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Tevatron BØ Low Beta Tuning Report

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A detailed study of the low beta insertion for the B0 experimental area has been carried out and is described below. This insertion is similar to the Type C low beta previously report, $\bar{p}$ Note 169, although some changes have been made to the quadrupole lengths and positions. This insertion is designated Type E. The purpose of the study was to see if it is possible to turn the insertion on in a smooth and continuous manner and tune the insertion to a value of β^* of less than one meter while maintaining the overall tune of the Tevatron to a constant value. This was found to be possible. An examination of chromaticity corrections for the Tevatron with the low beta insertion on in various configurations was also undertaken.

A layout of the low beta insertion is shown in Fig. 1. As before, it requires the replacement of the 32" quadrupoles at A48 and B12 with separately powered 66" quadrupoles and the addition of two 180" quadrupoles and six 144" quadrupoles within the long-straight section. These ten quadrupoles are powered anti-symmetrically on four separate circuits and

must reach a maximum gradient of 25.5 KG/in at 1 TeV. In order to keep the maximum luminosity point close to the Tevatron B0 location, the quadrupoles at A48/B12 must be pushed as far upstream as possible. To do this, the normal dipole interace-to-quadrupole magnetic length has been reduced from 18.137" to 7.137" by changing the upstream bellows and moving the beam detector to the downstream end of the quadrupoles. This motion puts the maximum luminosity point 0.9 inches downstream of the Tevatron B0 for the final low beta of about one meter.

For normal fixed target operation, Q1 must run at approximately 10 KG/in and Q2, Q3, and Q4 must all be off. By contrast, at the "beginning of low beta", as shown in previous reports, all of the quadrupoles must be on and running quite hard. The problem is to find a method of connecting these two solutions in a stepwise continuous manner while maintaining the overall tune of the Tevatron. This is by no means a simple straightforward process. The two solutions are in fact quite different and probably cannot be connected without disturbing the normal lattice functions outside the insertion region. A method has been found, however, which does not greatly disturb the rest of the machine. A plot of quadrupole gradients along with quad correction gradients versus step number is shown in Table I. On Figure 2, step number 0 corresponds to a retuned fixed-target mode and step number 28 corresponds to a low beta of approximately one meter. The step size is rather arbitrary. This turn-on sequence was initially made of steps such that no gradient changed by more than 1.3 KG/in per step. A curve was then drawn through a plot of those points, larger step sizes were taken and connected by straight lines. These are the points shown. On the left side of Fig. 2 are listed β^* values for several steps. It should be

be noted that β^* does not decrease linearly with these steps. That is, if one looks at step 27, for example, one should not infer a value of $\beta^*=1.5$. Gradients read off the graph for number 27 will indeed give a good low beta with β^* between one and two meters, but closer to two than one.

In all of this sequence, the Tevatron has been retuned to 19.585 in each plane. For particle-antiparticle collisions it is desirable to be above the half integer and the value of .585 centers the tune in a region free of all resonances of order lower than 11th. The correction quadrupoles consist of two families, QFC and QDC, located next to the corresponding quadrupoles, QF or QD, at all stations 13 through 47. These corrections have a range of approximately ±2 KG/in at 50 amps. QFC has been plotted and ranges from +0.4 KG/in to -0.9 KG/in. QDC is given simply by

$$QDC = 0.0457 - QFC \text{ (KG/in)}$$

In this turn-on sequence, there is some disturbance to the lattice functions outside the insertion region. This is due to three distinct reasons.

1. The "off" solution and the "low beta" solution are, in fact, quite different. It is doubtful that they can be connected without allowing some mismatch.
2. The initial sequence, in steps of less than 1.3 KG/in, was not a very smooth curve. Some amount of mismatch was allowed in order to produce the curves plotted in Figure 2.

3. It was found that a higher luminosity can be achieved in the "1 meter low beta" by introducing some mismatch. This is because the long-straight sections are not exactly anti-symmetric, one side has more dipole edge focusing than the other, while the low beta quads of necessity are symmetric.

The amount of disturbance to the normal lattice functions, however, is quite small and should cause no problem since this turn on will not start until high energy where the beam is very small. The amount of disturbance can be easily calculated. If the mismatch at the end of the insertion is given by $\Delta\alpha$, $\Delta\beta$, where α and β are the usual lattice parameters, then the amplitude of oscillation about the normal functions is given by

$$A = \frac{\beta_0}{2\sin 2\pi\nu}\left[\frac{a^2 + b^2}{1+b}\right]^{1/2}$$

where ν is the tune, and a and b are given by

$$a \equiv \Delta\alpha - \alpha_0\Delta\beta/\beta_0$$

$$b \equiv \Delta\beta/\beta_0$$

with α_0 and β_0 the matched lattice functions. In terms of A, the percent increase in the average lattice functions due to the mismatch is

$$\langle A \rangle = (\beta_o^2 + A^2)^{1/2}/\beta_o$$

For the sequence given, this quantity has a maximum of about 1.40 around step number 13. Table II lists various lattice functions versus step number for this tuning sequence. Figures 3-8 show plots of beta and dispersion functions across the B0 straight section for several steps. In all cases the scales are beta:(0,1000m) and eta:(-10,10m). Figures 9-14 show a plot of β_x for the entire ring for various steps. These show the nature of the betatron mismatch. Vertical beta function plots are very similar, although not identical.

In addition to this betatron mismatch, there is an unavoidable change in the dispersion function around the machine as this low beta is turned on. Plots of the dispersion function around the ring are shown in Figs. 15-20 for various steps. Again, this should cause no problem due to increased beam size as the momentum spread at 1 TeV is much smaller than at injection. This could lead to a problem with chromaticity corrections, but it has been found that it does not. The correction sextupoles are also in two families and located at the same spots as the correction quadrupoles. They have an integrated field of

$$B''\ell = \pm 100 \text{ KG/in} \quad \text{at } 50A$$

During the low beta turn-on sequence, the natural, uncorrected chromaticity ranges from -21 to -30. For colliding beam mode, the

chromaticity should be made slightly positive in order to avoid longitudinal head-tail instabilities. This has been accomplished for both the "off" solution and the one meter low beta solution as well as for several intermediate steps. The needed sextupole ranges from 11.4, -19.1 KG/in to 14.6, -23.5 KG/in for the two families. Table III lists the integrated sextupole fields and achieved chromaticity for several steps.

A solution for the actual running of the BO low beta has been presented. Beam can be injected into the normal Tevatron lattice and the low beta can be slowly and smoothly turned on after acceleration to 1 TeV. There is an increase in the beta and dispersions functions during the turn on which does not present a beam size problem due to the small emittance and momentum spread at 1 TeV. Both the overall tunes and chromaticities can be held constant with the standard correction elements as this tuning sequence is followed. The major objection to this sequence is the large number of steps to be programmed into the various power supplies. While this is not a serious problem, it would be nice to have many fewer steps. Recent reports from other colliding beam machines, CERN-SPS, PETRA, indicate that they have been found to be able to turn on a low beta region in a few steps - 3 to 5. Once the Tevatron is running and the low beta quadrupoles have been installed we should certainly be able to empirically reduce the number of steps needed in our case.

The author would like to acknowledge helpful conversations with T. Collins, D. Edwards, and L. Teng.

TABLE I.

STEP	ν_x (1)	QC_F (2) (KG/m)	Q1 (KG/m)	Q2 (KG/m)	Q3 (KG/m)	Q4 (KG/m)
0	19.585	16.80	369.6186	0.0000	0.0000	0.0000
1	19.581	9.69	510.0000	0.0000	- 50.0000	0.0000
2	19.589	5.94	590.0000	0.0000	- 70.0000	0.0000
3	19.585	2.95	670.0000	0.0000	- 78.0000	26.0000
4	19.585	2.10	670.0000	100.0000	-160.0000	50.0000
5	19.582	- 0.52	670.0000	200.0000	-240.0000	75.0000
6	19.586	- 1.08	720.0000	275.0000	-280.0000	85.0000
7	19.585	- 1.45	770.0000	350.0000	-320.0000	100.0000
8	19.585	- 1.85	790.0000	425.0000	-350.0000	85.0000
9	19.582	- 3.88	805.0000	500.0000	-380.0000	70.0000
10	19.586	- 3.91	785.0000	575.0000	-410.0000	65.0000
11	19.583	- 6.44	760.0000	650.0000	-440.0000	55.0000
12	19.582	- 6.44	740.0000	725.0000	-480.0000	90.0000
13	19.588	- 7.00	720.0000	800.0000	-520.0000	130.0000
14	19.585	- 8.22	620.0000	825.0000	-530.0000	115.0000
15	19.583	-11.77	520.0000	850.0000	-545.0000	100.0000
16	19.586	-12.43	400.0000	870.0000	-550.0000	75.0000
17	19.584	-15.61	275.0000	890.0000	-560.0000	50.0000
18	19.585	-16.53	180.0000	890.0000	-570.0000	50.0000
19	19.585	-17.11	90.0000	890.0000	-580.0000	50.0000
20						
21	19.584	-20.57	-105.0000	930.0000	-710.0000	325.0000
22						
23	19.585	-24.50	-215.0000	955.0000	-820.0000	610.0000
24	19.585	-25.62	-280.0000	956.0000	-870.0000	740.0000
25						
26	19.585	-25.99	-285.0000	945.0000	-925.0000	940.0000
27						
28	19.586	-35.00	-878.9719	1005.5897	-971.0883	999.1776

