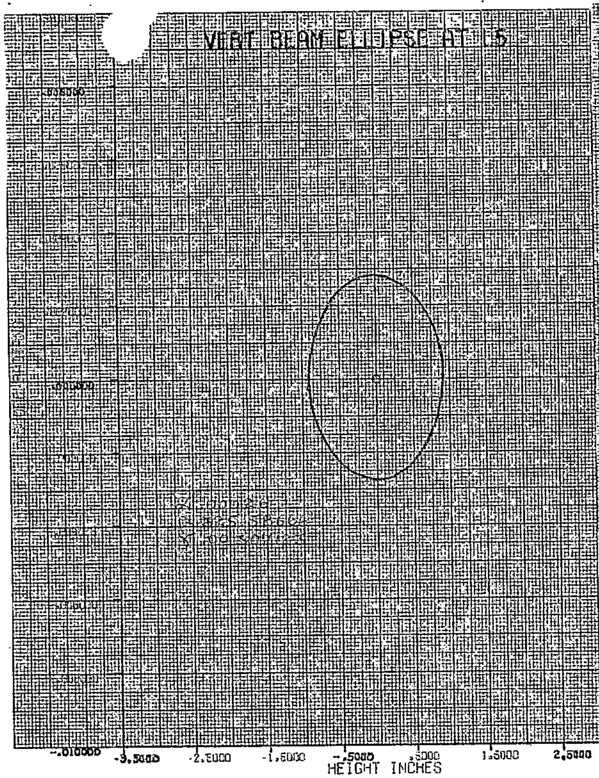

HOR BEAM
PSE AT L9
-.010000 -3.5000 -2.5000 -1.5000 -.5000 .5000 1.5000 2.5000
RADIUS INCHES

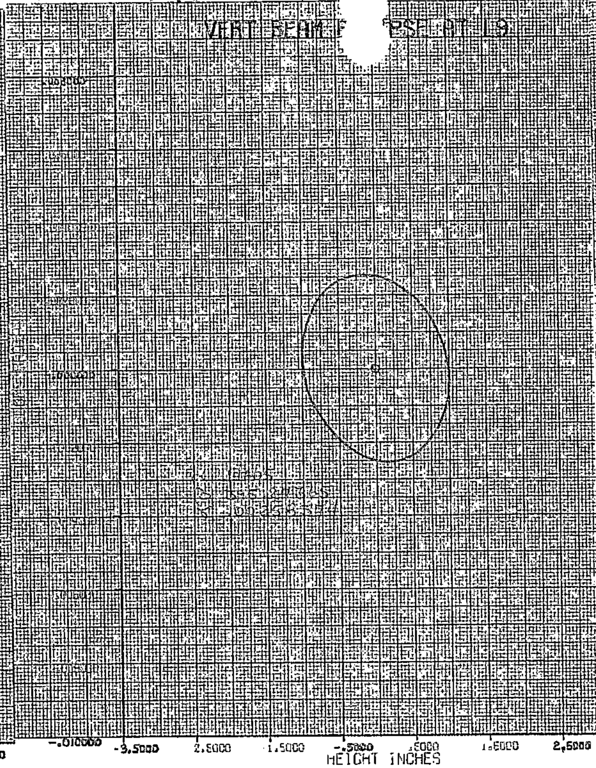

HOR BEAM ELLIPSE AT L10
-.010000 -3.5000 -2.5000 -1.5000 -.5000 .5000 1.5000 2.5000
RADIUS INCHES


