Fermilab

Pbar Note # 453

MAIN RING CYCLE TIME LIMITATIONS AND MULTI-BATCH OPERATION

G. Dugan, P. Martin, S. Pruss

February 1986

This note is a compilation of comments on the limitations on the Main Ring cycle time, and multi-batch operation of the Main Ring. The first page is a summary of three talks given in January 1986 by the authors about limitations to Main Ring cycle rates and the possibilities for multi-batch targeting schemes. Following this is a writeup by Stan Pruss on the Main Ring cycle time limitations. This is followed in turn by some comments by G. Dugan on the general topic, from the pbar Source perspective. Finally, there are copies of the transparencies from the talks.

The basic conclusions of the talks were:

1). (S. Pruss) The Main Ring should be able to ramp to 120 GeV with a cycle time of less than 2.15 sec, with existing hardware. The principal limits are due to voltage limitations on the MR power supplies, both on the upramp and on invert, and RF bucket area limitations. The magnet cooling is adequate to run at 120 GeV DC.

2). (P. Martin) Bunch narrowing techniques for multiple batch operation, with up to 4 batches on flat top, is possible with the existing hardware and results in a very small ($\sim$3%) longitudinal emittance dilution per batch. This conclusion does not include the effects of instabilities, if any. Although the optimum bunch length with multiple batches will be wider than with one batch, this is not a large effect and probably is of no significance for the pbar yield (although this should be checked).

3)(G. Dugan) With a small modification to the existing hardware, the E17 kicker can be upgraded to allow operation with 3 batches on flat top. Some additional effort (which is planned) will be required to allow four batches; beyond this point, major effort (not planned at present) will be required.

ALL VALUES APPLY TO BEGINNING OF SEGMENT

SEGMENT NUMBER	TIME	ENERGY	SLOPE	SLOPE RATE	SEGMENT NUMBER	TIME	ENERGY	SLOPE	SLOPE RATE
1	0	8.9	0	0					
2	.133	8.9	0	400					
3	.808	37.83	150	0					
4	.8969	65.36	150	-140					
5	1.054	110	100	0					
6	1.054	110	100	0					
7	1.054	110	100	0					
8	1.054	110	100	-500					
9	1.254	120	0	0					
10	1.304	120	0	-3000					
11	1.396	107.4	-275	0					
12	1.483	105.5	-275	250					
13	1.803	15.5	-175	0					
14	1.803	15.5	-175	0					
15	1.803	15.5	-175	0					
16	1.804	15.31	-175	1000					
17	1.979	0	0	0					
18	1.979	0	0	750					
19	2.085	4.267	80	0					
20	2.09	4.633	80	-750					
21	2.197	8.9	0	0					

D R A F T

January 27, 1986

Stan Pruss

Main Ring Cycle Time and Limits on It.

There has been much discussion on rapid cycling main ring for $\bar{p}$ production. Table I shows a possible short cycle ramp. There are several interacting constraints which inhibit speeding up this ramp much more. These constraints are as follows.

I. 8-GeV Dwell Time for Injection. I have used 0.133 sec. For a single booster batch this might be made shorter by including pre pulses at the end of the previous cycle. For multiple booster batches more time may be needed for stabilization of the magnetic fields before injection of the first batch (as well as the 0.067 secs needed between batches).

II. Parabola from dE/dt = 0 to Max. If max is 150 GeV/sec and d^2E/dt^2 is 400 GeV/sec^2, this parabola takes 0.375 sec. The limitation here is the interaction of the 400 GeV/sec^2 with transition, and the eddy current sextupoles. It might be possible to increase d^2E/dt^2 but I believe beam studies time would be needed to investigate this.

III. Max dE/dt. This is determined by the maximum rf voltage available and the required bucket area. We have run at 150 GeV/sec with 18 stations in the past. With the power supply

limits described below, this part of the ramp takes 0.189 sec.

IV. Max power supply voltage. This is the extra voltage required by L dI/dt. For sometime I thought this was limited by the dipole bus power supplies and that it could be easily increased. However, the BØ overpass supply will limit us at a level equivalent to 16 normal supplies (~13,400 volts). Even with the planned reduction in number of supplies in service, there will be 22 available. This part of the ramp takes 0.35 sec. If there were no power supply voltage problem, only 0.057 sec could be saved before the rf voltage became a limitation.

V. Parabola into Flattop. There is considerable uncertainty on how sharp this can be. For this example I have picked -500 GeV/sec^2, and this part of the ramp thus takes 0.2 sec. This is somewhat faster than has ever been done in the past, but appears feasible. As with the parabola at the start of the ramp, beam studies are necessary to determine exactly how fast this parabola can be.

VI. Flattop for Bunch Rotation and Extraction. For one batch 0.05 sec seems reasonable.

VII. Invert and Ramp Down. This is limited by invert power supply voltage required for L dI/dt and the parabolas. The total time to get from 120 GeV back to zero is 0.675 sec. If there were no parabolas about 0.1 sec could be saved. I have assumed only 0.75 of forward voltage is available in invert.

VIII. Restore to 8 GeV/c Without Overshoot. During the last running period when we first started using the undershoot ramp, this took 0.4 sec. This can probably be reduced to 0.2 sec or less, but depends on subtleties of regulation and thus needs study time to determine.

Heating, in general, was found to not be a problem. This includes heating in rf cavities, magnets, and bypass SCRs in power supplies. Bill Miller says the rf cavities can run at 150 keV/cavity rms without needing excessive bias current to keep in tune. This ramp (with 18 cavities) is just at this level. Only if the rf were kept at a high level during non-accelerating parts of the ramp would cavity heating become a problem. There will be hot days in summer when pond water cooling capacity is inadequate to keep magnets as cool as is desirable, but this should be rare.

The latest calculations of Max Palmer before he left, said that once the flow restrictors are removed from the "twice current" dipoles, the magnets can stay at 120 GeV dc with ~20°F ΔT.

Dan Wolff cites the single SCR rms current capability at 1450 amps. Thus, even if one of the two bypass SCRs in a power supply fail to conduct, the supply is within ratings up to ~130 GeV. Since the thermal time constant for the SCRs is only about two seconds, they are overrated on 150 GeV flattop.

ALL VALUES APPLY TO BEGINNING OF SEGMENT

Segment Number	Time	Energy	Slope	Slope Rate
1	0	8.9	0	0
2	0.133	8.9	0	400
3	0.508	37.83	150	0
4	0.6969	65.36	150	-140
5	1.054	110	100	0
6	1.054	110	100	0
7	1.054	110	100	0
8	1.054	110	100	-500
9	1.254	120	0	0
10	1.304	120	0	-3000
11	1.396	107.4	-275	0
12	1.403	105.5	-275	250
13	1.803	15.5	-175	0
14	1.803	15.5	-175	0
15	1.803	15.5	-175	0
16	1.804	15.31	-175	1000
17	1.979	0	0	0
18	1.979	0	0	750
19	2.085	4.267	80	0
20	2.09	4.633	80	-750
21	2.197	8.9	0	0

Comments from the Pbar Source Perspective

It is clear from the above that acheivement of very close to the TeV I design rate of 0.5 Hz for pbar production should be possible with existing hardware, using one batch per MR cycle. One might then ask whether there is any point in pursuing the multiple batch technique any further, or worrying about further reductions in the MR cycle time. In the context of long-term improvements in the pbar flux, I think that both of these efforts will be very important.

The tradeoffs in the mutiple batch technique are illustrated by the developments on page 3. We can relate R= the maximum instantaneous rate at which proton batches are targeted (the rate at which the pbar Source must operate) to $\overline{R}$ = the average rate at which proton batches are targeted (which determines the pbar flux to the Source). The relation is

$$\overline{R} = \frac{N}{T_0 + (N-1)\left(\frac{1}{R} + T_8\right)}$$

where N=number of batches on flat top, T_0 = MR cycle time for one batch, and T_8 = the extra time required per batch at 8 GeV for N>1

Figure 1 shows R vs $\overline{R}$ for various N, with T_0 = 2 sec and T_8 =1/15 sec. Among other things, it is clear that the gain in $\overline{R}$ (i.e., pbar flux) with large N is greater for large R: to obtain a given $\overline{R}$, we must run the Source (at rate R) significantly faster than $\overline{R}$. For example, in figure 2 we show the instantaneous rate R required to acheive $\overline{R}$= 1 Hz (a factor of two increase in pbar flux) vs N. For N=6, we need R=1.36 Hz, that is, a factor of 2.7 increase in the Source cycle rate is required to obtain a factor of 2 increase in pbar flux.

The price of such a large increase in R for the Source is high, involving substantial effort in targeting and cooling systems hardware. Some of this cost can be relieved by a reduction in the MR cycle time T_0, and by using as many batches as possible on flat top. The tradeoff between smaller T_0 and R is shown in fig. 3, which displays R vs T_0 for various N required to get $\overline{R}$=1 Hz. If T_0 could be reduced to 1.5 sec, for example, and N pushed to 6 or 8, R can be reduced below 1.2 Hz for $\overline{R}$= 1 Hz. For long term improvements in the pbar flux achieved by the multi-batch technique, pushing the MR cycle time for one batch to its

ultimate minimum and the number of batches on flat top to the maximum will be very valuable in moderating the demands on the Source cycle rate.

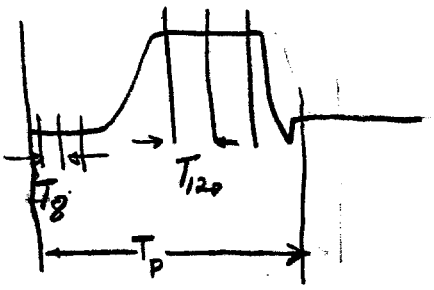
Another important consideration which can now be quantitatively addressed regards the gains afforded by increasing the proton beam energy for pbar production. Figure 4 shows the variation in the forward pbar yield vs. proton energy; since the shape of the pbar angular distribution is essentially constant over this energy range, the total yield can be expected to be proportional to the forward yield. Fig. 4 implies an approximately linear dependence of yield on energy, with a slope of about .57%/GEV. To estimate the extra time required per cycle to get to higher energies, we use a ramp rate of 107 GeV/sec (the "ps limited" part of the minimum Main Ring cycle, from 70-117 GeV in the 120 GeV cycle). Then if we define G(x)= the factor by which the pbar flux is multiplied over that for x=0, when proton targeting is at energy E=120 + x GeV, the above assumptions lead to

$$G(x) = \frac{1 + .00567\,x}{1 + .00933\,x\,\bar{R}/N}$$

In this expression, $\bar{R}$ = the average rate for x=0. The numerator expresses the gain due to the pbar yield increase; the denominator expresses the loss due to the increased ramp time required at higher energies.

At N=1 and $\bar{R}$=0.5 Hz, there is little gain at x=30 GeV; G(30)=1.026. The most gain comes for large N, as would be naively expected; in the limit $N \to \infty$, G(30)=1.17, which is the maximum possible. Fig. 5 presents G vs. x for R=0.7 Hz, T_0 = 2.0 sec (for x=0), and T8=1/15 sec., for various N. The gain at N=4 is about typical, 12% at 150 GeV. As is clear from the form of G(x), the gains would be even less at larger R.

A gain of order 10% is obviously not decisive, but should not be ignored either. Pbars are difficult to produce and any increase in yield is welcome. It should be appreciated that the problems in running the Main Ring at 150 GeV in the mode discussed above, which have not been addressed here (for example, possible heating limitations to the flat top duration), are not the only technical difficulties with 150 GeV operation. There are problems in the extraction line also, which would require new power supplies for the extraction Lambertson and some of the AP-1 magnet strings.



$$T_p = T_0 + (N-1)(T_{120} + T_8)$$

$$T_{120} = 1/R \qquad N/T_p = \bar{R} \qquad \bar{R} = T_p/N$$

$$\frac{1}{\bar{R}} = \frac{T_0 + (N-1)(1/R + T_8)}{N}$$

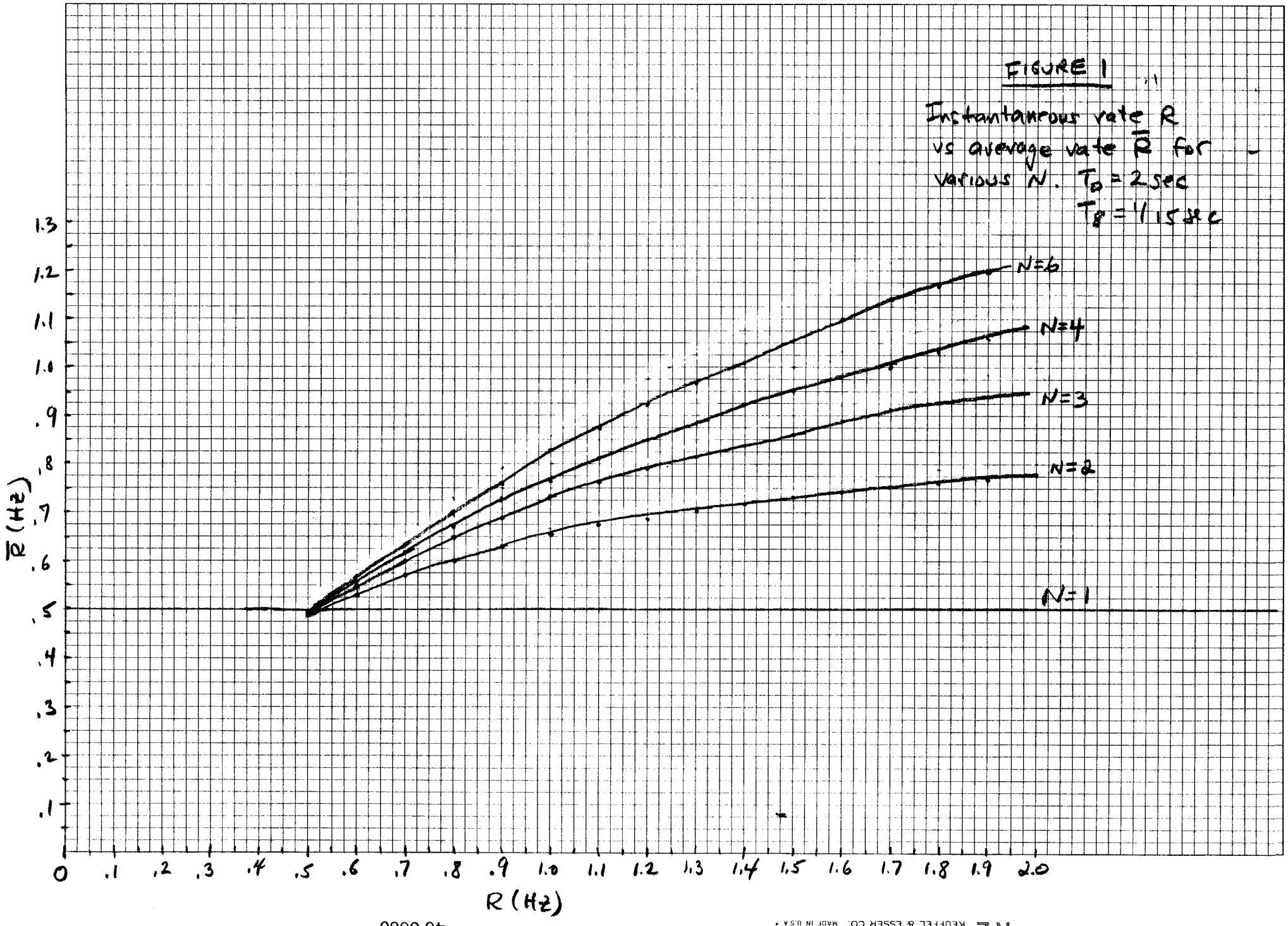
$$\bar{R} = \frac{N}{T_0 + (N-1)(1/R + T_8)}$$