(1) ν_y is very close to ν_x

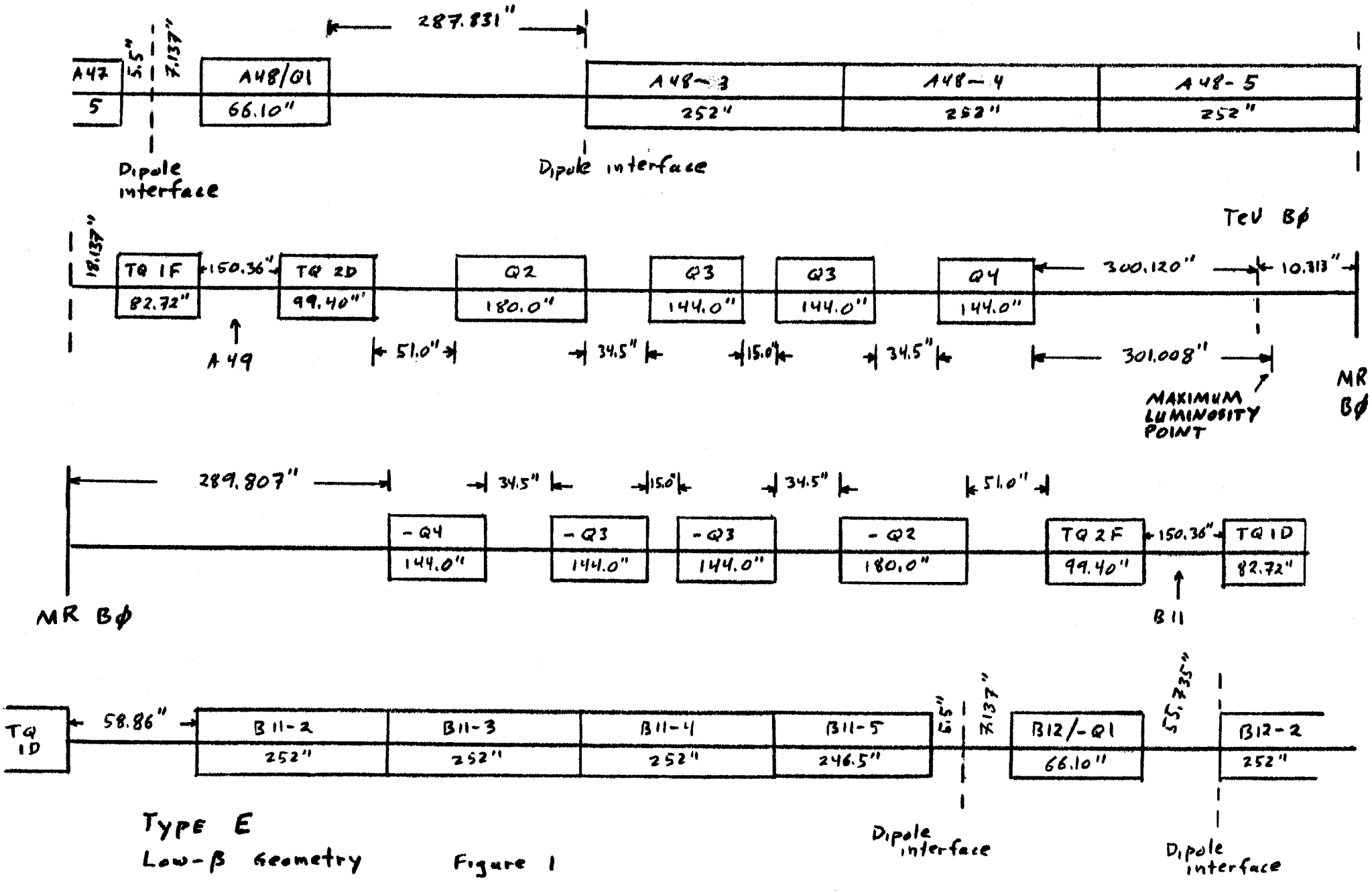
(2) $QC_D = 1.80 - QC_F$ (KG/m)

TABLE II.

STEP	$\hat{\beta}_x$ (m)	$\hat{\beta}_y$ (m)	$\check{\beta}_x$ (m)	$\check{\beta}_y$ (m)	$\hat{\eta}$ (m)	$\check{\eta}$ (m)	β_x^* (m)	η^* (m)
0	249	248	28.0	28.0	5.7	1.2	72.8	2.72
1	289	274	19.0	20.0	6.7	0.6		
2	288	299	17.0	17.0	7.0	0.3		
3	270	273	15.0	15.0	7.1	0.4	51.1	1.75
4	266	274	13.0	13.0	7.2	0.3		
5	327	348	11.0	11.0	7.4	0.1		
6	263	270	10.0	10.0	7.5	0.1		
7	291	287	10.0	10.0	7.6	0.1	107.0	1.42
8	345	339	8.0	8.0	7.7	-0.1		
9	348	342	8.0	8.0	7.8	-0.1		
10	367	361	7.0	7.0	7.9	-0.3		
11	325	327	6.0	6.0	8.0	-0.3		
12	364	360	5.0	5.0	8.1	-0.4		
13	402	397	5.0	5.0	8.1	-0.5		
14	378	376	3.0	3.0	8.2	-0.5	111.4	1.04
15	286	322	4.0	4.0	8.3	-0.4		
16	283	284	3.0	3.0	8.3	-0.5		
17	266	255	3.0	3.0	8.3	-0.5	∿54.0	
18	248	240	3.0	3.0	8.4	-0.6	47.2	0.76
19	246	250	3.0	3.0	8.5	-0.7	∿41.0	
20								
21	313	307	3.0	3.0	8.7	-0.8	23.0	0.53
22								
23	345	336	6.0	6.0	8.8	-1.0	∿10.0	
24	430	413	4.0	3.0	8.9	-1.1	∿ 4.5	
25								
26	436	419	2.0	2.0	9.0	-1.1	∿ 2.0	
27								
28	958	866	0.8	0.9	9.4	-1.3	0.81	0.18

TABLE III.

STEP	$B''\ell_F$ (KG/m)	$B''\ell_D$ (KG/m)	ξ_x	ξ_y
0	450.0	-750.0	0.4	0.2
3	460.0	-775.0	1.2	1.7
7	460.0	-775.0	0.9	1.4
14	460.0	-775.0	0.5	1.0
18	470.0	-775.0	1.5	1.2
21	475.0	-787.0	1.1	1.2
28	575.0	-925.0	1.2	0.3



Type E
Low-β Geometry

Figure 1

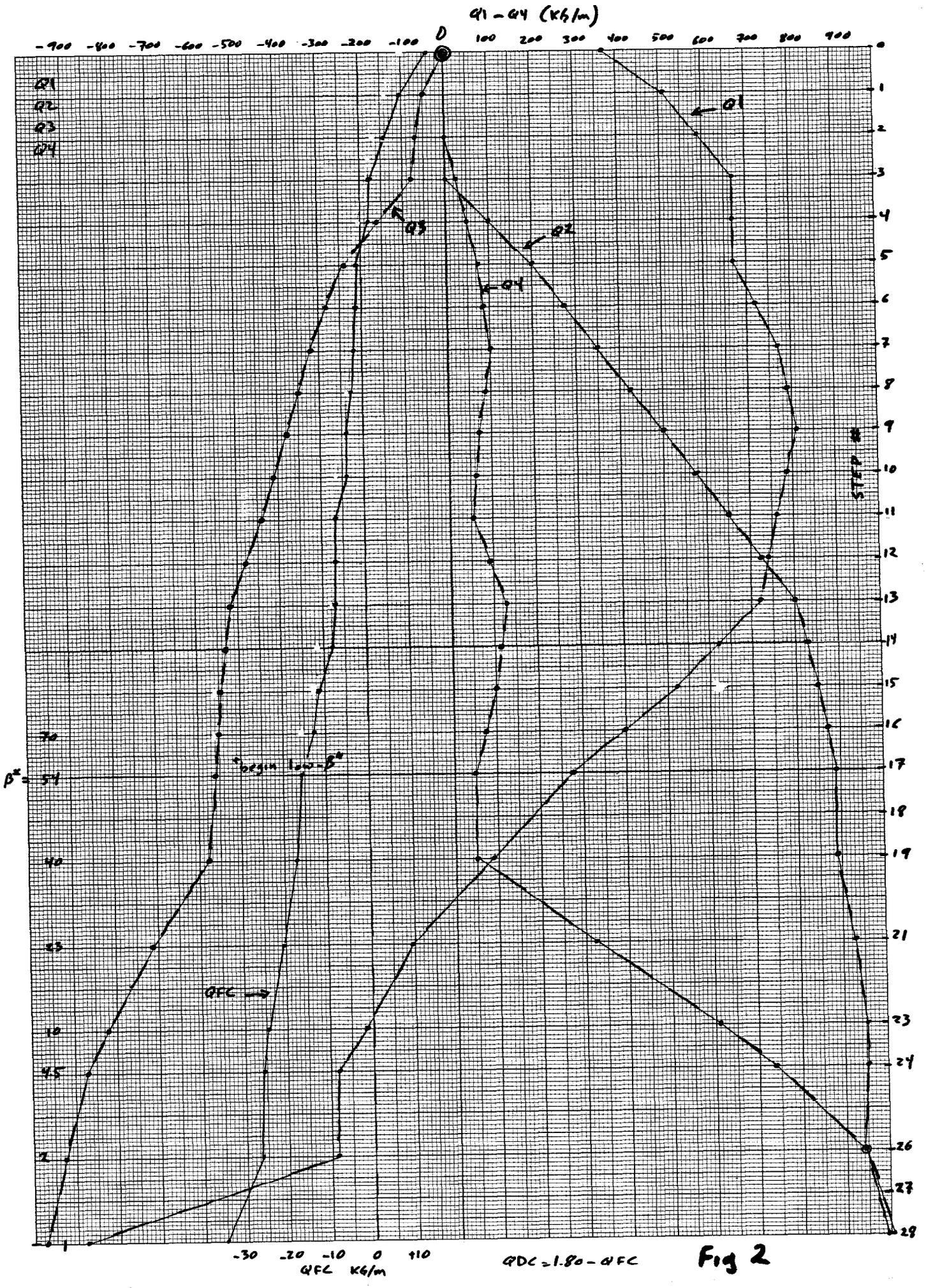

Q1 - Q4 (KG/m)
-900 -800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800 900
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
STEP #
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 23 24 26 27 28
70
β* = 54
40
25
10
4.5
2
1
begin low-β*
QFC →
-30 -20 -10 0 +10
QFC KG/m
QDC = 1.80 - QFC