HOR BEAM ELLIPSE AT L11
-.010000 -3.5000 -2.5000 -1.5000 -.5000 .5000 1.5000 2.5000
RADIUS INCHES


HOR BEAM ELLIPSE AT L12
-.010000 -3.5000 -2.5000 -1.5000 -.5000 .5000 1.5000 2.5000
RADIUS INCHES


HOR BEAM ELLIPSE AT L13
-.010000 -3.5000 -2.5000 -1.5000 -.5000 .5000 1.5000 2.5000
RADIUS INCHES


VERT BEAM ELLIPSE AT L5
HEIGHT INCHES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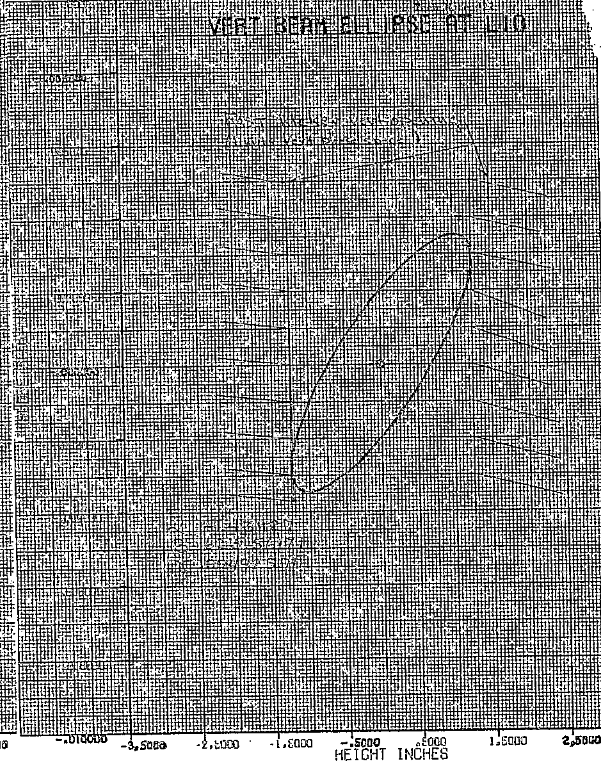
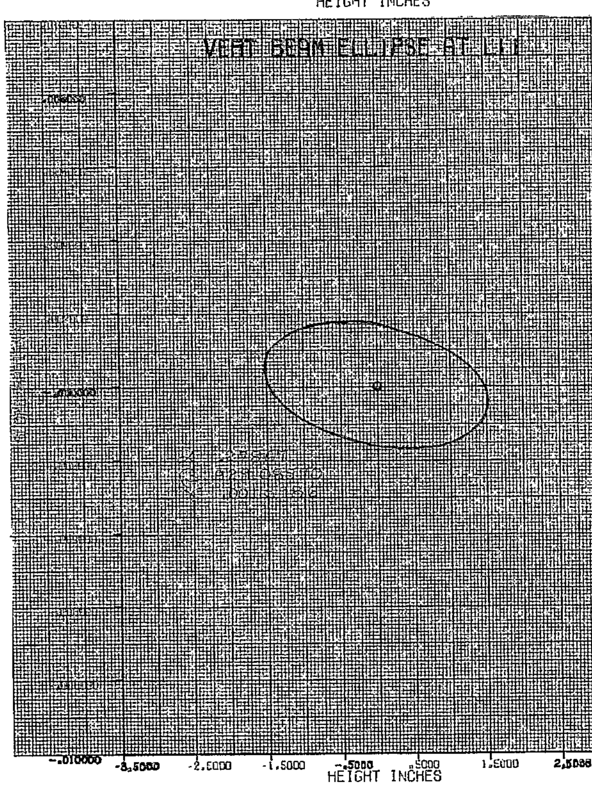
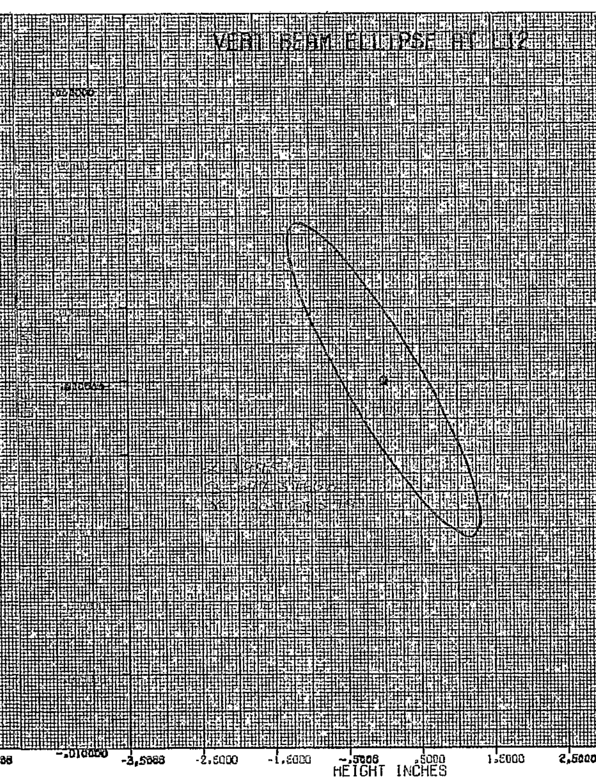
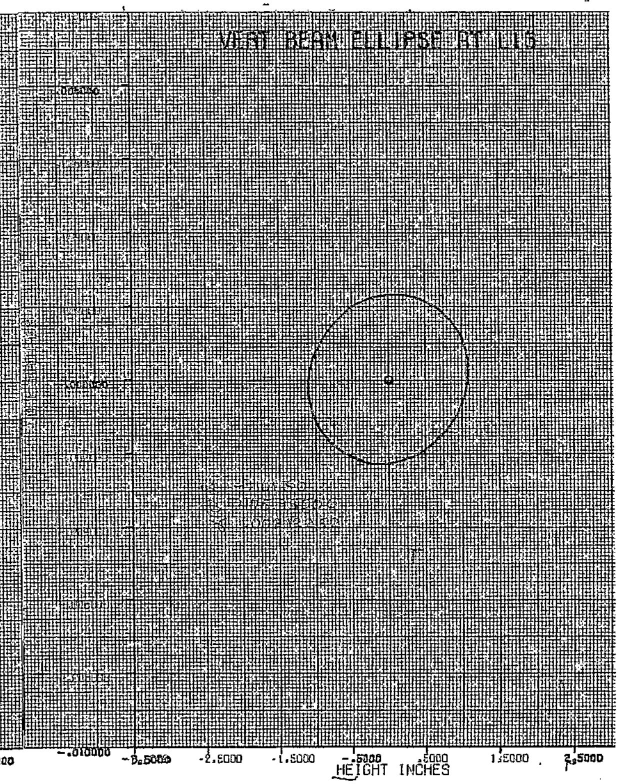