$$\bar{R}(T_0 + (N-1)/R + (N-1)T_8) = N$$

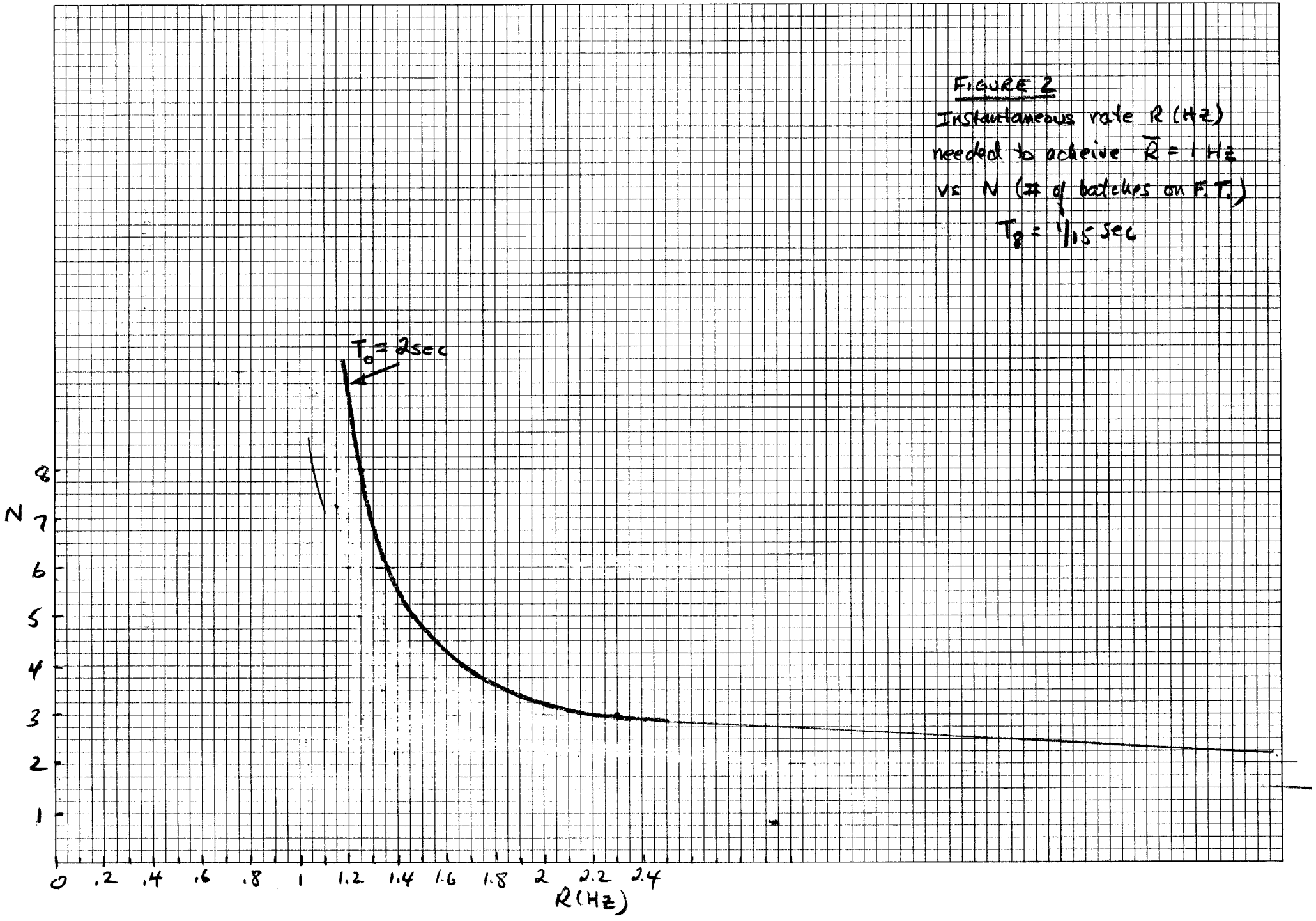
$$(N-1)/R + (N-1)T_8 + T_0 = N/\bar{R}$$

$$\frac{N-1}{R} = N/\bar{R} - T_0 - (N-1)T_8$$

$$R = \frac{N-1}{N/\bar{R} - T_0 - (N-1)T_8}$$



46 0660
K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



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KEUFFEL & ESSER CO. MADE IN U.S.A.

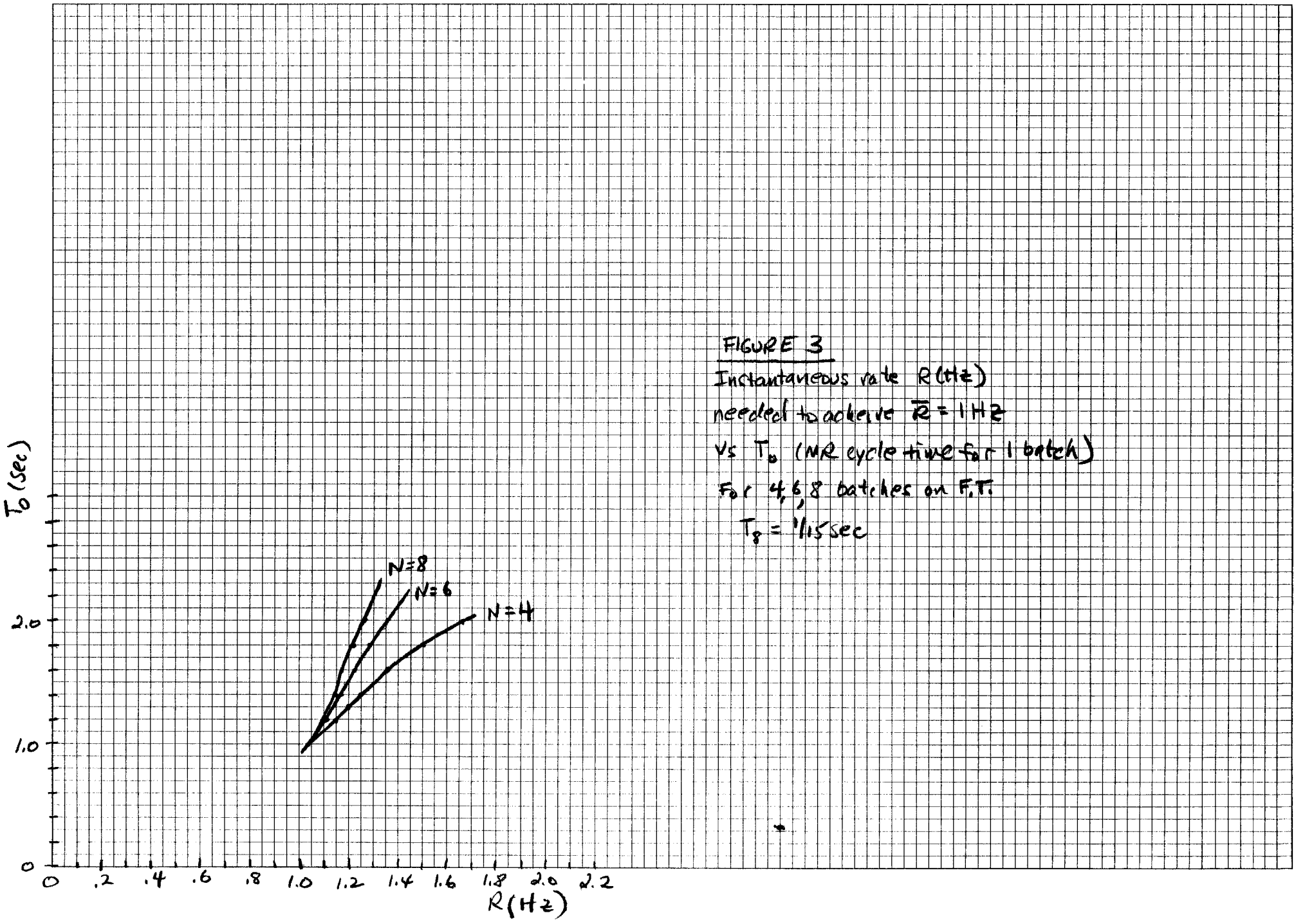

FIGURE 3

Instantaneous rate R(Hz) needed to achieve $\bar{R} = 1$ Hz vs T_0 (MR cycle time for 1 batch)

For 4, 6, 8 batches on F.T.

$T_8 = 1\frac{1}{2}$ sec

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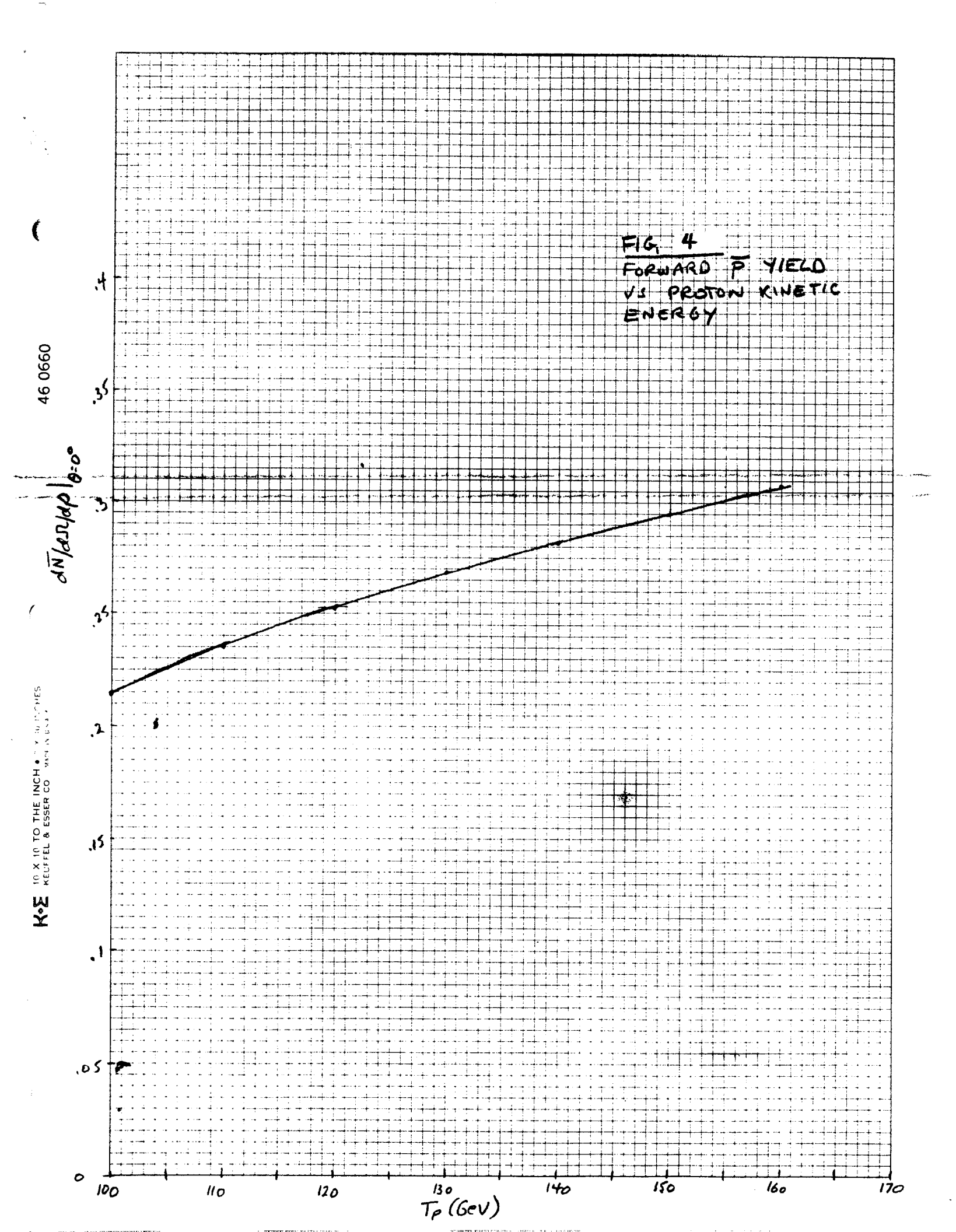
FIG. 4
FORWARD $\bar{p}$ YIELD VS PROTON KINETIC ENERGY
$d\bar{N}/d\Omega dp|_{\theta=0°}$
T_p (GeV)
0
.05
.1
.15
.2
.25
.3
.35
.4
100
110
120
130
140
150
160
170
46 0660
K&E 10 X 10 TO THE INCH
KEUFFEL & ESSER CO