Fig 2

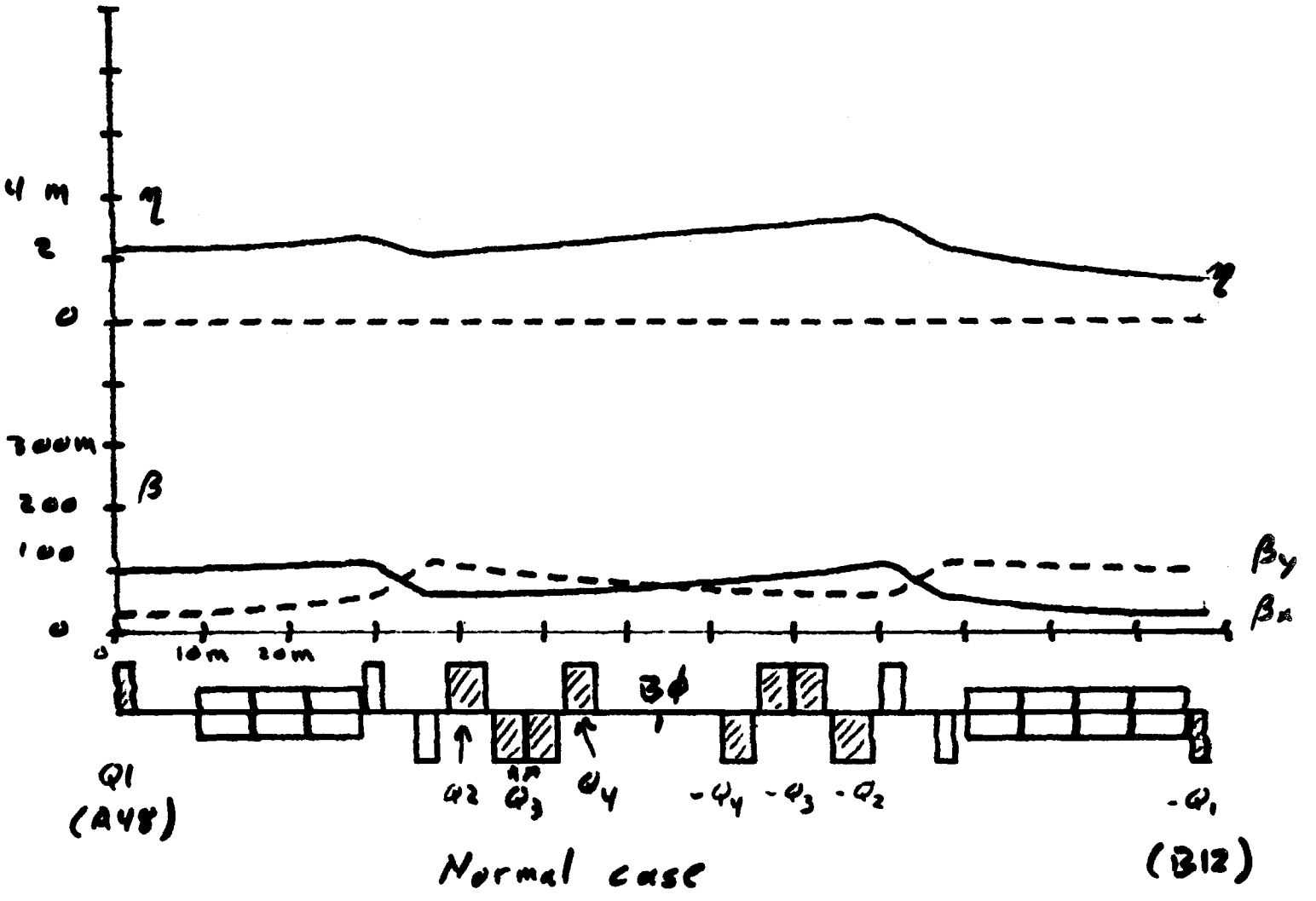

4 m
2
0
η
η
300m
200
100
0
β
β_y
β_x
0
10m
20m
3φ
Q1
(A48)
Q2
Q3
Q4
-Q4
-Q3
-Q2
-Q1
(B12)
Normal case