VERT BEAM ELLIPSE AT L10
HEIGHT INCHES


VERT BEAM ELLIPSE AT L11
HEIGHT INCHES


VERT BEAM ELLIPSE AT L12
HEIGHT INCHES


VERT BEAM ELLIPSE AT L15
HEIGHT INCHES

Computations

From EDC-10

$$T((S+C)/S) = \begin{pmatrix} \cos\mu + \alpha \sin\mu & \beta \sin\mu \\ -\gamma \sin\mu & \cos\mu - \alpha \sin\mu \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$

With $\beta\gamma = 1 + \alpha^2$

$$\mu = \cos^{-1} \tfrac{1}{2}(a_{11} + a_{22})$$

$$\alpha = (a_{11} - a_{22}) / 2 \sin\mu$$

$$\beta = a_{12} / \sin\mu$$

$$\gamma = -a_{21} / \sin\mu$$

Again EDC-10

$$T(S_2/S_1) = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}$$

$$\alpha_2 = (b_{11} b_{22} + b_{12} b_{21})\alpha_1 - b_{21} b_{11} \beta_1 - b_{12} b_{22} \gamma_1$$

$$\beta_2 = -2 b_{11} b_{12} \alpha_1 + b_{11}^2 \beta_1 + b_{12}^2 \gamma_1$$

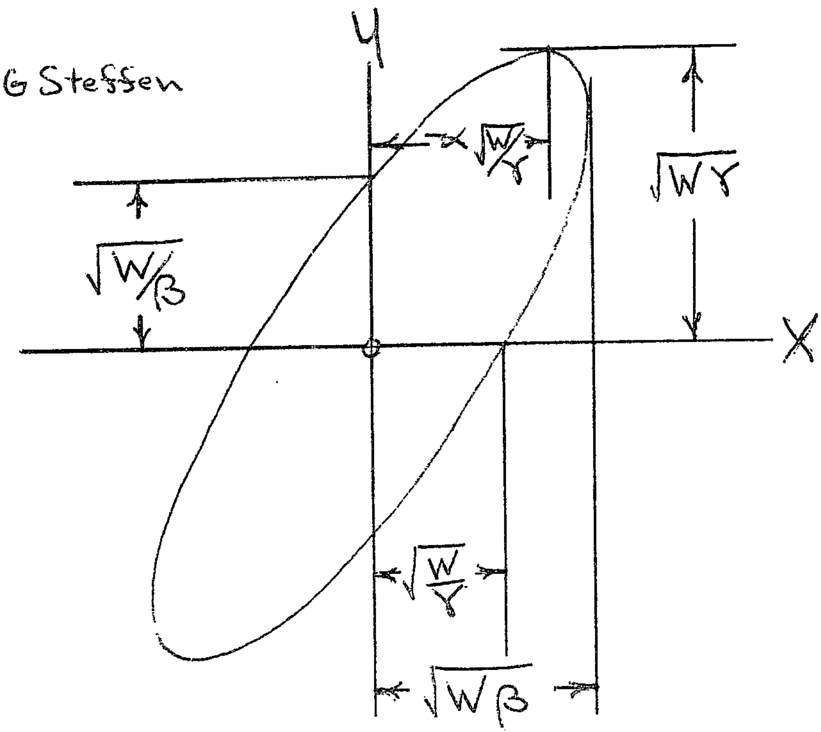
$$\gamma_2 = -2 b_{22} b_{21} \alpha_1 + b_{21}^2 \beta_1 + b_{22}^2 \gamma_1$$

$$W = \text{admittance}/\pi = a^2/\beta_{max}$$

$$W_H = (2.86)^2 / \beta_H(5) = .0074848 \text{ inches radians}$$

$$W_V = (1.25)^2 / \beta_V(10) = .002505 \text{ inches radians}$$

after K G Steffen



all points on the ellipse must satisfy an equation of the form

$$X = X_o(\sin(\omega t+\phi)) + X(\text{equilibrium})$$
$$Y = Y_o(\sin\omega t) + Y(\text{eq})$$

at $\omega t = 0$

$$X = X_o \sin\phi + X(\text{eq}) = \sqrt{W/\gamma} + X_{\text{eq}}$$
$$Y = 0 + Y(\text{eq}) = Y(\text{eq})$$