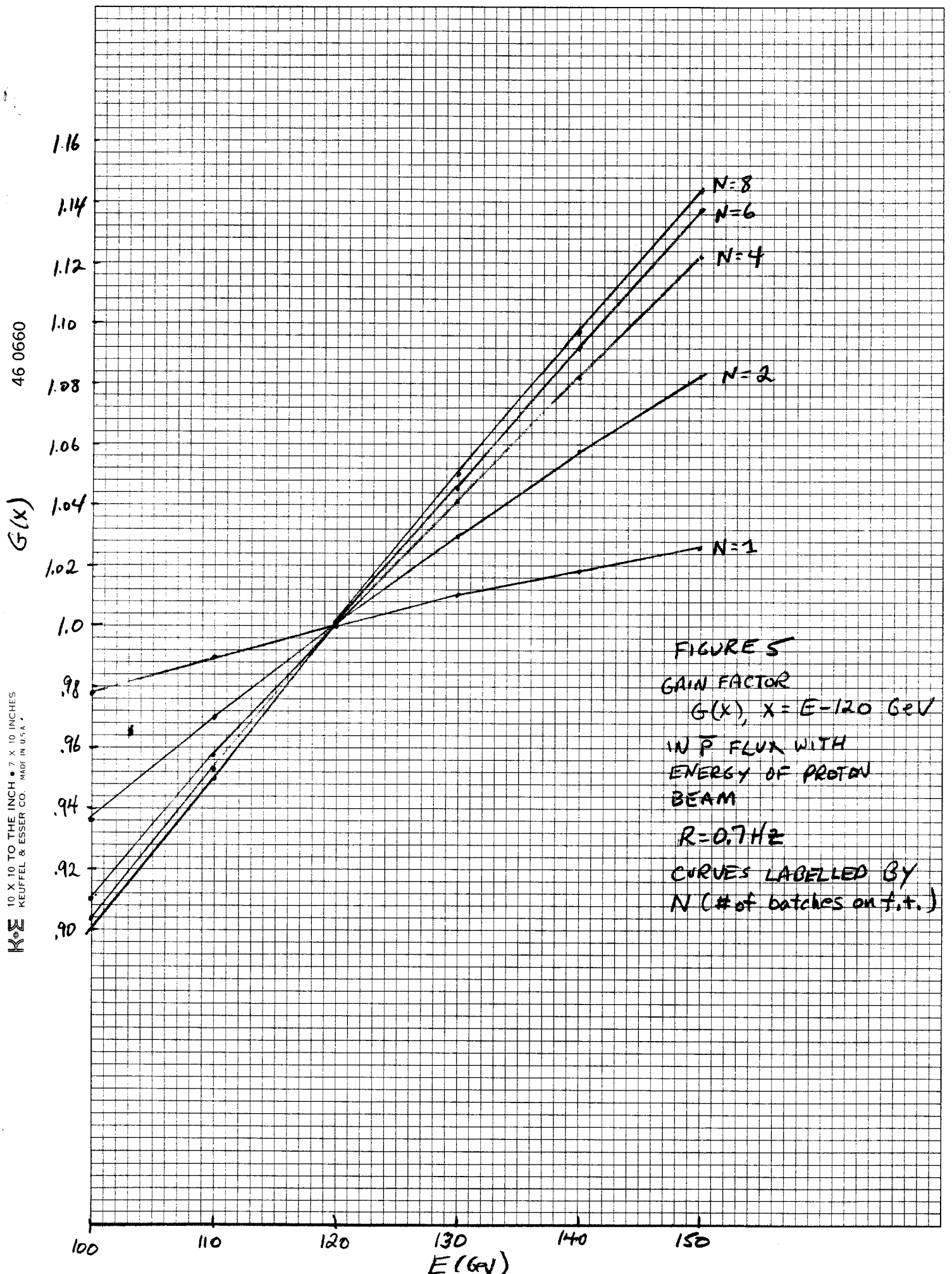

FIGURE 5
GAIN FACTOR
G(X), X = E-120 GeV
IN P FLUX WITH
ENERGY OF PROTON
BEAM
R=0.7Hz
CURVES LABELLED BY
N (# of batches on f.t.)

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KE 10 X 10 TO THE INCH • 7 X 10 INCHES
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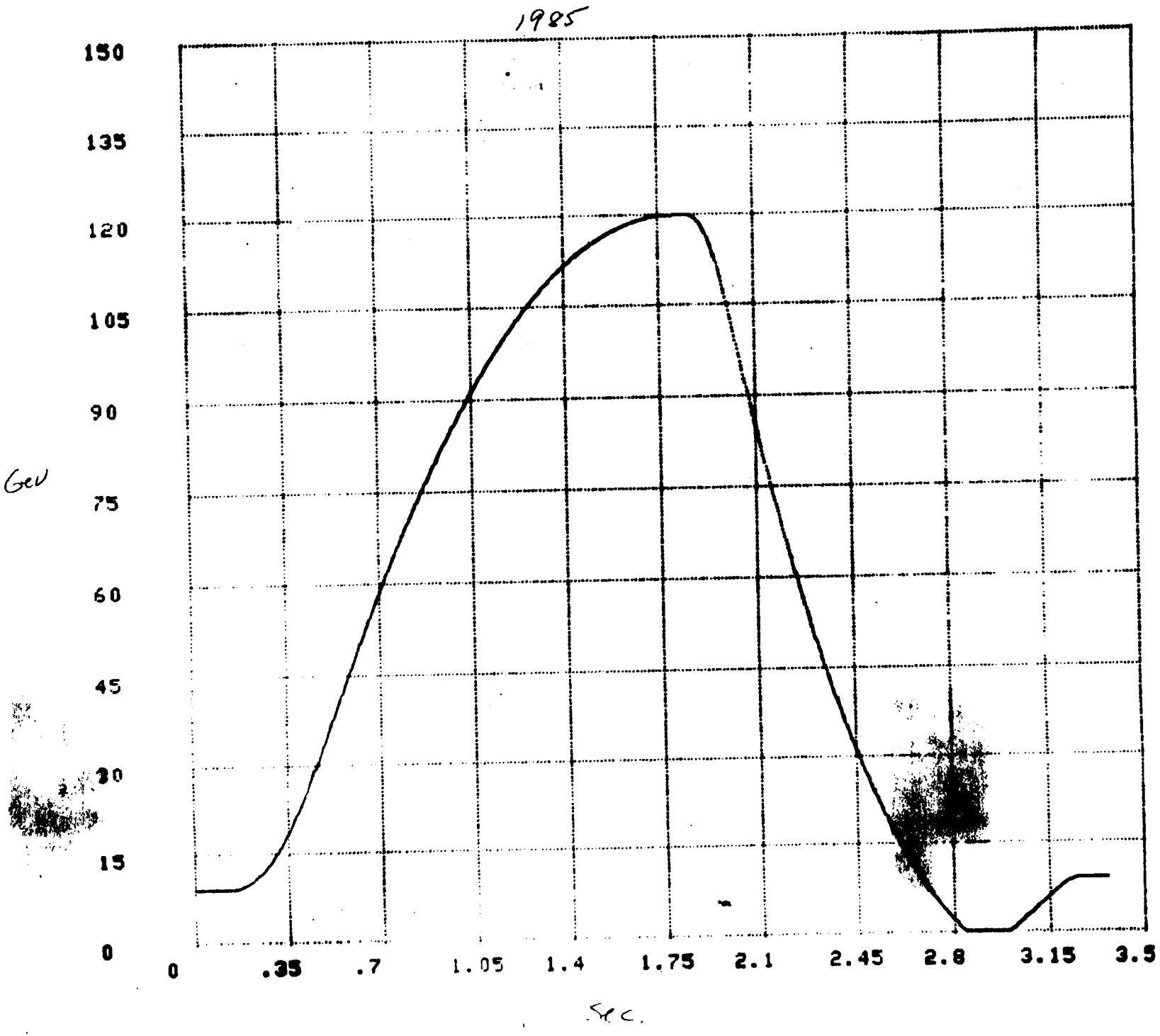
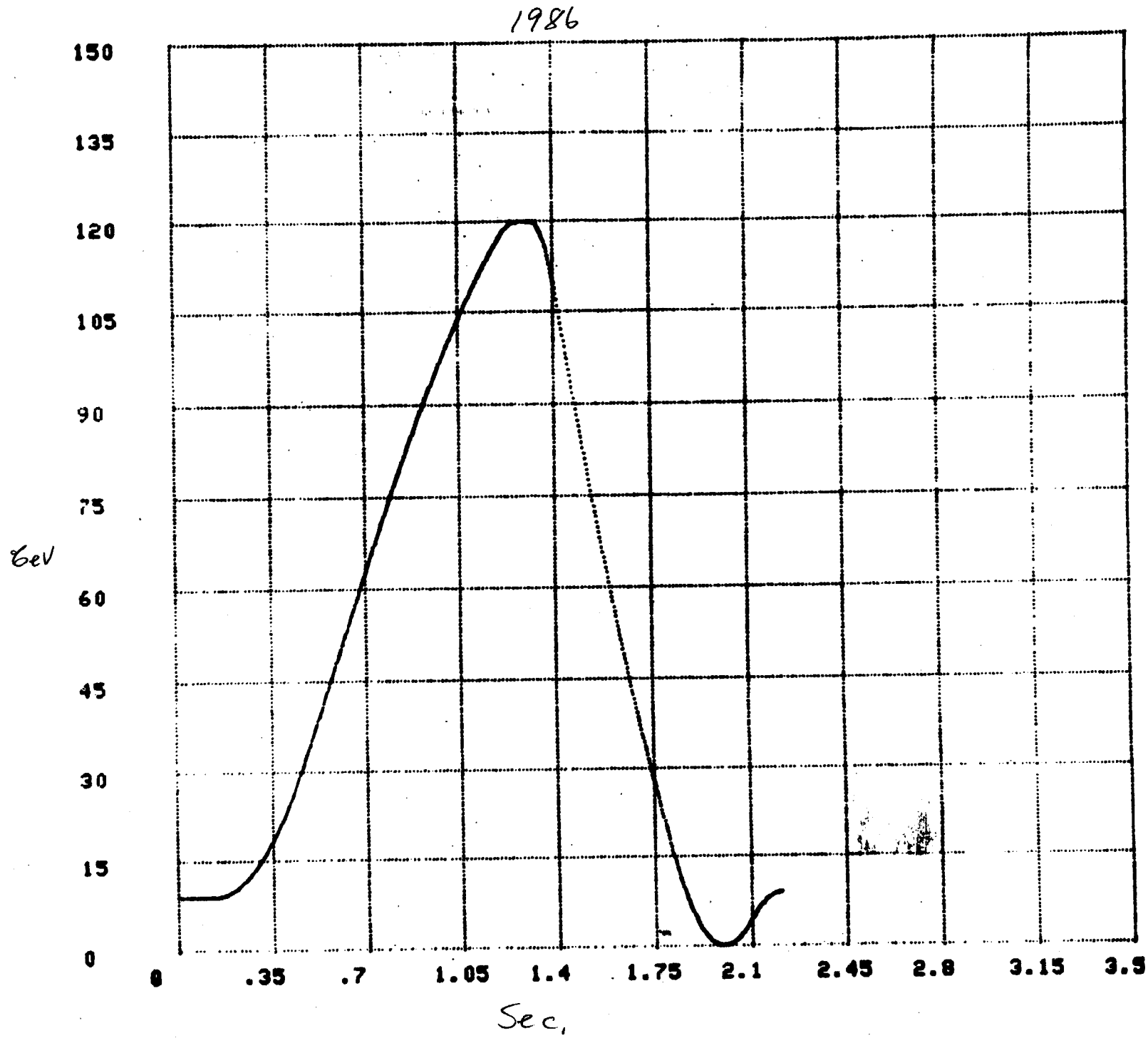
S. PRUSS

MINIMUM MAIN RING CYCLE - 120 GEV

ENERGY	Δt	$\Sigma \Delta t$	COMMENT
8 GEV	.133	.133	2 BOOSTER CYCLES (ALLOW ONE PREPULSE)
8 - 25 GEV	.26	.39	MIL PARABOLA - ($\dot{F}$, TRANSITION CROSSING)
25 - 70 GEV	.35	.74	RF / BUCKET AREA LIMITED
70 - 117 GEV	.44	1.18	PS LIMITED
117 - 120 GEV	.06	1.25	PARABOLA
120 GEV	.05	1.3	RF MANIPULATIONS / EXTRACTION
120 - 105 GEV	.1	1.4	PARABOLA
105 - 15 GEV	.35	1.75	PS LIMITED
15 - 0 - 8 GEV	.35	2.1	UNDERSHOOT RAMP


1985
150
135
120
105
90
75
60
45
30
15
0
GeV
0
.35
.7
1.05
1.4
1.75
2.1
2.45
2.8
3.15
3.5
sec.


1986
150
135
120
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90
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GeV
60
45
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1.75
2.1
2.45
2.8
3.15
3.5
Sec.

FERMILAB

January 10,1986

To: Stan Pruss
From: Dan Wolff
Subject: Main Ring Power Supply rms current capability

The rms current capability of the M.R. Power Supplies with reference to the DC magnet bus is determined by the number of bypass SCR's conducting in parrallel. The present plan is to eliminate two modules from the power supplies to help improve reliability and maintenance. This would leave two parallel bypass SCR's operating. The rms current capability of our SCR's is presently 1450 amps. Therefore the maximum rms bus current would be 2900 amps. Allowing for some current sharing unbalance leaves a safe number of about:

**** 2700 amps. ****

The issue of running with a no-fire SCR condition is a little more complicated. Experience from our last run seems to indicate that no-fires are a relatively rare event. If a no-fire were to occur there is a 1 in 4 chance of it being in a bypass position. Finally, if the supply is phased on at flattop the bypass SCR's are not conducting and therefore would not be a limiting factor. If, however, all these conditions were met the above rating of 1450 amps would apply.

One item to remember when calculating rms current values is that our SCR's have a thermal time constant of about 2 seconds. It is not valid to allow a long flattop and control the rms current with the ramp cycle time.