Fig 3

SCALES, MIN. BETA 0.00 ETA -10.00
MAX. 1000.00 10.00

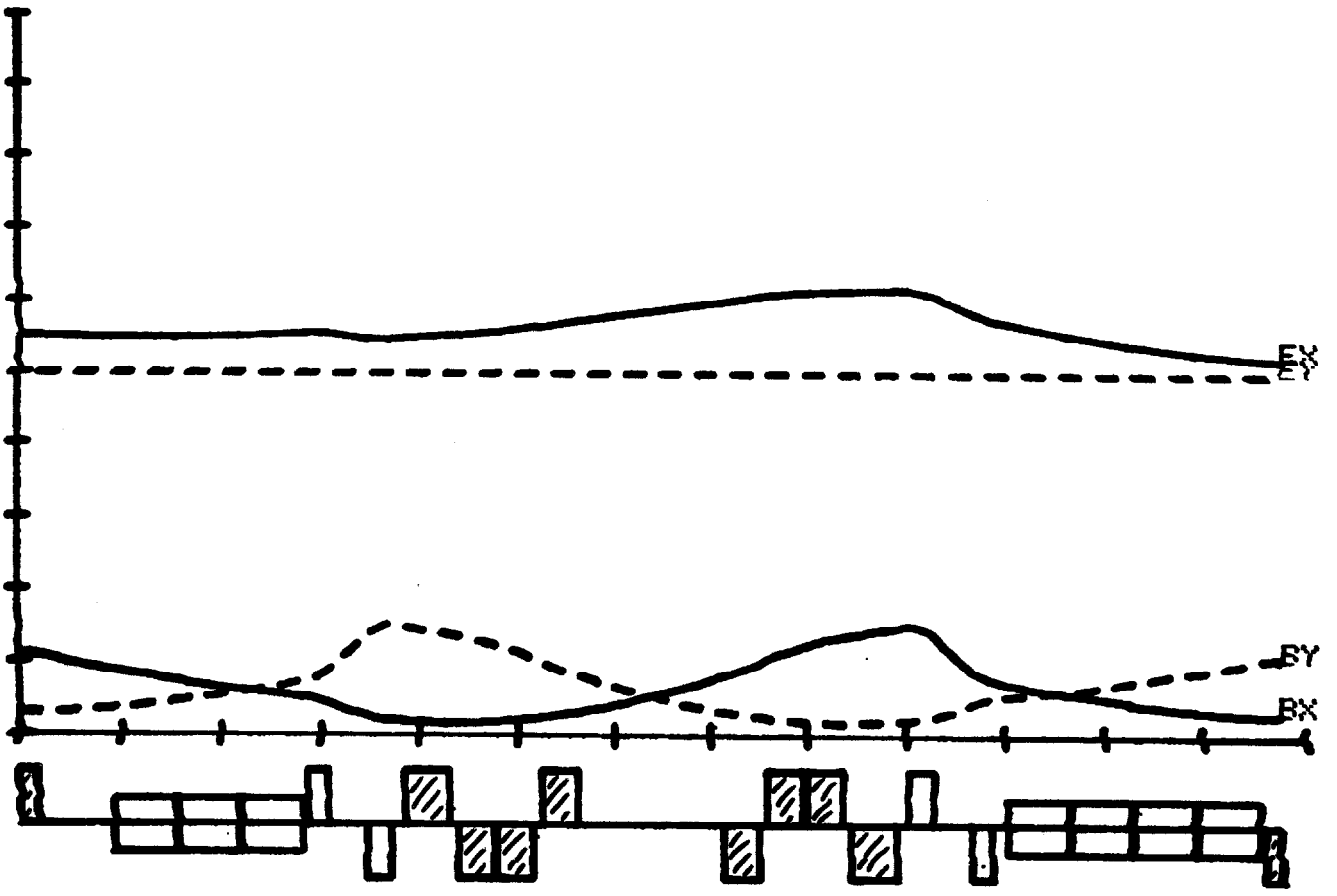


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Fig 4

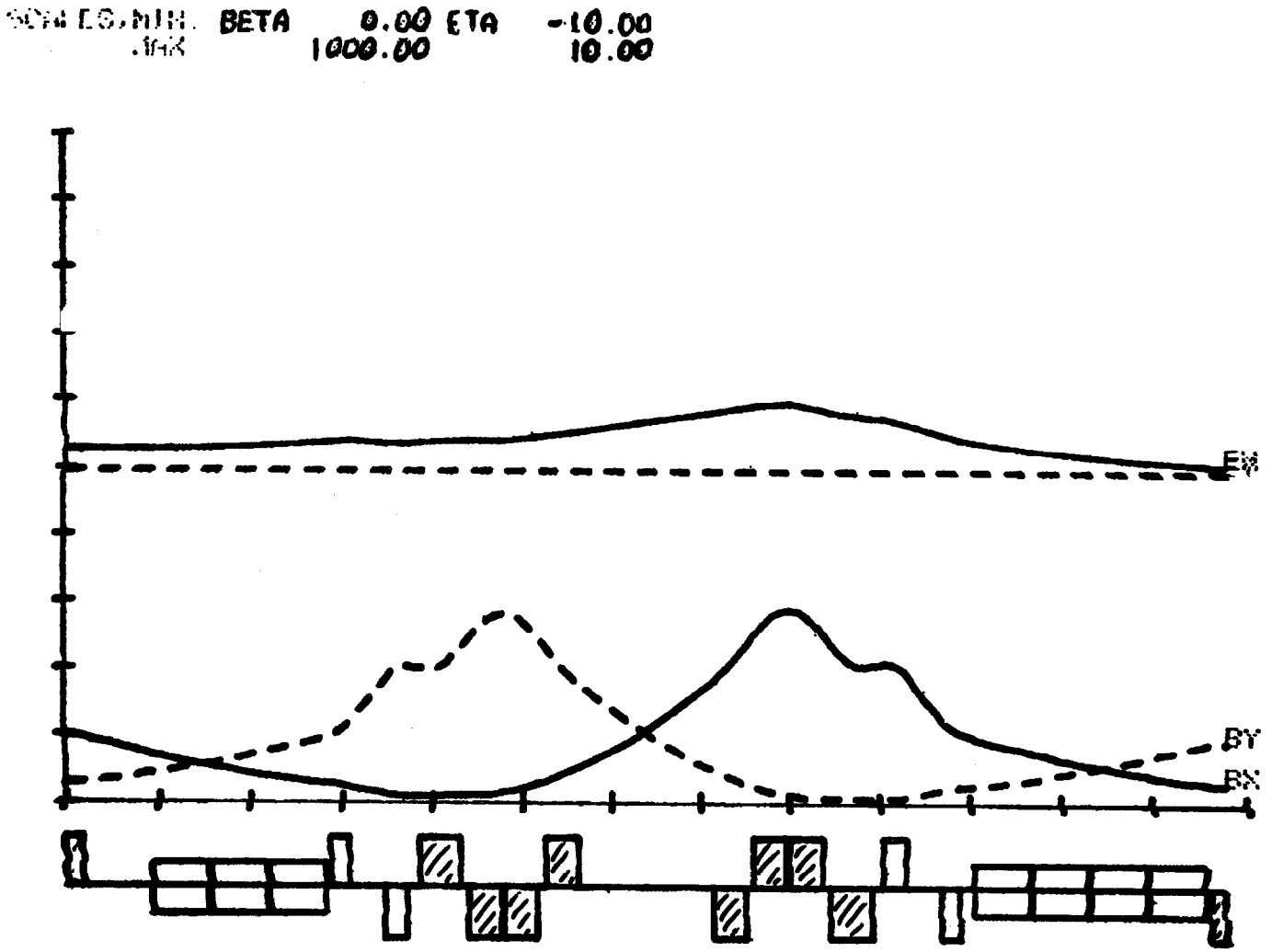

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Fig 5

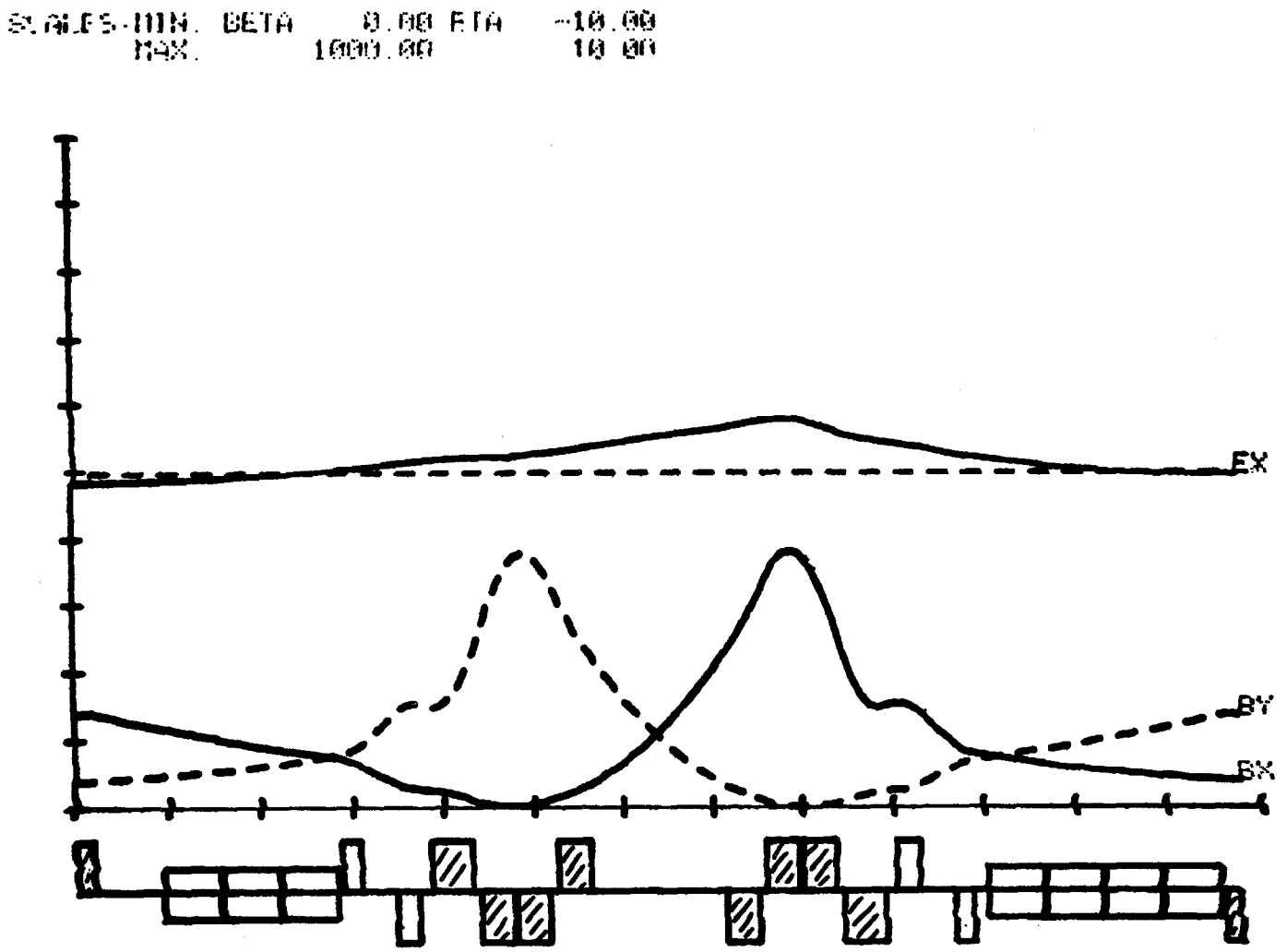

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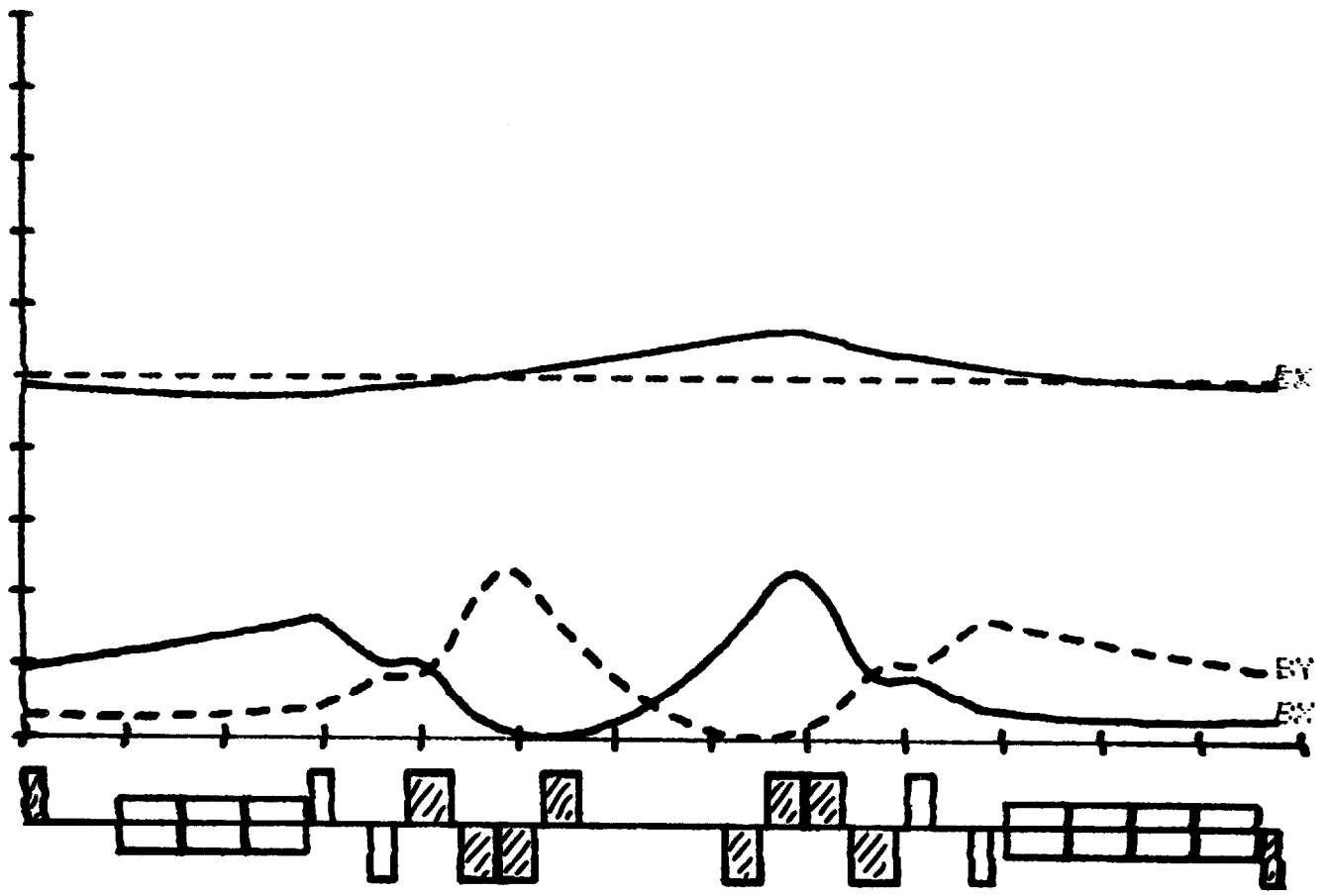
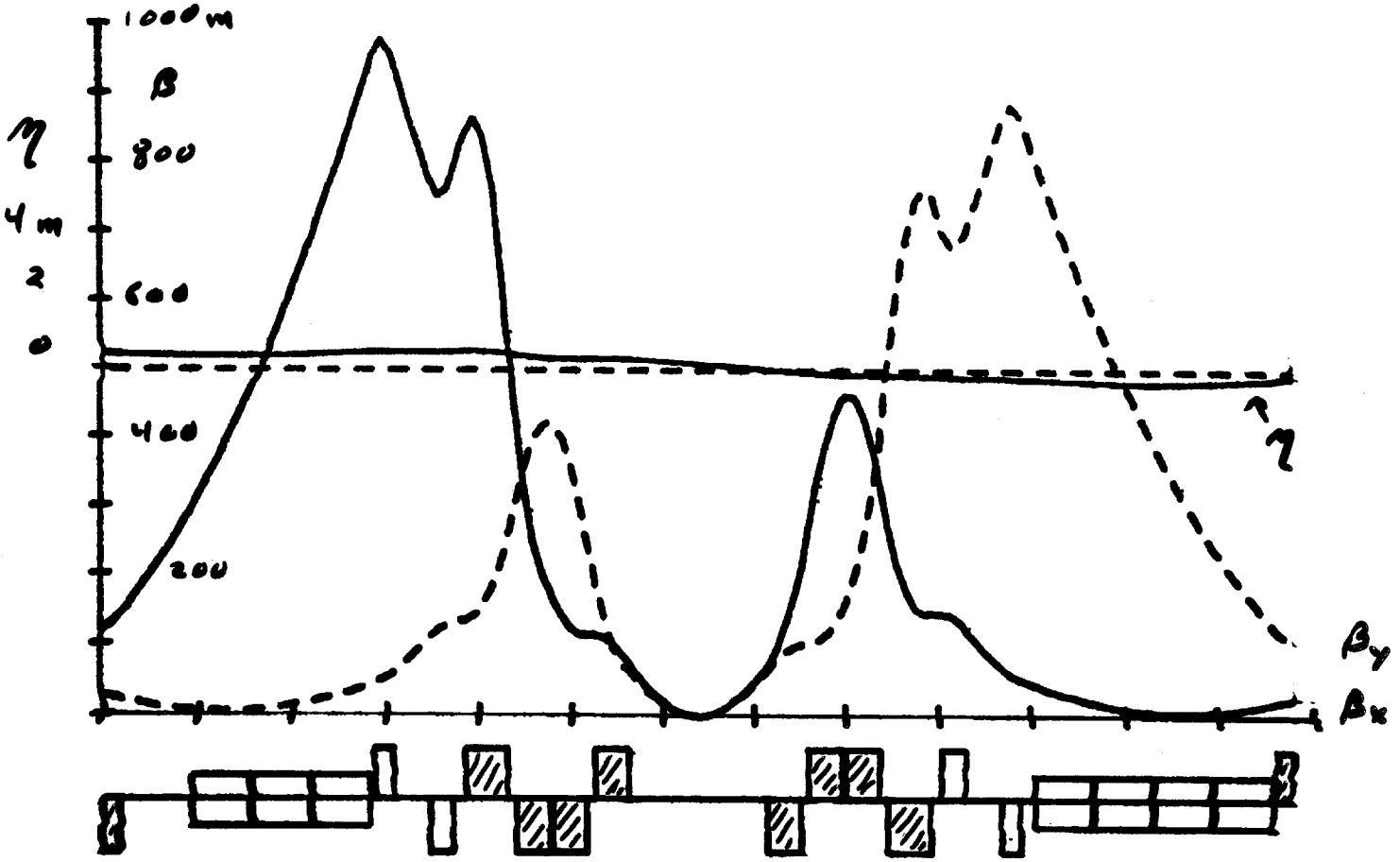
Fig 6