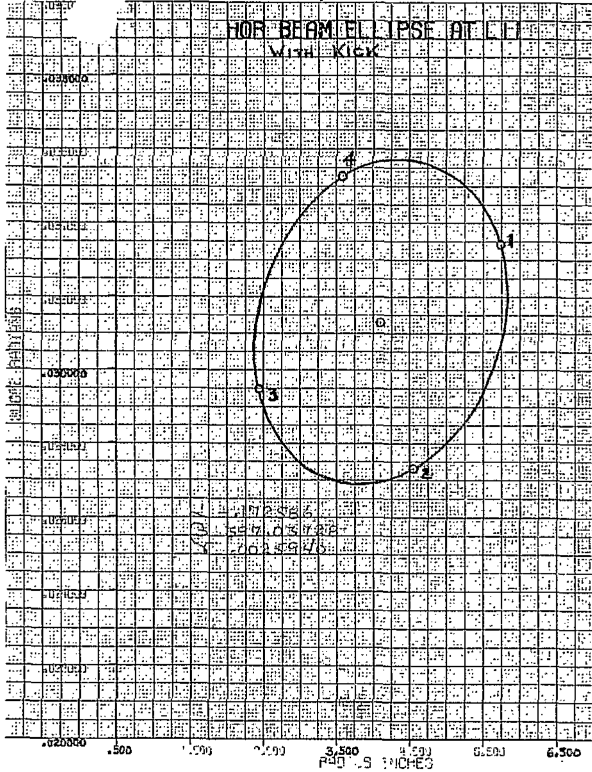
at $\omega t = \pi/2$

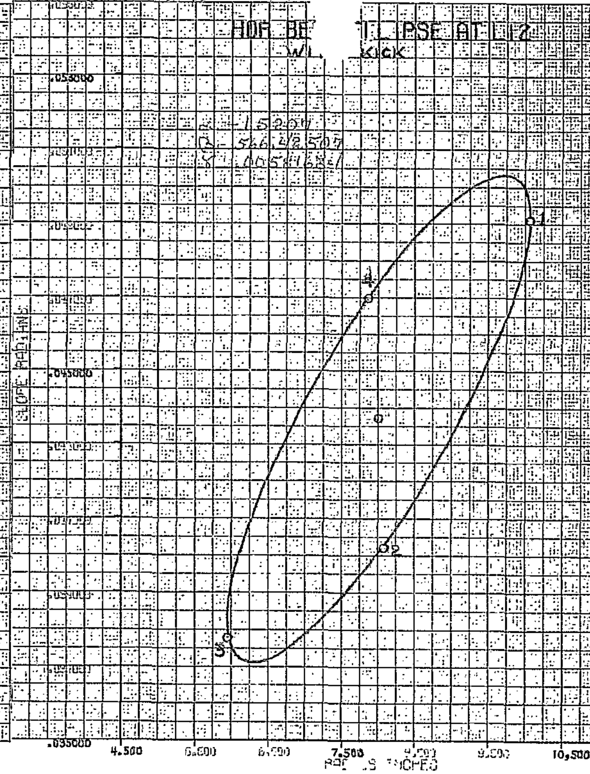
$$X = \left(X_o \sin(\pi/2+\phi) = X_o\cos\phi\right) + X_{\text{eq}} = -\alpha\sqrt{W/\gamma} + X(\text{eq})$$
$$Y = Y_o = \sqrt{W\gamma}$$

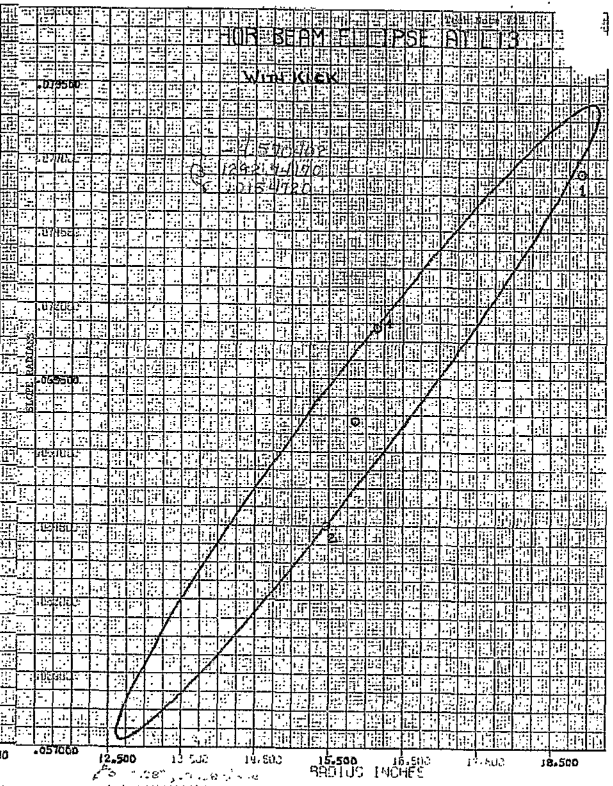
$$\frac{X_o\sin\phi}{X_o\cos\phi} = \frac{\sqrt{W/\gamma}}{-\alpha\sqrt{W/\gamma}} = \frac{-1}{\alpha} = \tan\phi$$