1985

ALL VALUES APPLY TO BEGINNING OF SEGMENT

SEGMENT NUMBER	TIME	ENERGY	SLOPE	SLOPE RATE	SEGMENT NUMBER	TIME	ENERGY	SLOPE	SLOPE RATE
	0	8.9	0	0					
	.133	8.9	0	400					
	.433	26.9	120	0					
4	.6088	48	120	-100					
5	1.809	120	0	0					
6	1.859	120	0	-1500					
7	1.992	106.7	-200	0					
8	2.045	96	-200	200					
9	2.846	0	-40	0					
10	2.846	0	-40	500					
11	3.006	0	40	0					
12	3.188	7.3	40	-500					
13	3.268	8.9	0	0					
14	3.368	8.9	0	0					

1985

WED 13-JAN-86 15:4

MAIN RING RAMP RAMP RUNNING

PBOLA1 GEV/S2	SLOPE GEV/S	PBOLA2 GEV/S2	ENERGY GEV	FTTIME SEC	FTILT GEV/S
INJECTION LEVEL ->			8.9	.133	0
400	120	-100	120	.05	0
-1500	-200	200	0	0	-40
500	40	-500	8.9	.1	0

INTERRUPT HERE WHEN DONE-> RAMP DONE
RAMP TEXT->(120 GEV .3S FT .4S INJ, US)
*FILE DIRECTORY *RECALL RAMP FILE(8)
*DISPLAY TIMES ( )

*SEND TO DISK FILE( ) *SEND TO DECC ( )

	ENGMIN	ENGMAX	TMIN	TMAX
*PLOT RAMP	(0)	(150)	(0)	(3.5)

1986 (Proposed)

WED 15-JAN-86 [illegible]

M7 MAIN RING RAMP RAMP RUNNING

PBOLA1 GEV/S2	SLOPE GEV/S	PBOLA2 GEV/S2	ENERGY GEV	FTTIME SEC	FTTILT GEV/S
INJECTION LEVEL ->			8.9	.133	0
400	135	-115	117	0	80
0	80	-1200	120	.05	0
-3000	-275	250	15.5	0	-175
0	-175	1000	0	0	0
750	80	-750	8.9	0	0

INTERRUPT HERE WHEN DONE->
RAMP TEXT->(120GEV FAST RAMP - STAN)
*FILE DIRECTORY *RECALL RAMP FILE(3)
*DISPLAY TIMES ( )

*SEND TO DISK FILE( ) *SEND TO DECC ( )

	ENGMIN	ENGMAX	TMIN	TMAX
*PLOT RAMP	( )	( )	( )	( )

1986

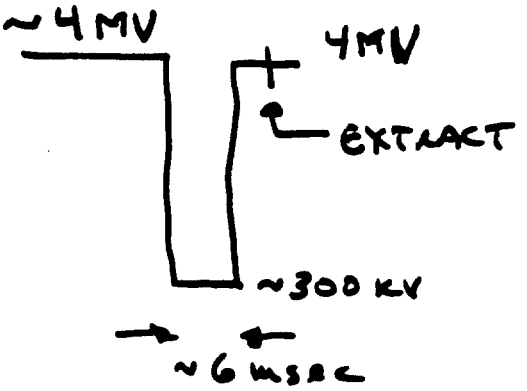
ALL VALUES APPLY TO BEGINNING OF SEGMENT

SEGMENT NUMBER	TIME	ENERGY	SLOPE	SLOPE RATE	SEGMENT NUMBER	TIME	ENERGY	SLOPE	SLOPE RATE
1	0	8.9	0	0					
2	.133	8.9	0	400					
3	.4705	31.68	135	0					
4	.7217	65.59	135	-115					
5	1.2	117	80	0					
6	1.2	117	80	0					
7	1.2	117	80	0					
8	1.204	117.3	80	-1200					
9	1.271	120	0	0					
10	1.321	120	0	-3000					
11	1.412	107.4	-275	0					
12	1.419	105.5	-275	250					
13	1.819	15.5	-175	0					
14	1.819	15.5	-175	0					
15	1.819	15.5	-175	0					
16	1.82	15.31	-175	1000					
17	1.995	0	0	0					
18	1.995	0	0	750					
19	2.102	4.267	80	0					
20	2.107	4.633	80	-750					
21	2.213	8.9	0	0					
22	2.213	8.9	0	0					

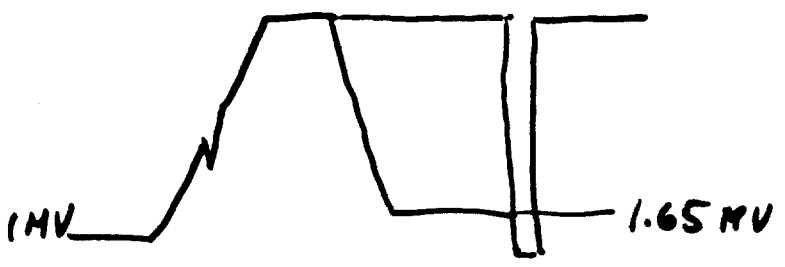
P. MARTIN

MULTI-BATCH BUNCH ROTATION TECHNIQUES

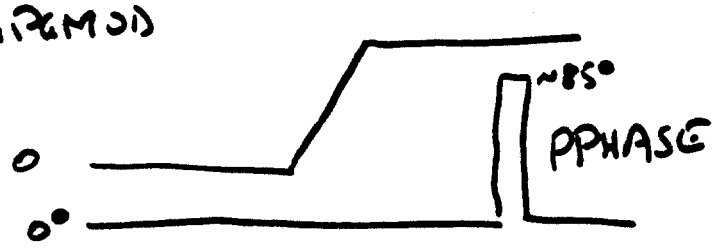
1985 - SINGLE BATCH



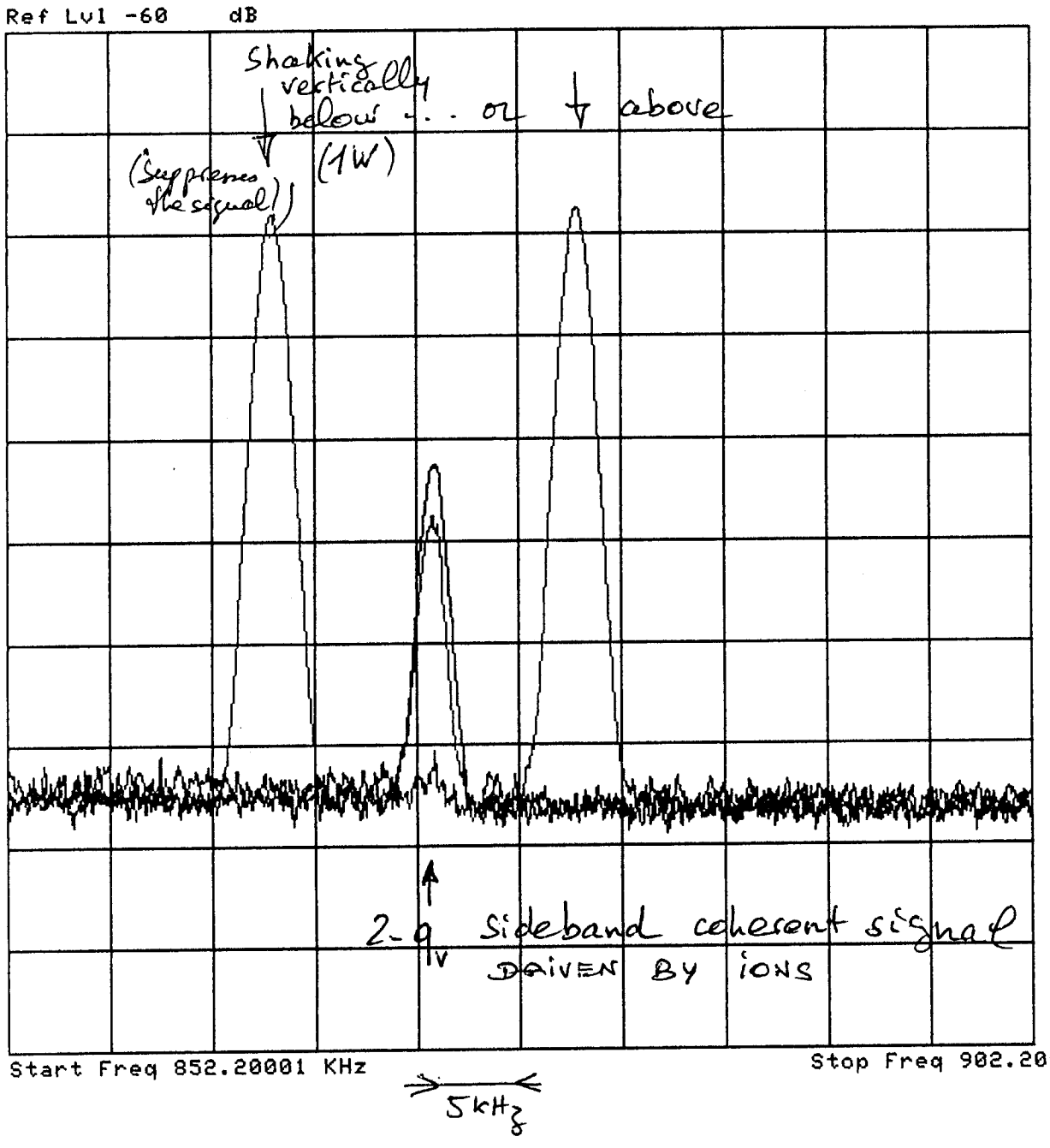
NORMAL RF



ADIABATIC



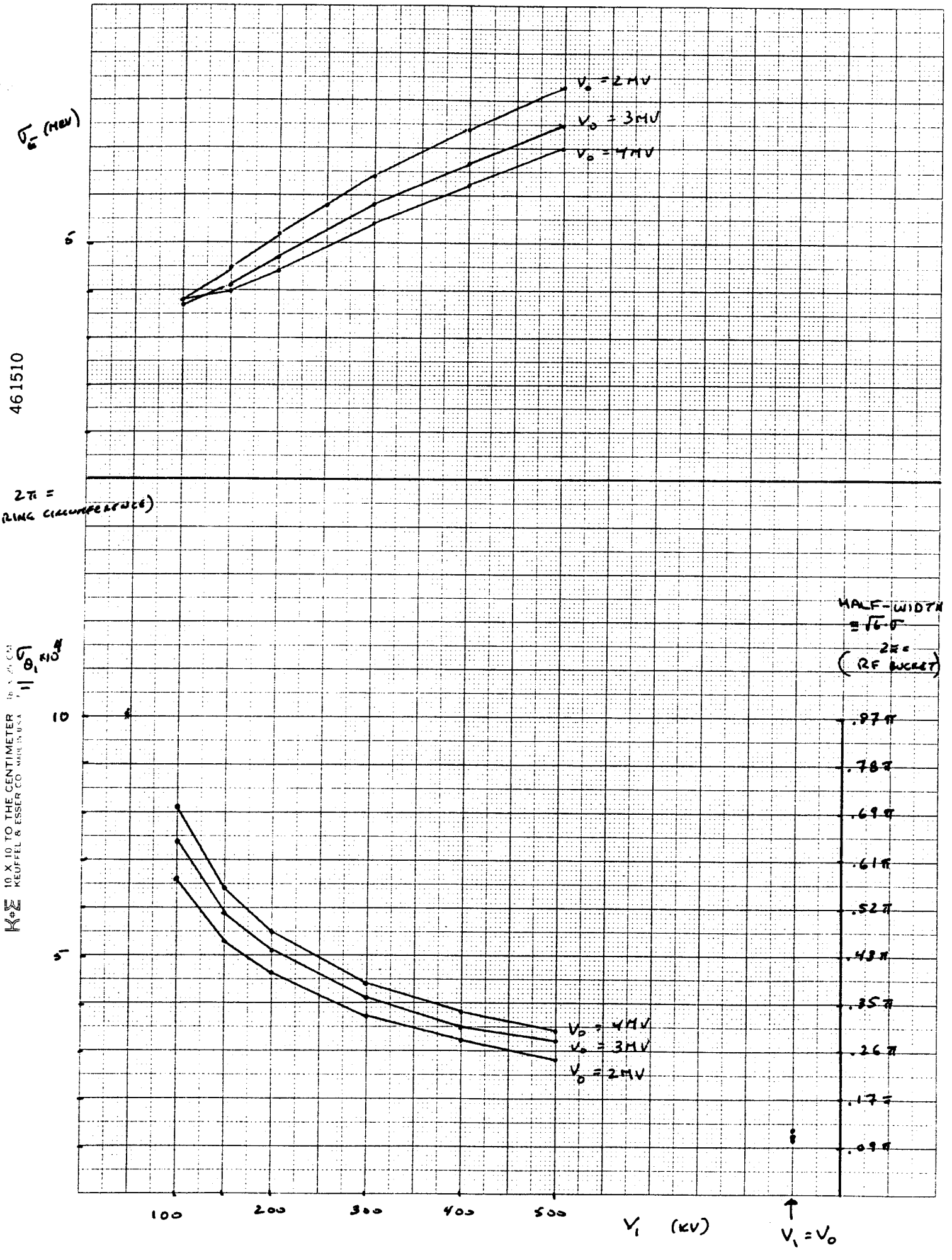
CONS .E LOCATION 02, MCR-N2 19-MAR-1989 18:38
beam shaking - no instability



03/19/89 1802
Scale 5 dB/div
Atten 0 dB
Swp .3 sec
Vid BW 300 Hz
Res BW 1 KHz
VID AVG