18 $\beta^* = 46\,m$

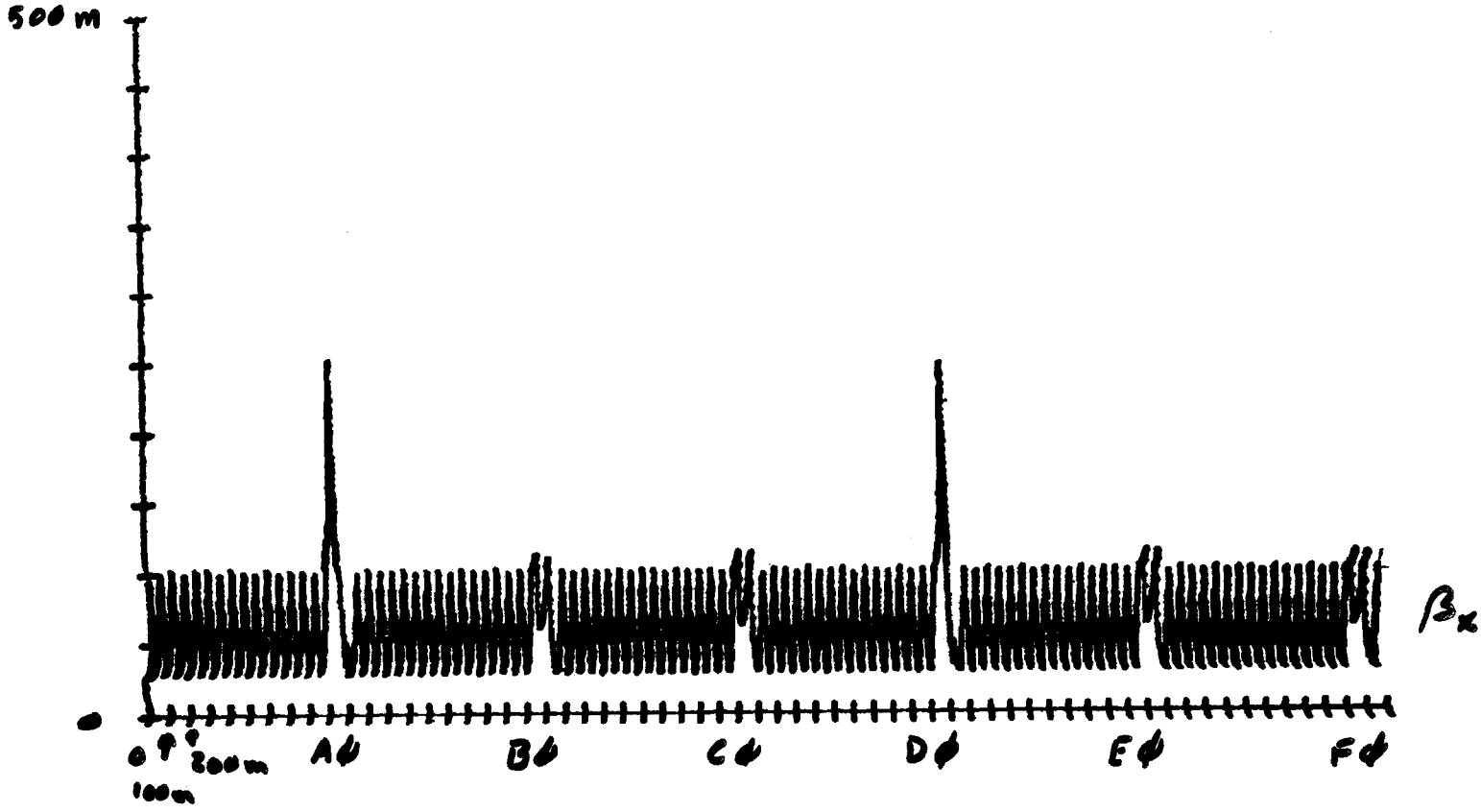
Fig 7



#28 $\beta_x^* = 0.81$ m

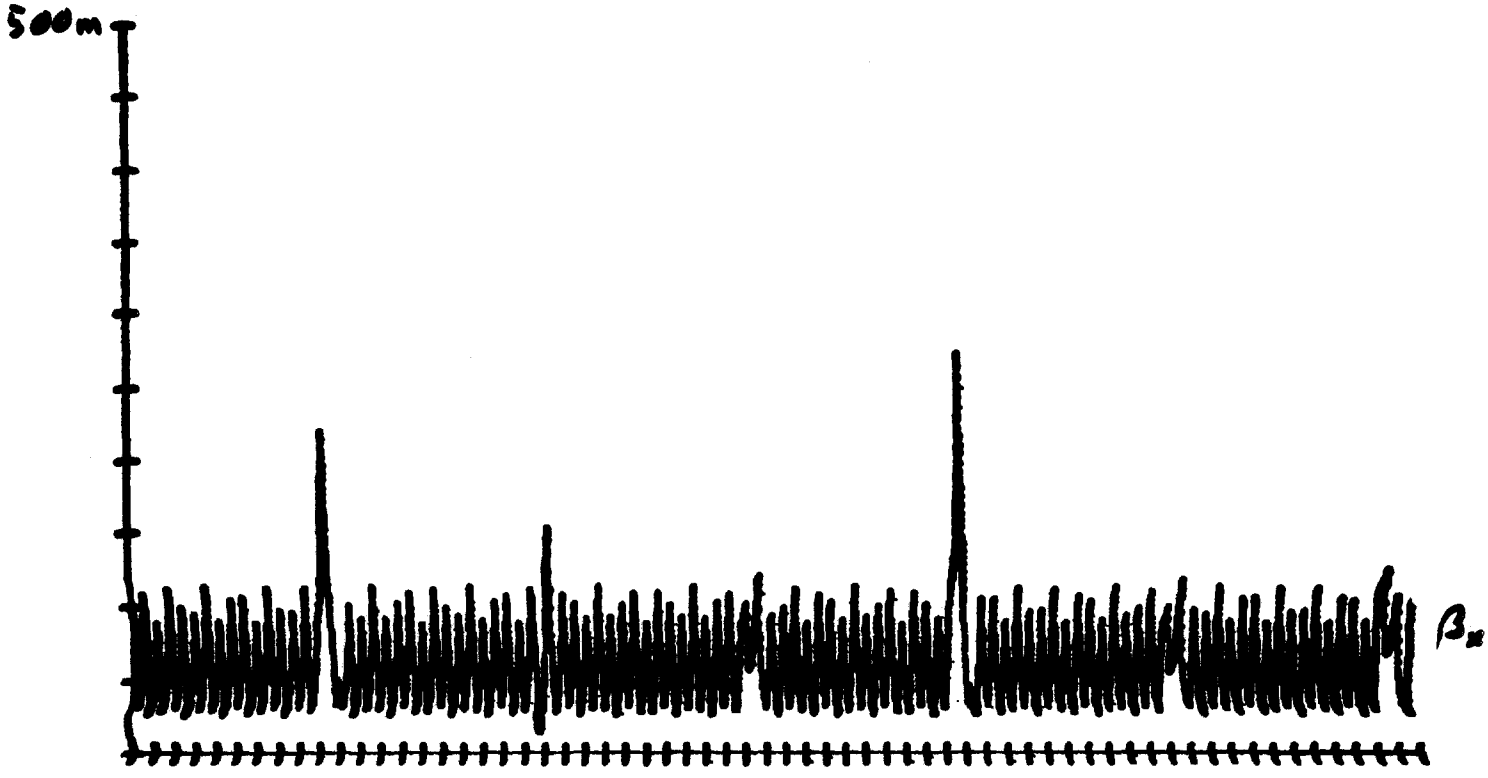
$\beta_y^* = 0.90$ m

Fig 8



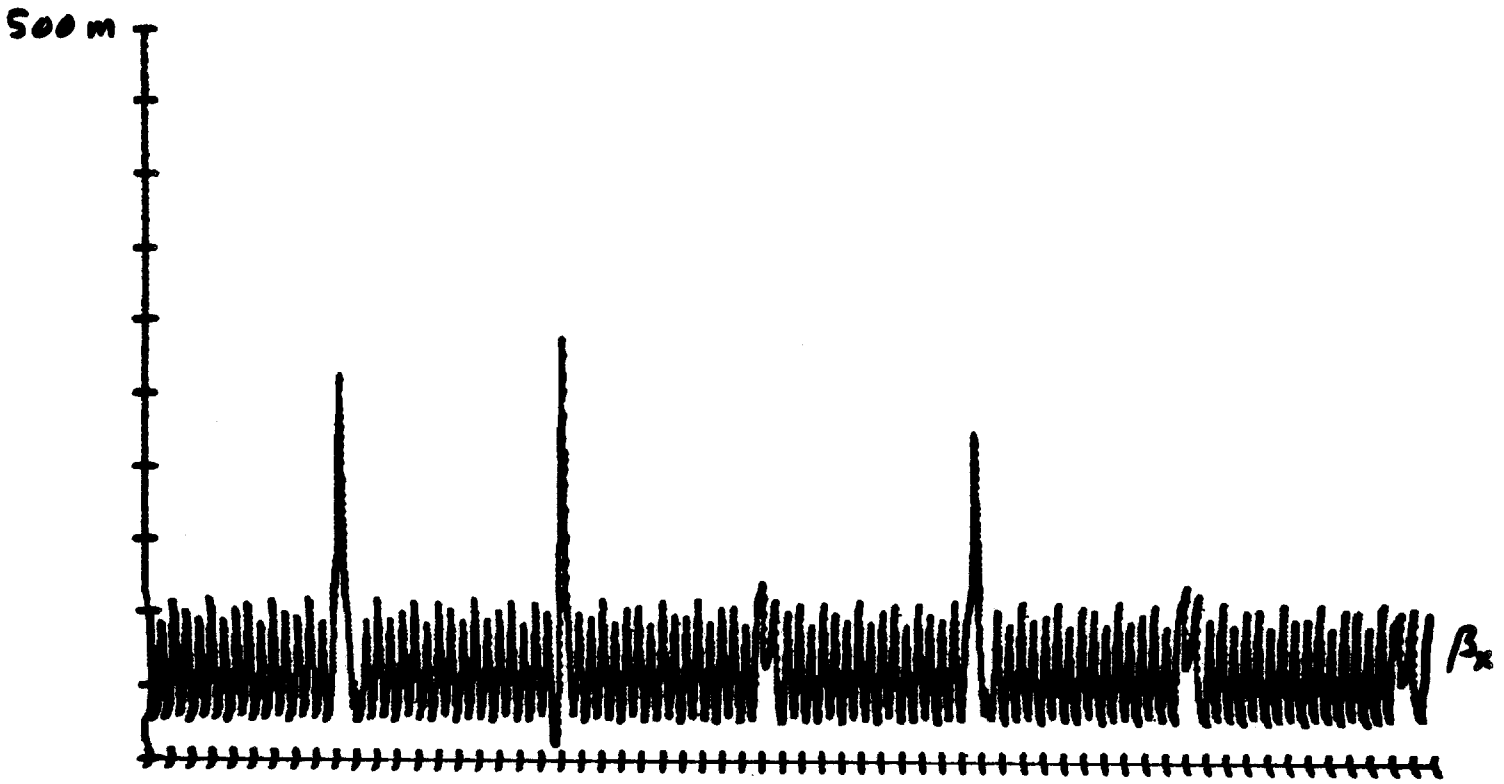
Normal Case

Fig 9