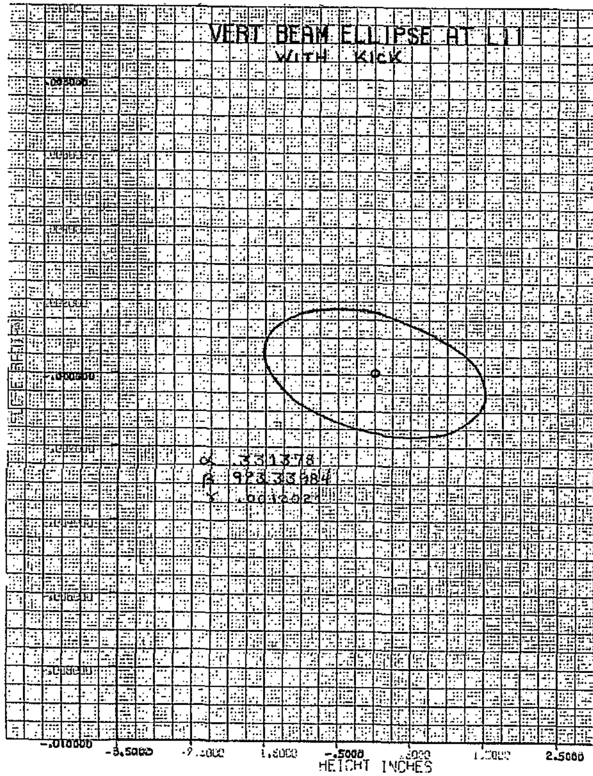
$$\phi = \tan^{-1}\frac{-1}{\alpha}$$

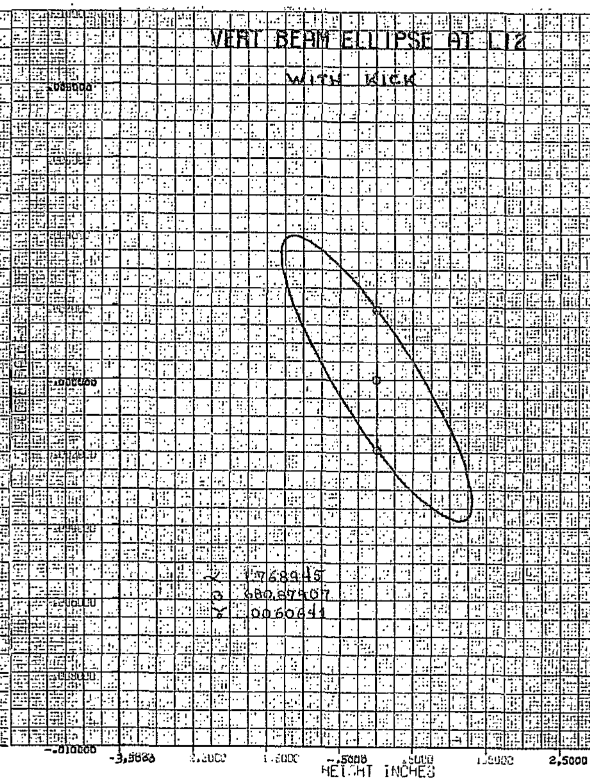
The ellipse may be generated letting ωt go from 0 to 2π.

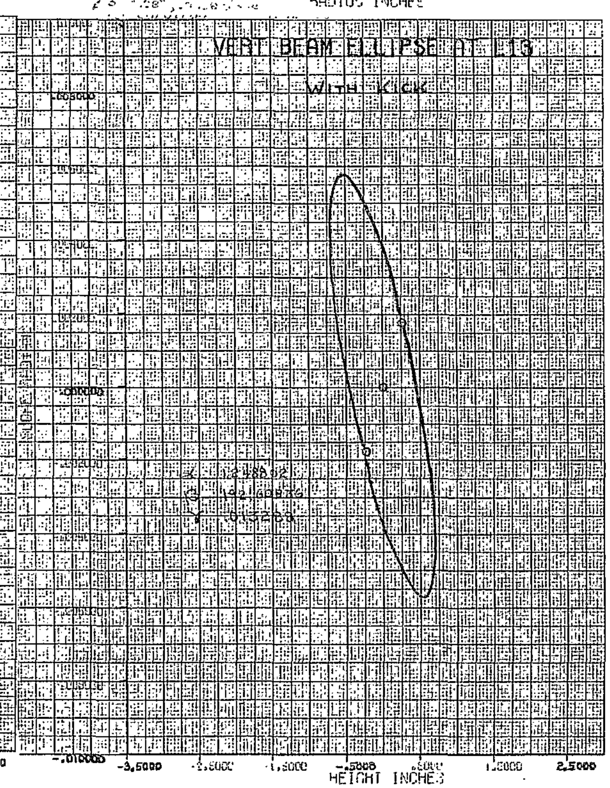

HOR BEAM ELLIPSE AT L11
WITH KICK
RADIUS INCHES
SLOPE RADIANS
1
2
3
4


HOR BEAM ELLIPSE AT L12
RADIUS INCHES
SLOPE RADIANS
1
2
3
4


HOR BEAM ELLIPSE AT L13
WITH KICK
1292.4170
.0154720
RADIUS INCHES
SLOPE RADIANS
1
2
3
4


VERT BEAM ELLIPSE AT L11
WITH KICK
α .331378
β 923.33984
HEIGHT INCHES


VERT BEAM ELLIPSE AT L12
WITH KICK
680.87907
HEIGHT INCHES


VERT BEAM ELLIPSE AT L13
WITH KICK
HEIGHT INCHES