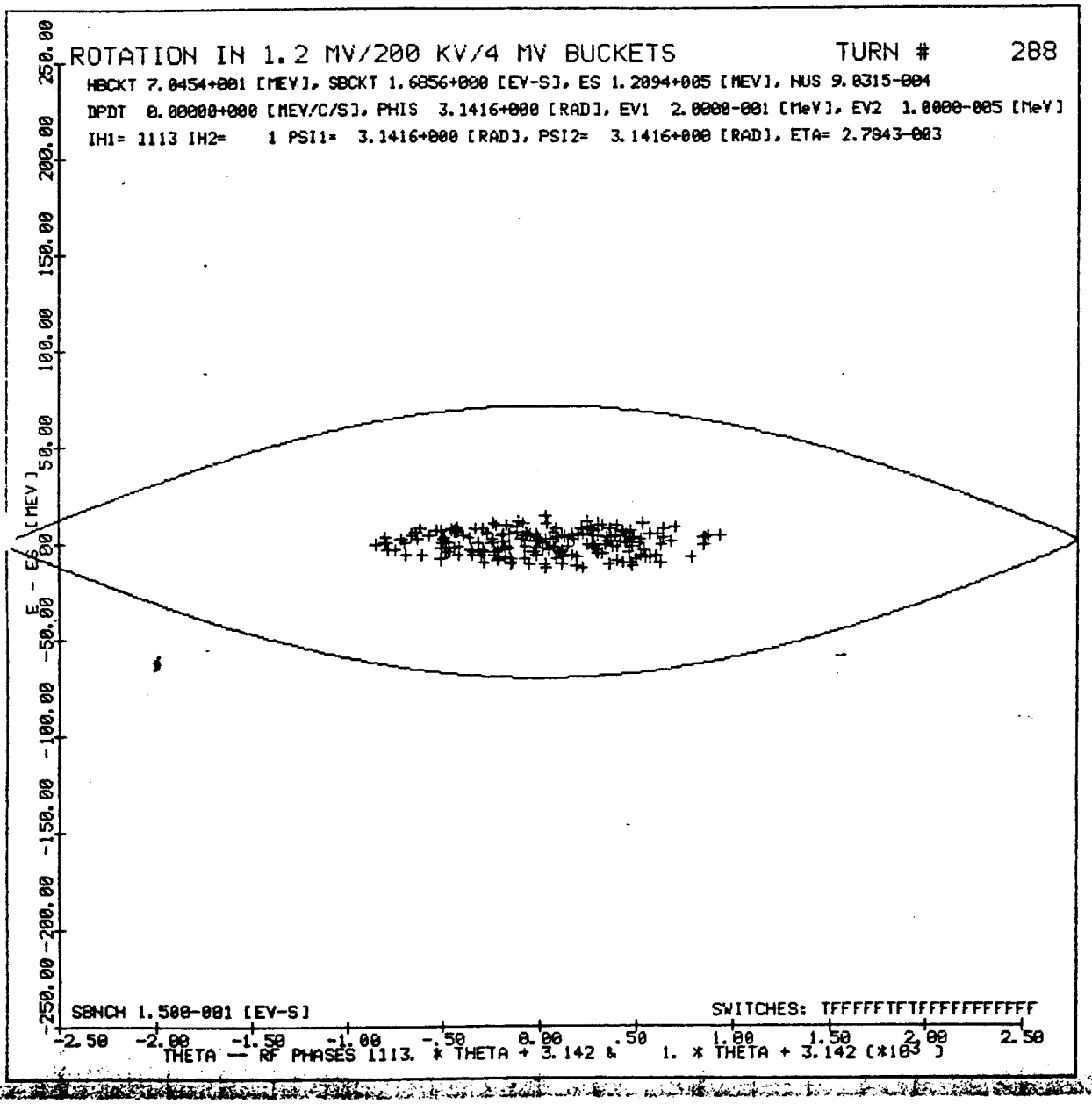
$55 \cdot 10^{10}$ pbars

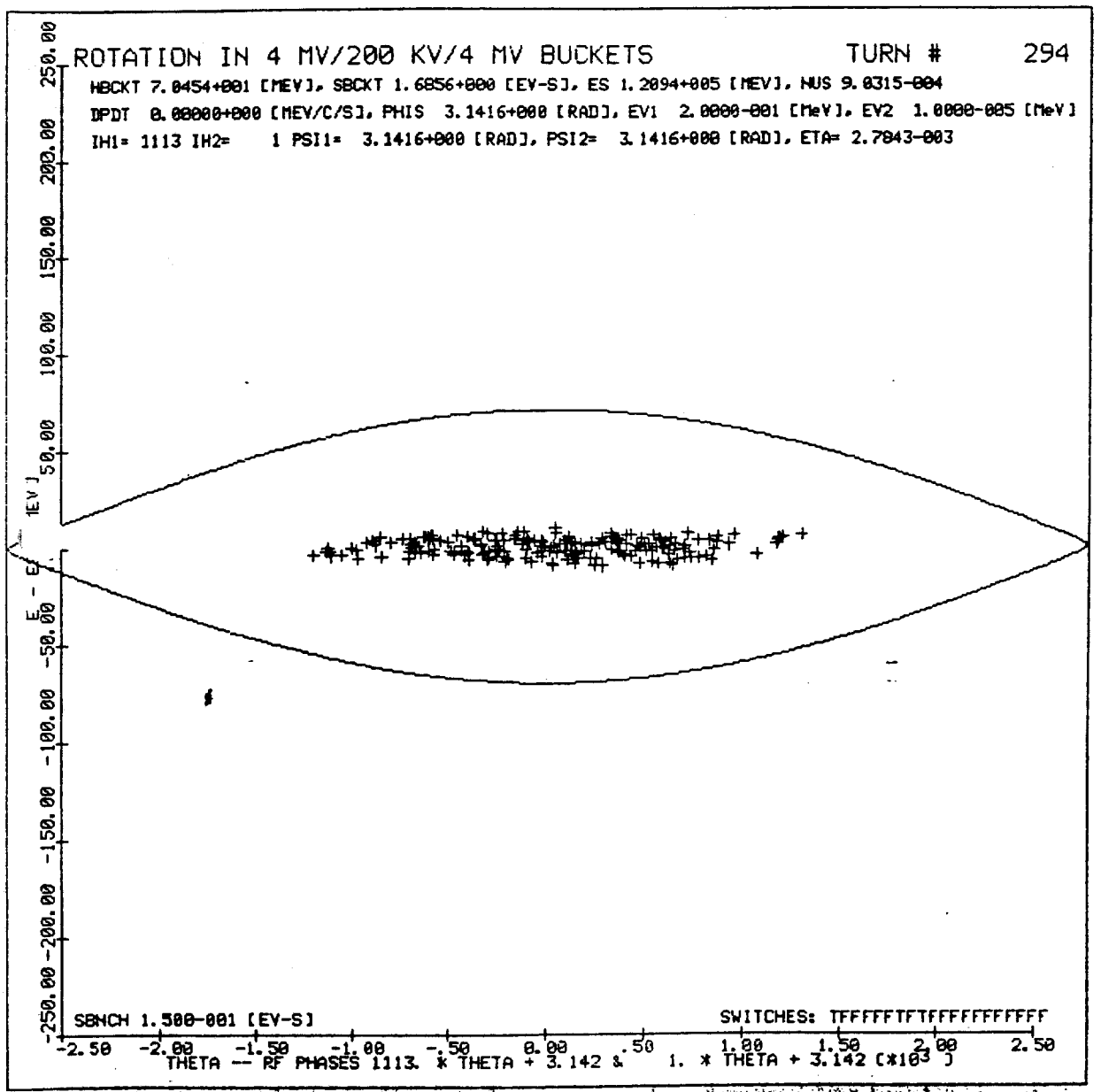
$\epsilon = .15$ eV-sec

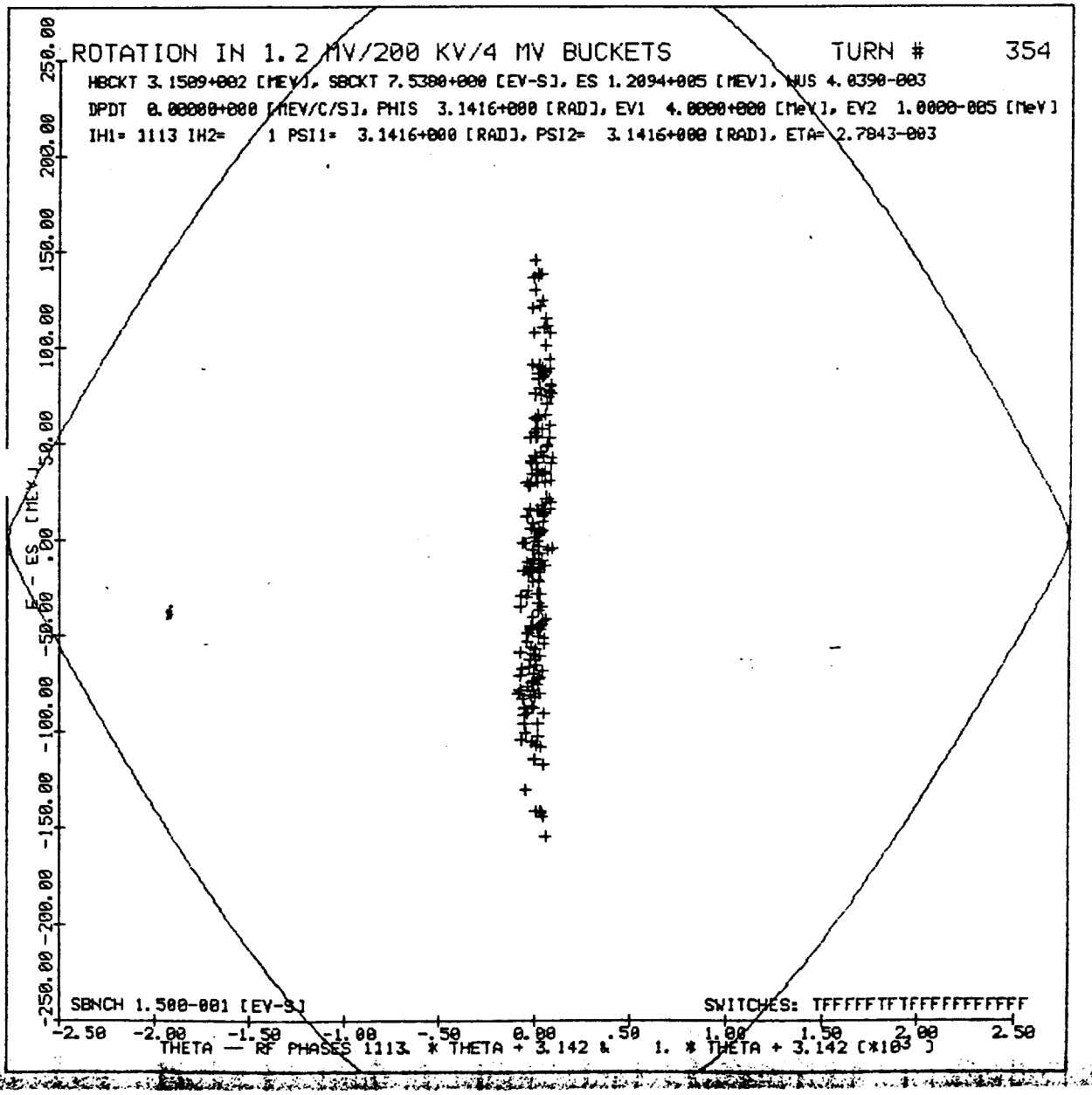


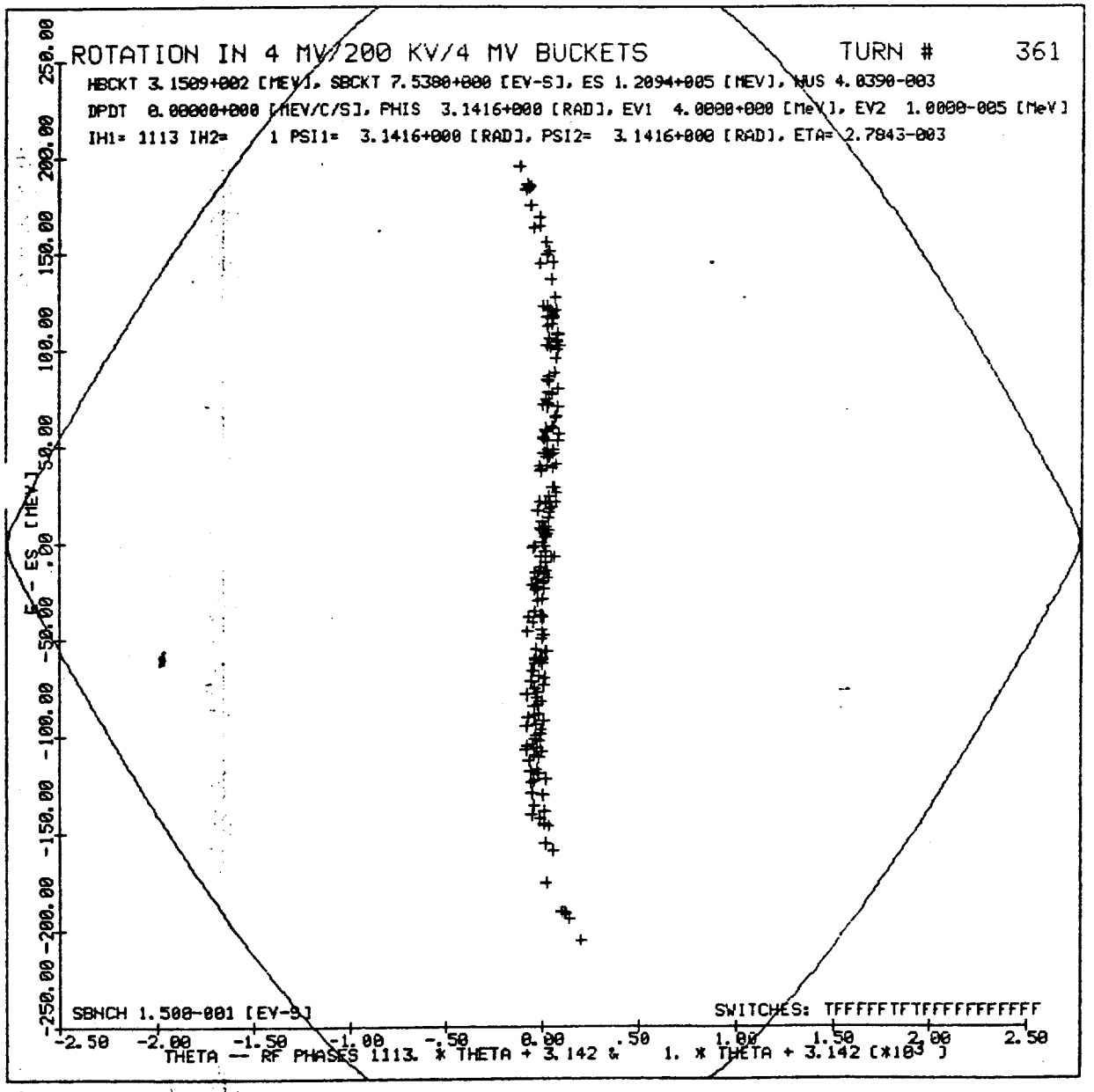
461510

10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO

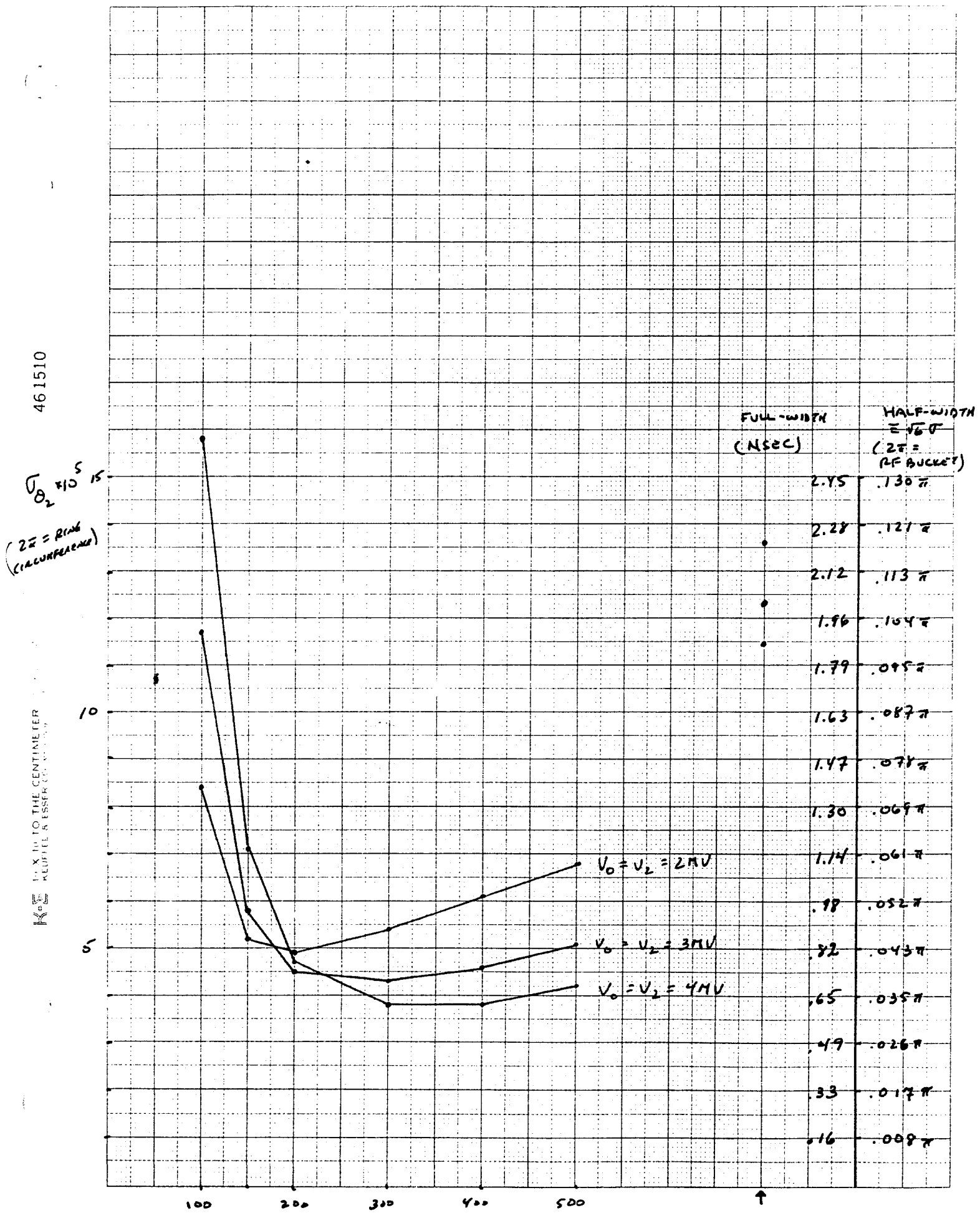

ROTATION IN 1.2 MV/200 KV/4 MV BUCKETS
TURN # 288
HBCKT 7.0454+001 [MEV], SBCKT 1.6856+000 [EV-S], ES 1.2094+005 [MEV], NUS 9.8315-004
DPDT 0.00000+000 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 2.0000-001 [MeV], EV2 1.0000-005 [MeV]
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 3.1416+000 [RAD], ETA= 2.7943-003
E - Es [MEV]
250.00
200.00
150.00
100.00
50.00
.00
-50.00
-100.00
-150.00
-200.00
-250.00
SBNCH 1.500-001 [EV-S]
SWITCHES: TFFFFFTFTFFFFFFFFFFF
-2.50 -2.00 -1.50 -1.00 -.50 0.00 .50 1.00 1.50 2.00 2.50
THETA — RF PHASES 1113. * THETA + 3.142 & 1. * THETA + 3.142 (*10^3)


ROTATION IN 4 MV/200 KV/4 MV BUCKETS
TURN # 294
HBCKT 7.0454+001 [MEV], SBCKT 1.6856+000 [EV-S], ES 1.2094+005 [MEV], NUS 9.0315-004
DPDT 0.00000+000 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 2.0000-001 [MeV], EV2 1.0000-005 [MeV]
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 3.1416+000 [RAD], ETA= 2.7843-003
E - E [EV]
250.00
200.00
150.00
100.00
50.00
-50.00
-100.00
-150.00
-200.00
-250.00
SBNCH 1.500-001 [EV-S]
SWITCHES: TFFFFFTFTFFFFFFFFFFF