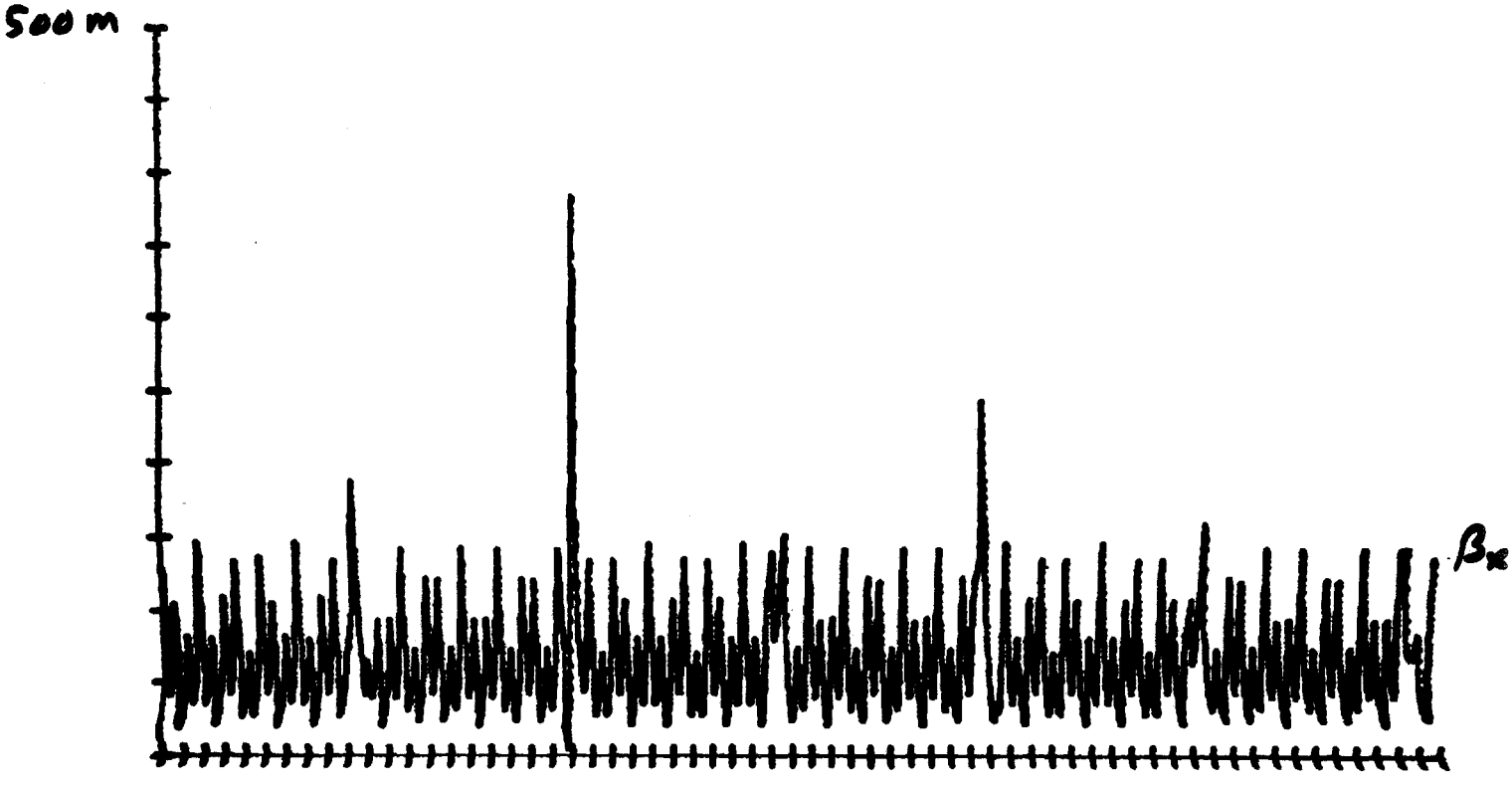
#3

Fig 10



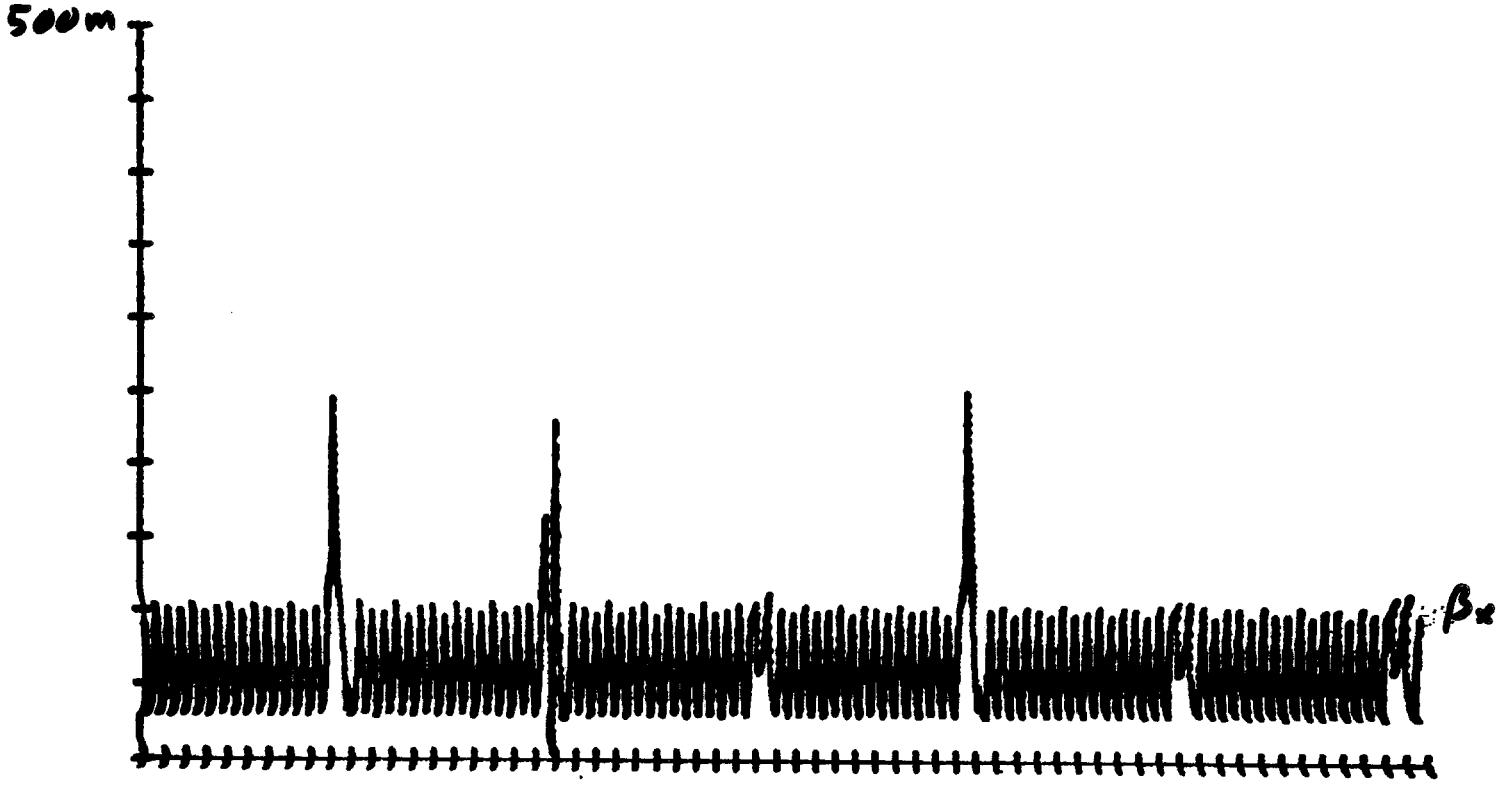
#7

Fig 11



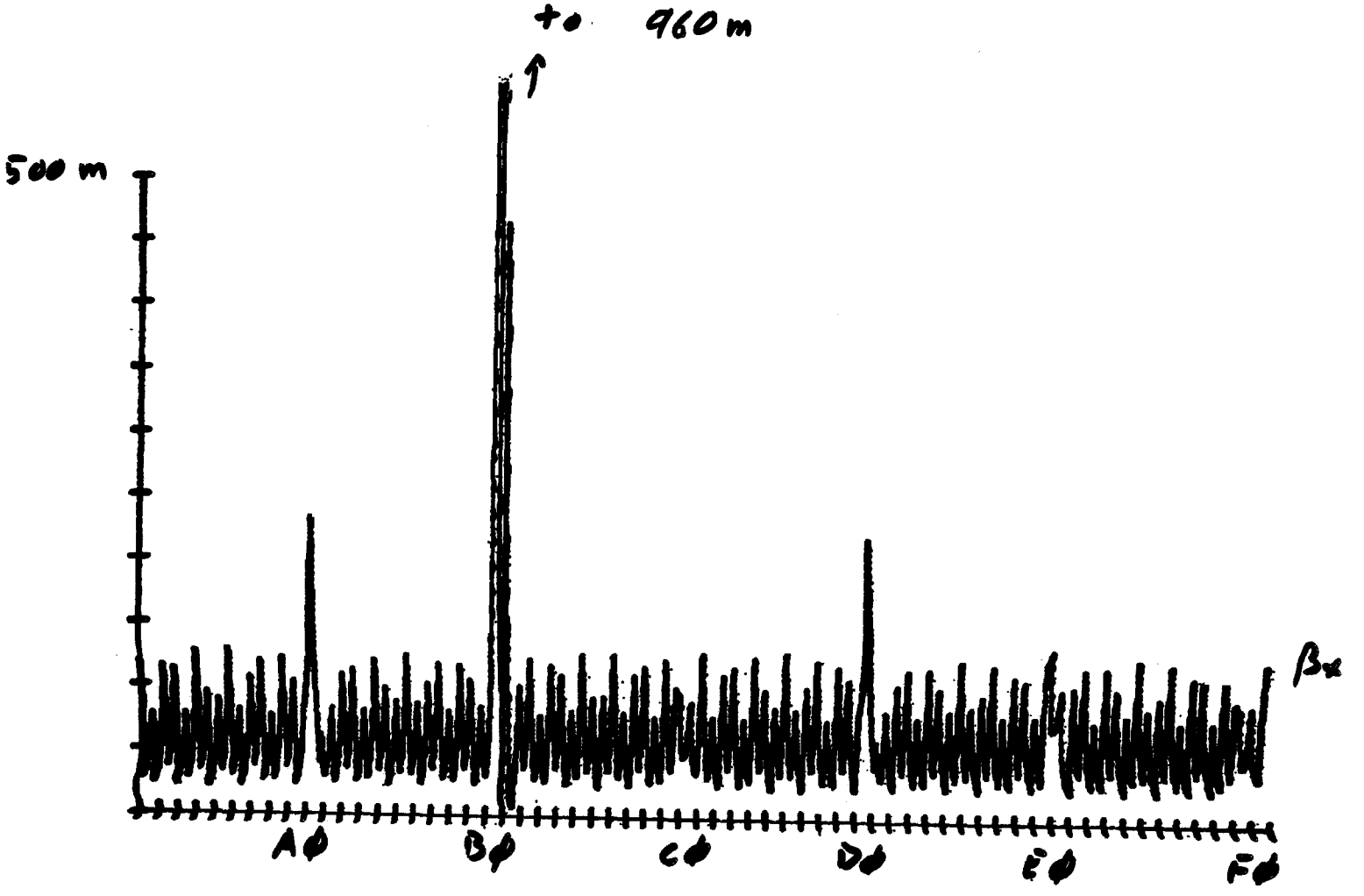
14

Fig 12



#18 $\beta^* = 46$ m

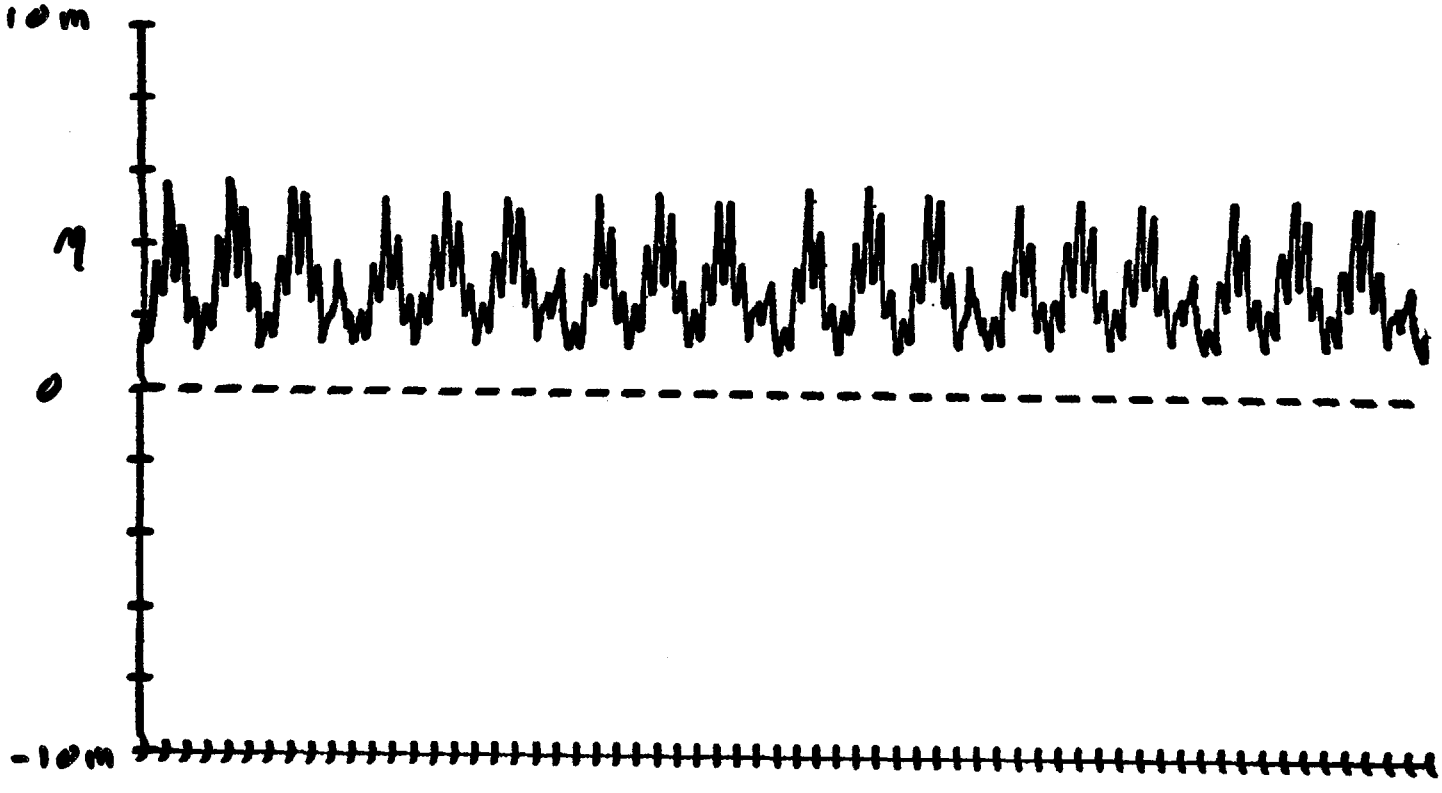
Fig 13



28 $\beta_x^* = 0.81m$

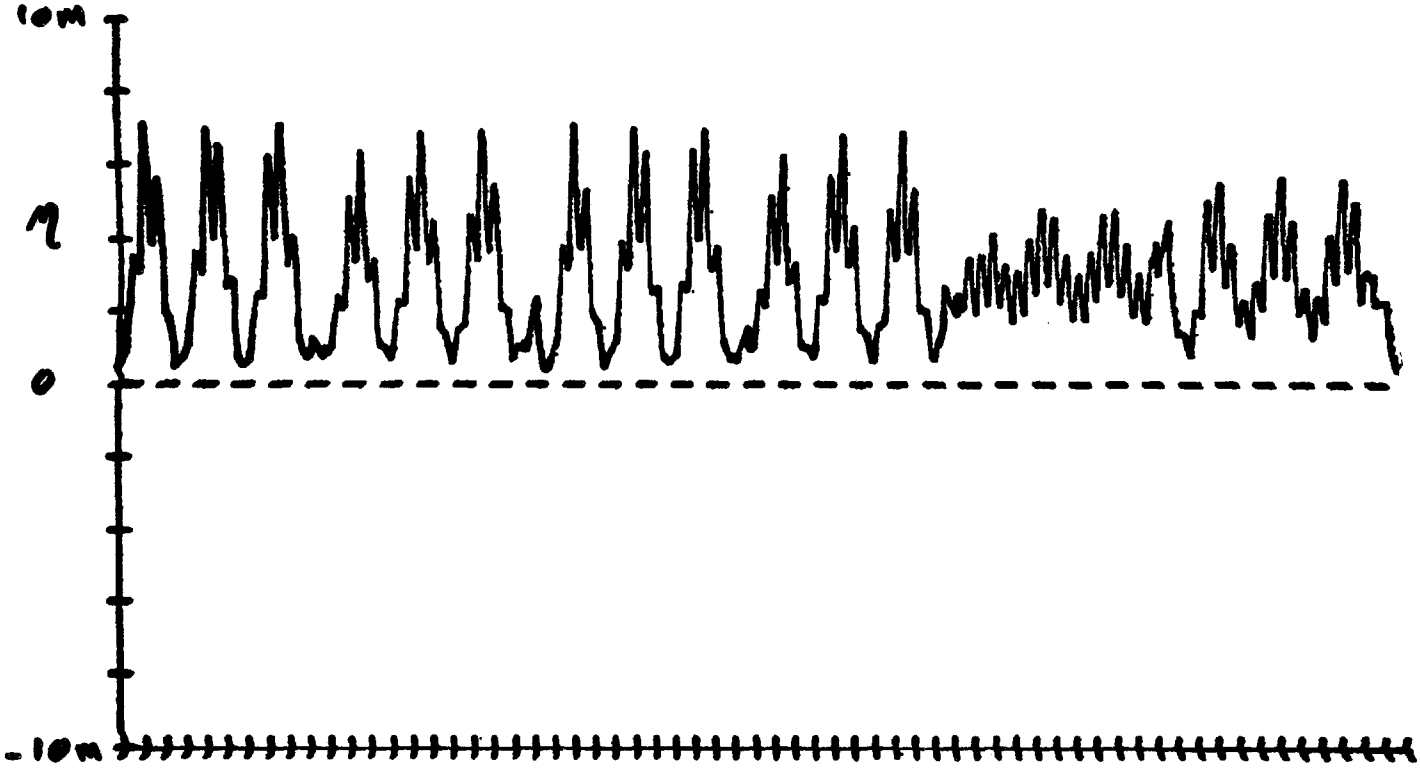
$\beta_y^* = 0.90m$

Fig 14



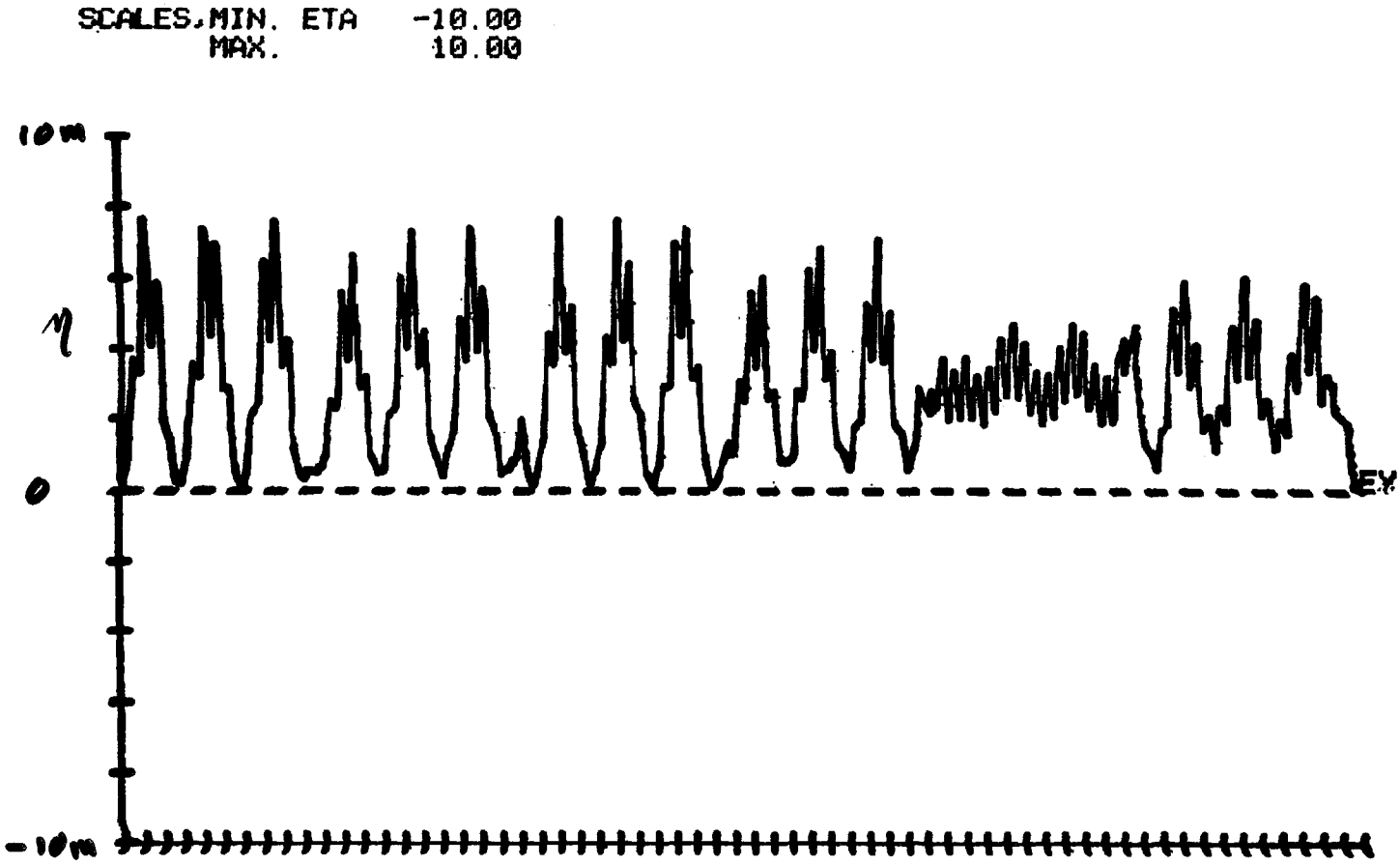
Normal Case

Fig 15



#3

Fig 16



7

Fig 17

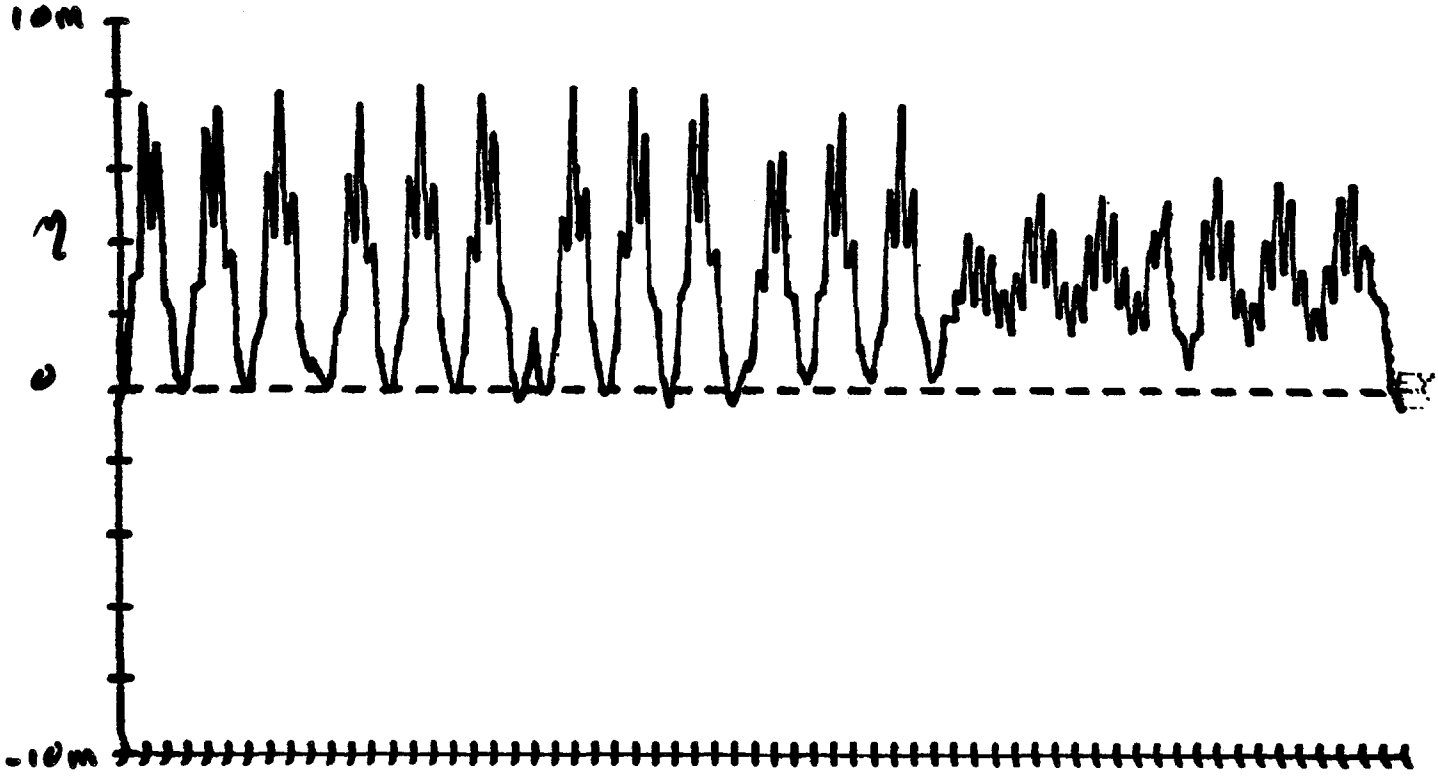