-2.50 -2.00 -1.50 -1.00 -.50 0.00 .50 1.00 1.50 2.00 2.50
THETA -- RF PHASES 1113. * THETA + 3.142 & 1. * THETA + 3.142 (*10^3)


ROTATION IN 1.2 MV/200 KV/4 MV BUCKETS
TURN # 354
HBCKT 3.1509+002 [MEV], SBCKT 7.5380+000 [EV-S], ES 1.2094+005 [MEV], WUS 4.0390-003
DPDT 0.00000+000 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 4.0000+000 [MeV], EV2 1.0000-005 [MeV]
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 3.1416+000 [RAD], ETA= 2.7843-003
E- ES [MEV]
250.00
200.00
150.00
100.00
50.00
.00
-50.00
-100.00
-150.00
-200.00
-250.00
SBNCH 1.500-001 [EV-S]
SWITCHES: TFFFFFTFTFFFFFFFFFFF
-2.50
-2.00
-1.50
-1.00
-.50
0.00
.50
1.00
1.50
2.00
2.50
THETA — RF PHASES 1113. * THETA + 3.142 & 1. * THETA + 3.142 [*10³]

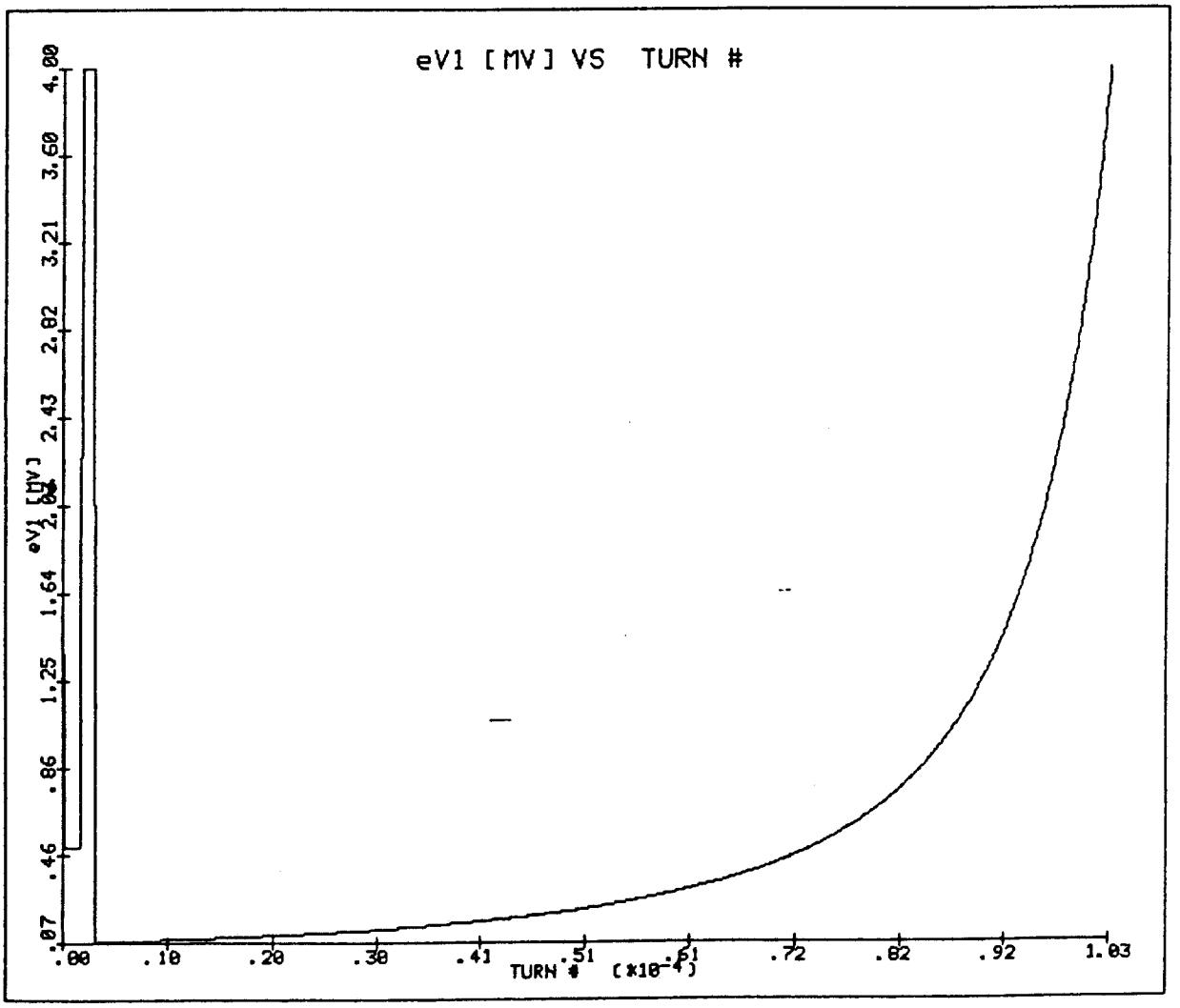

ROTATION IN 4 MV/200 KV/4 MV BUCKETS
TURN # 361
HBCKT 3.1509+002 [MEV], SBCKT 7.5380+000 [EV-S], ES 1.2094+005 [MEV], WUS 4.0390-003
DPDT 0.00000+000 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 4.0000+000 [MeV], EV2 1.0000-005 [MeV]
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 3.1416+000 [RAD], ETA= 2.7843-003
E- ES [MEV]
250.00
200.00
150.00
100.00
50.00
.00
-50.00
-100.00
-150.00
-200.00
-250.00
SBNCH 1.500-001 [EV-S]
SWITCHES: TFFFFFTFTFFFFFFFFFF
-2.50
-2.00
-1.50
-1.00
-.50
0.00
.50
1.00
1.50
2.00
2.50
THETA -- RF PHASES 1113. * THETA + 3.142 & 1. * THETA + 3.142 (*10^3)