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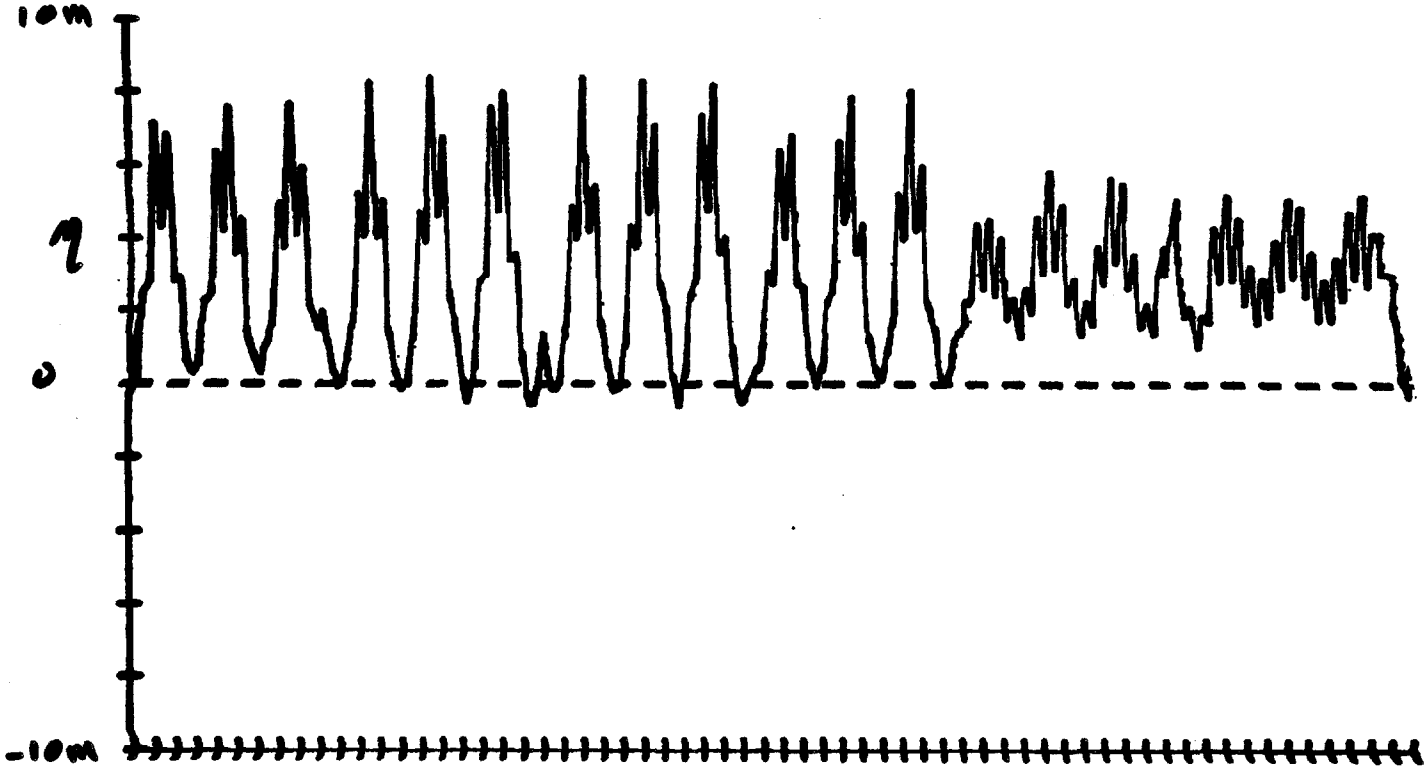
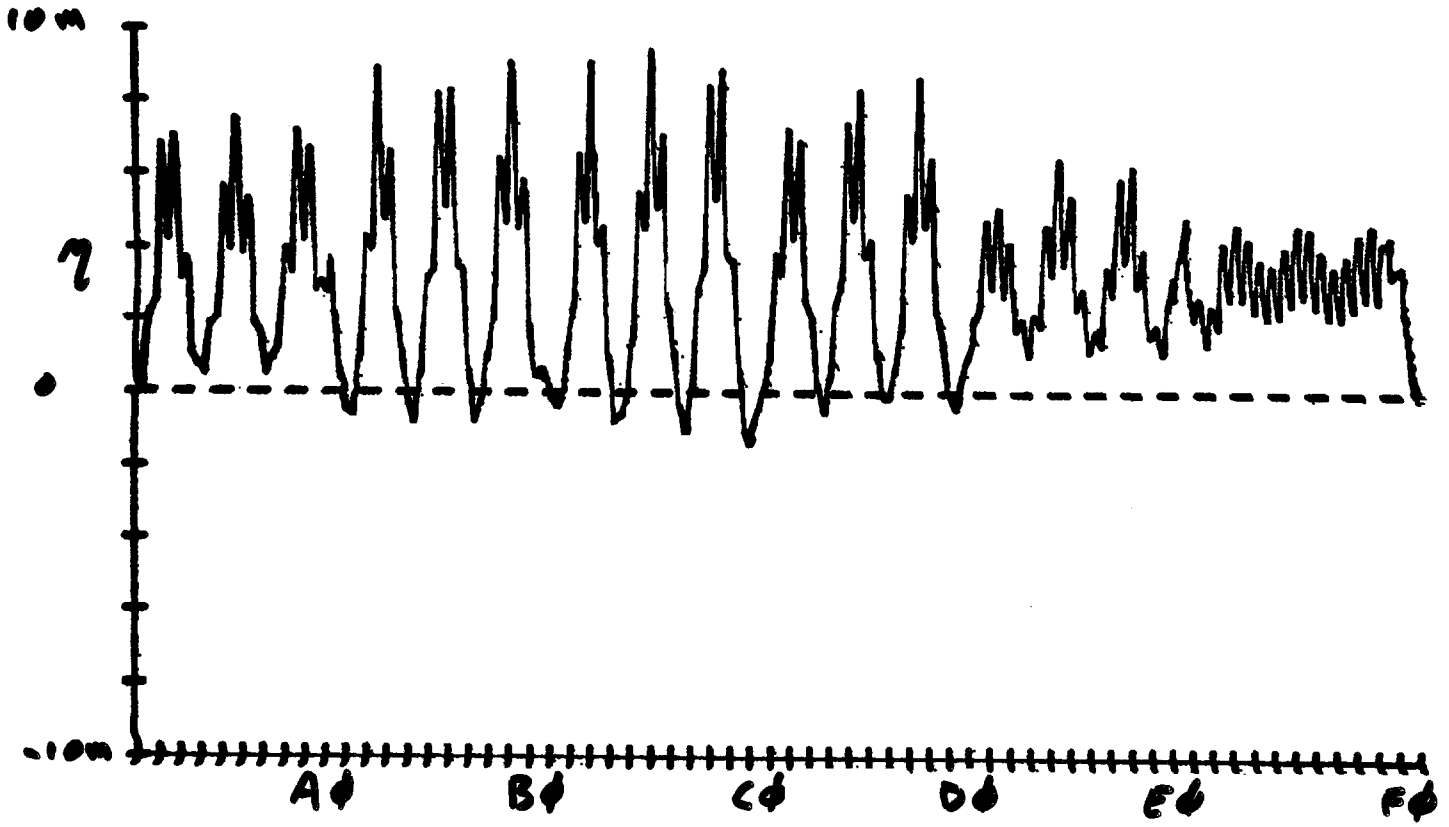
Fig 18



#18 $\beta^* = .46$ m

Fig 19



#28 $\beta_x^* = 0.81m$

$\beta_y^* = 0.90m$

Fig 20