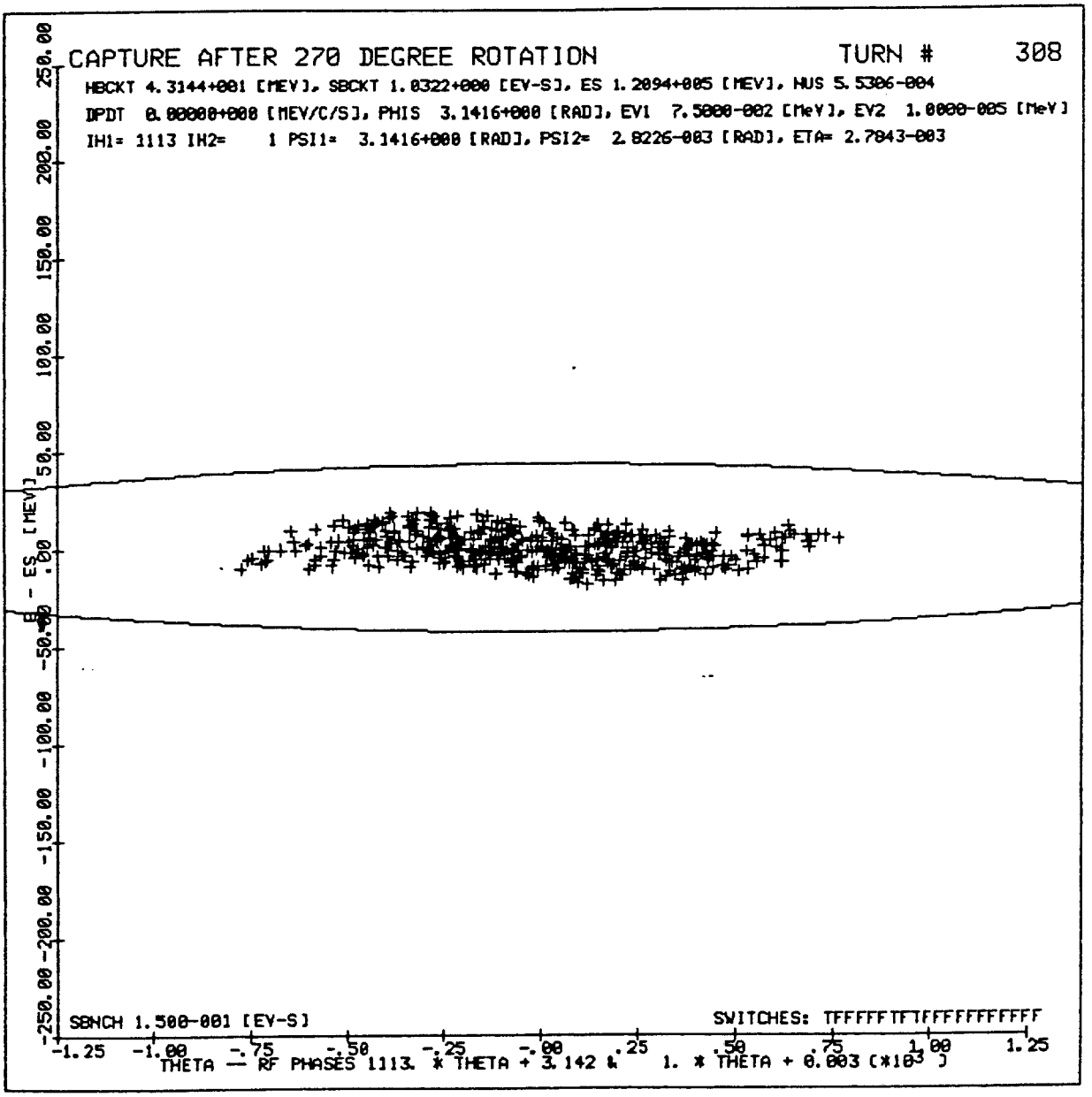
$\epsilon = .15$ eV-sec

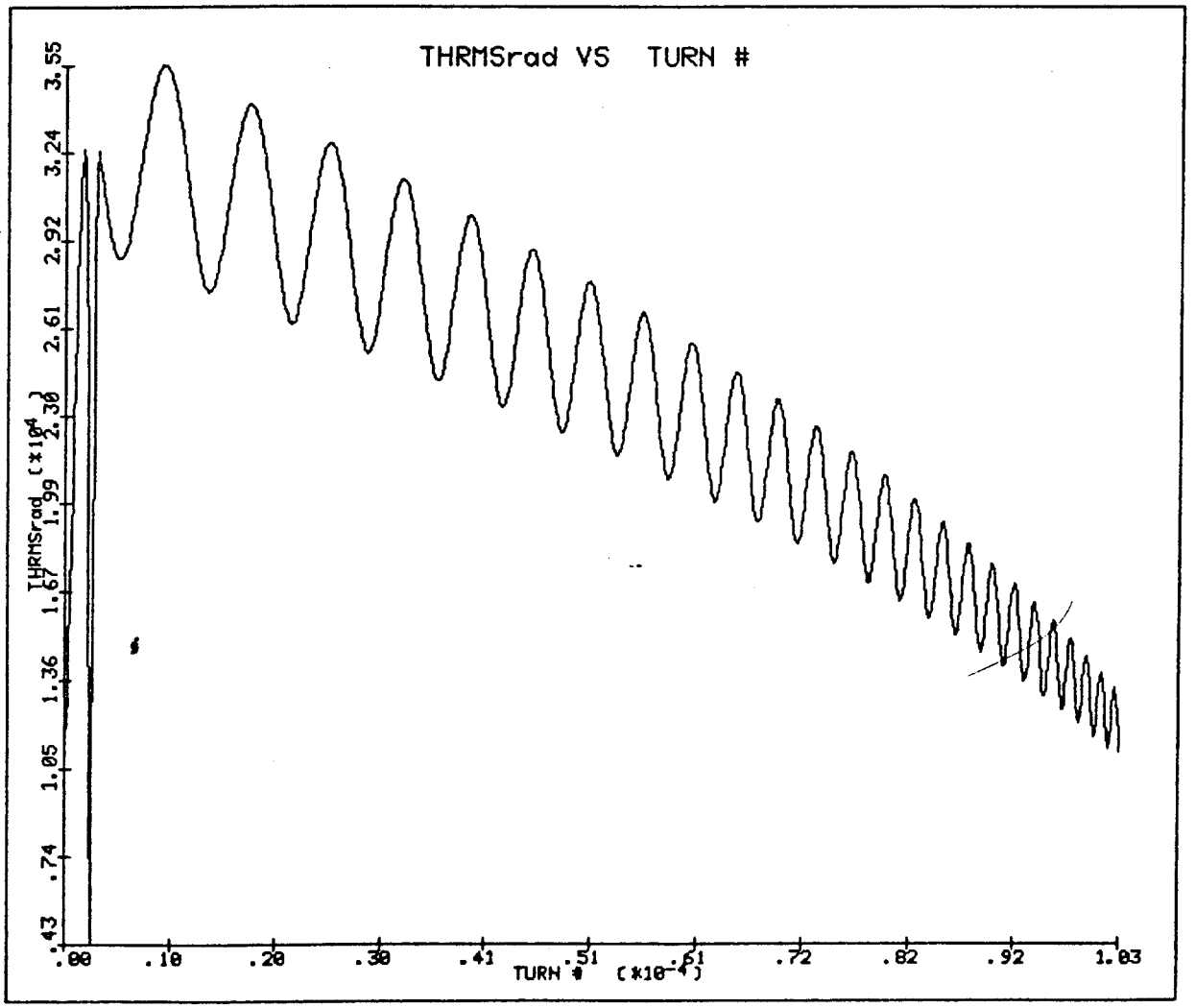


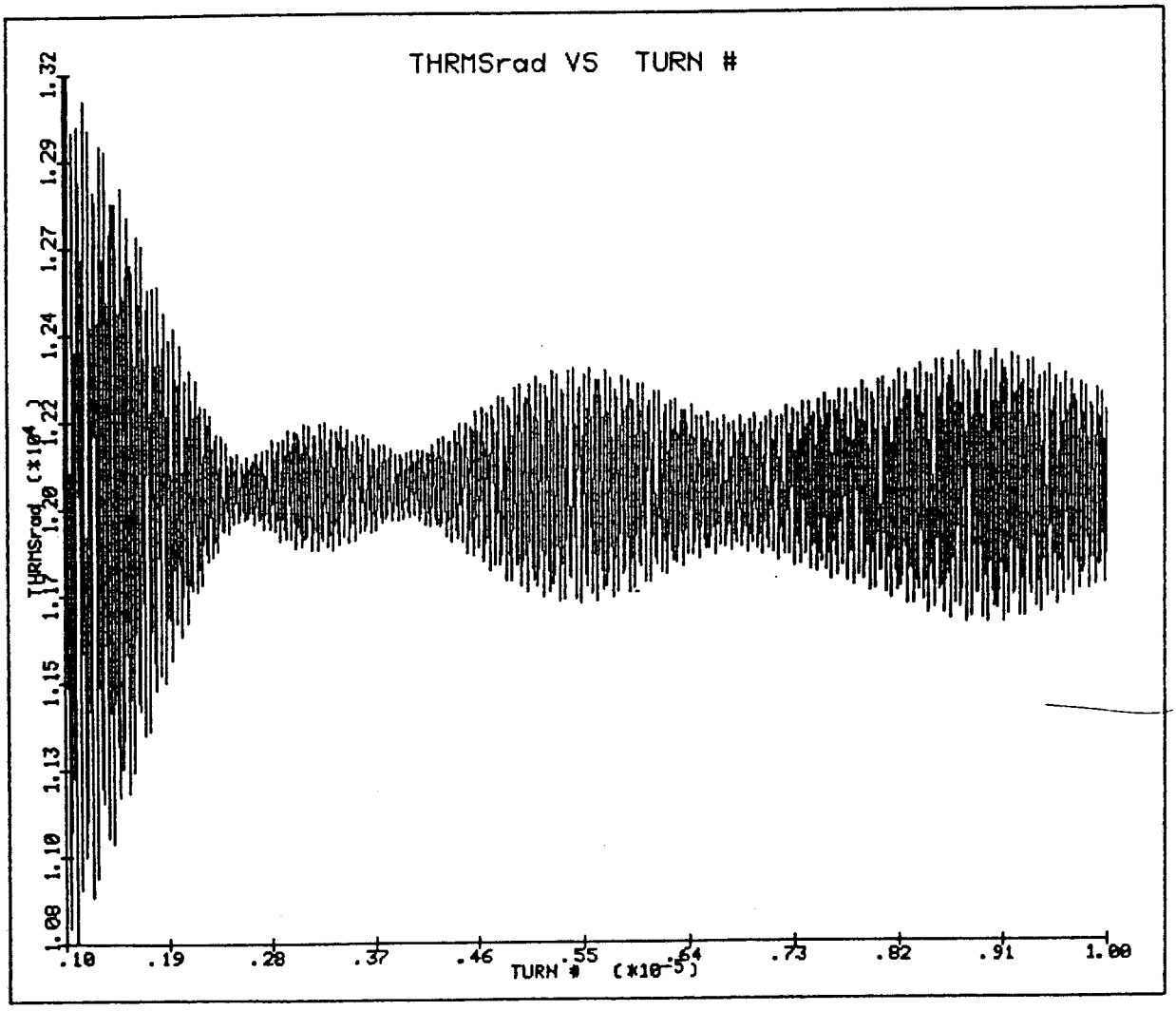
461510

K+E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO.

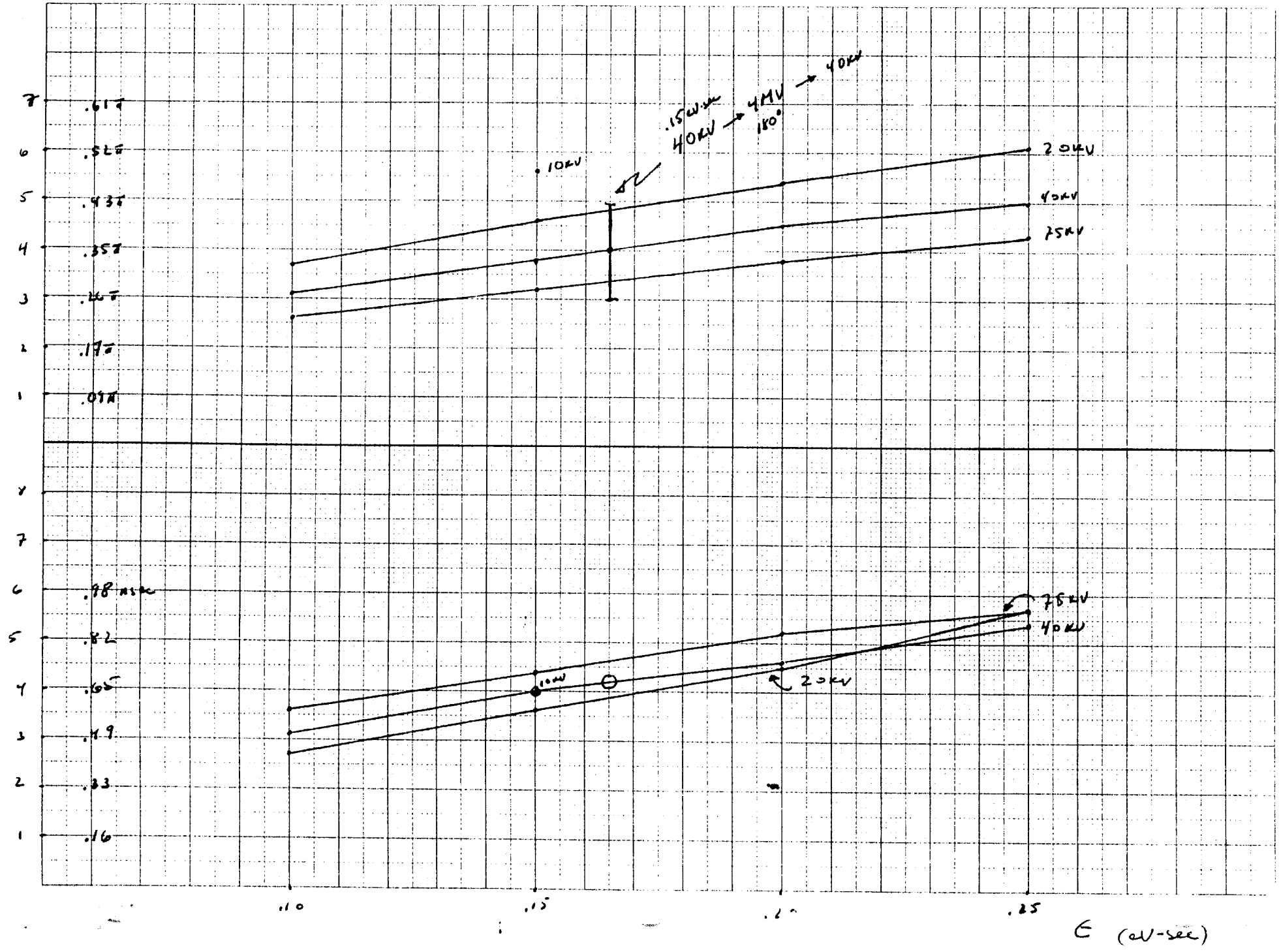

eV1 [MV] VS TURN #
eV1 [MV]
4.00
3.60
3.21
2.82
2.43
2.04
1.64
1.25
.86
.46
.07
.00
.10
.20
.30
.41
.51
.61
.72
.82
.92
1.03
TURN # (*10^-4)


CAPTURE AFTER 270 DEGREE ROTATION
TURN # 308
HBCKT 4.3144+001 [MEV], SBCKT 1.0322+000 [EV-S], ES 1.2094+005 [MEV], HUS 5.5306-004
DPDT 0.00000+000 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 7.5000-002 [MeV], EV2 1.0000-005 [MeV]
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.7843-003
DE - ES [MEV]
250.00
200.00
150.00
100.00
50.00
.00
-50.00
-100.00
-150.00
-200.00
-250.00
SBNCH 1.500-001 [EV-S]
SWITCHES: TFFFFFTFTFFFFFFFFFFF
-1.25
-1.00
-.75
-.50
-.25
-.00
.25
.50
.75
1.00
1.25
THETA — RF PHASES 1113. * THETA + 3.142 &
1. * THETA + 0.003 (*10^3)


THRMSrad VS TURN #
THRMSrad (*10^4)
.43
.74
1.05
1.36
1.67
1.99
2.30
2.61
2.92
3.24
3.55
.00
.10
.20
.30
.41
.51
.61
.72
.82
.92
1.03
TURN # (*10^-4)


THRMSrad VS TURN #
THRMSrad (*10^4)
1.08
1.10
1.13
1.15
1.17
1.20
1.22
1.24
1.27
1.29
1.32
.10
.19
.28
.37
.46
.55
.64
.73
.82
.91
1.00
TURN # (*10^-5)

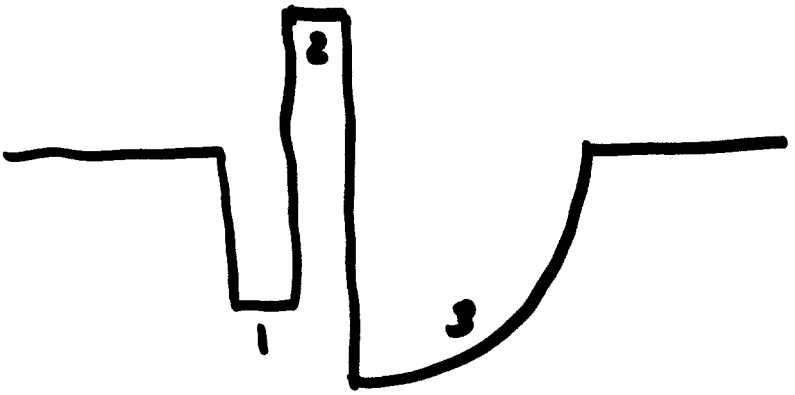
K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1510

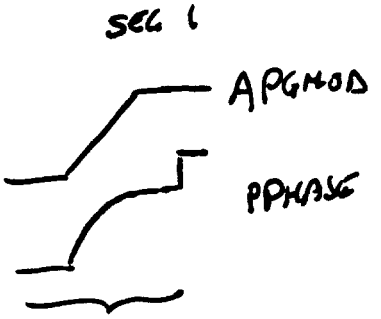


EXISTING 071 MODULES -

3 SEGMENTS

FAST ROTATION + RECAPTURE



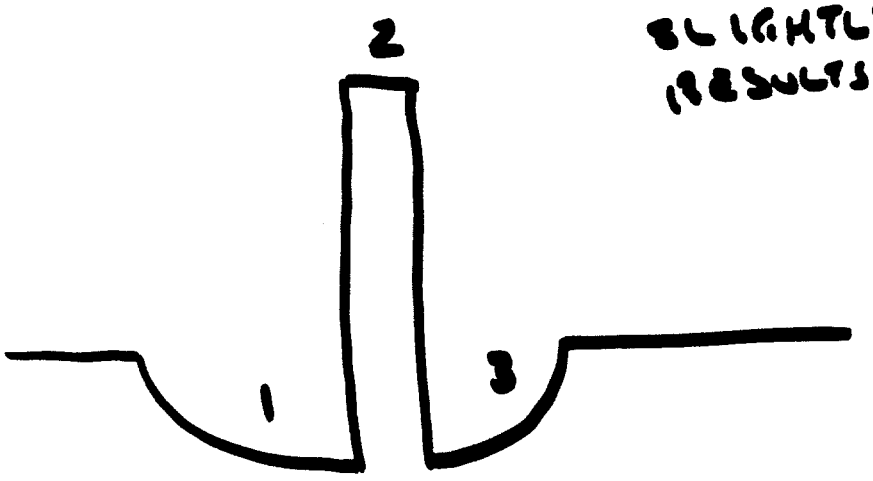


MIGHT WORK - PROBLEMS WITH CHANGING VOLTAGE

~.01 sec ?

SLOW REDUCTION - TAKES LONGER

SLIGHTLY BETTER RESULTS



SEGMENT 1 $.02 < \Delta t < .3$ sec

MULTIPLE BATCH RF MANIPULATIONS

CAN BE DONE

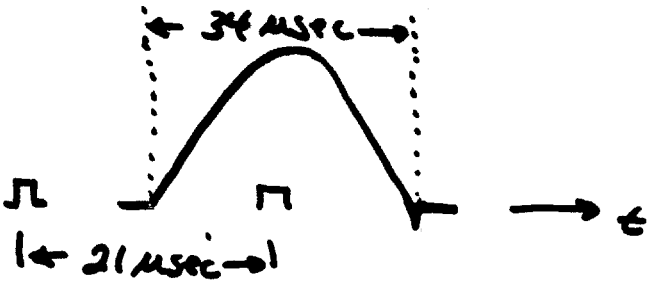
- UP TO 3 OR 4 TIMES
  LOOKS REASONABLE

- TO OPTIMISE, ALL BATCHES
  WILL BE WIDER THAN FOR
  SINGLE BATCH

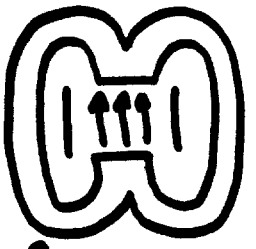
G. DUGAN

E17 KICKER AND MULTIPLE BATCHES

— USED FOR EXTRACTION OF 120 GeV protons from the Main Ring for $\bar{p}$ production

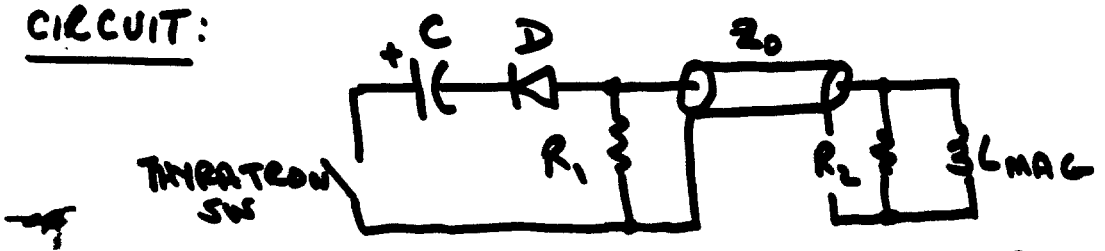


KICKER:



GAP $2'' \times 3\frac{1}{2}''$
72" LONG
$L \sim 5.5\,\mu h$
$\theta_K \sim 450$ mrad

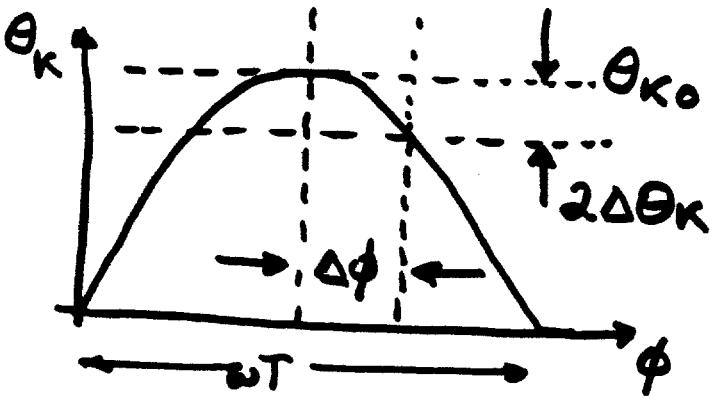
CIRCUIT:



$Z_0 = 25\ \Omega$
$R_1 = R_2 =$ [redacted] Ω
D: fast recovery diodes

V = 4kV I = 4.1 kA @ 120 GeV

— FOR OPERATION WITH MULTIPLE BATCHES, WE MUST SHORTEN THE PULSE DURATION BUT MAINTAIN ADEQUATE FLAT-TOP UNIFORMITY:



$$\Delta\theta_K/\theta_{K0} = \frac{\Delta\phi^2}{4}$$

$\omega\Delta\phi \cong 16\ \mu sec = T_b$ (one batch)

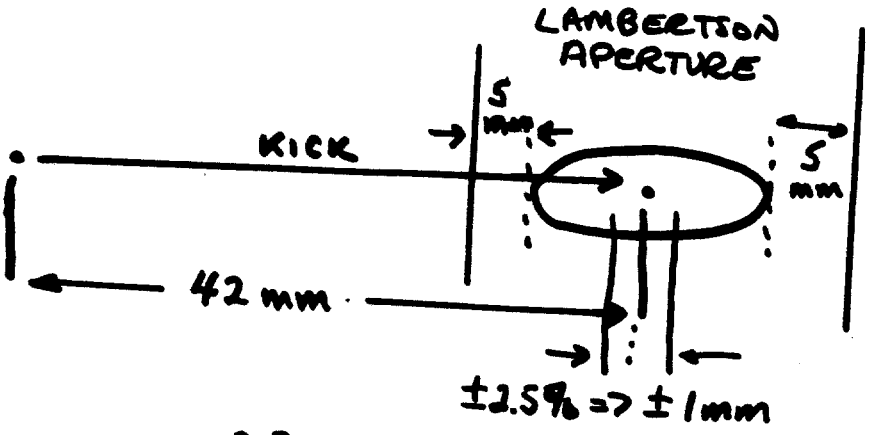
$\theta_{K0} \sim 450\ \mu rad$

CRITERIA ON $\Delta\theta_K/\theta_{K0}$: **2.5%**

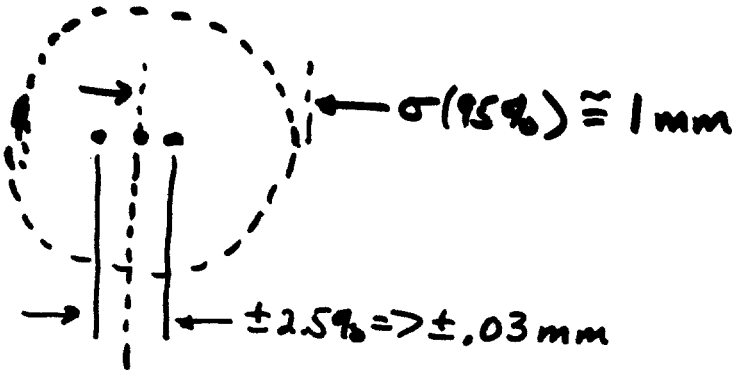
1) TREAT AS AN EMITTANCE DILUTION:

$\Delta\theta_K/\theta_{K0} \sim 2.5\% \Rightarrow \Delta\varepsilon \sim$ [redacted] 3%

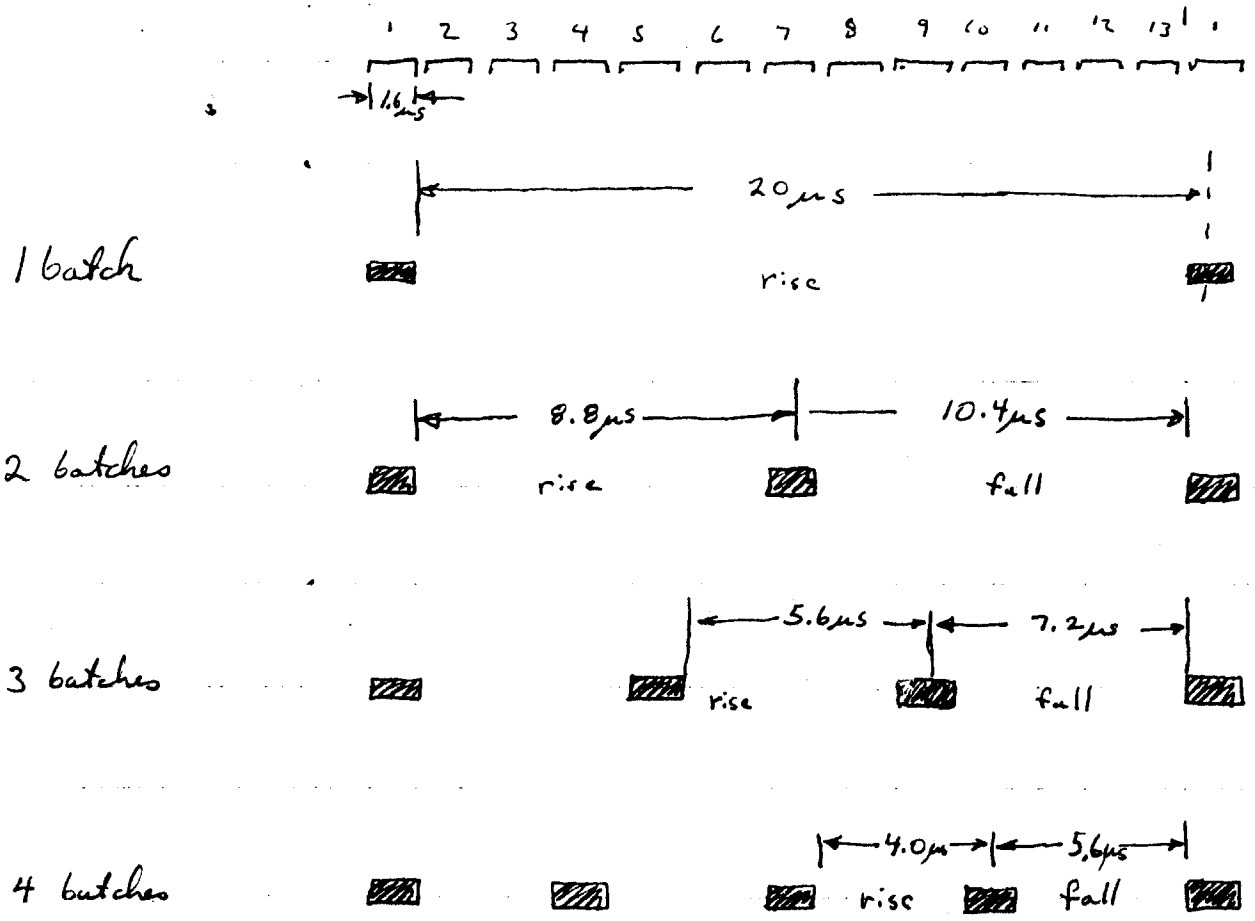
2) CONSIDER FULL RANGE OF BEAM MOTION:



AT THE TARGET:



12-17-85
GK


1 2 3 4 5 6 7 8 9 10 11 12 13 1
1.6 μs
1 batch
20 μs
rise
2 batches
8.8 μs
10.4 μs
rise
fall
3 batches
5.6 μs
7.2 μs
rise
fall
4 batches
4.0 μs
5.6 μs
rise
fall

$$\frac{\Delta\theta_K}{\theta_{K_0}} \leq 2.5\% \Rightarrow \Delta\phi \leq .31 \text{ rad}$$

$$\frac{2\Delta\phi}{T_B} = \frac{\pi}{T}$$

T = pulse duration
T_B = batch length = 1.6 μsec

$$\Rightarrow \boxed{T \geq 8.6 \text{ μsec}}$$

PULSES	T (μsec)	C (nf)	uniformity %	V (kV) (i = 6kA)	
1	37	12	±.1	6	present
2	17.6	2.6	±.5	12.8	use 2 magnets (existing)
3	11.2	1.1	±1.25	20.2	new caps
4	8.0	.54	±2.5	28.2	new caps, new powersupply, new diodes?

→ 3 pulses is "easy", 4 harder but doable

5 or more require totally new system