(file=tm31)

Beam Transport Optimization in the Transverse Plane: Matching from a 201 to 805 Mhz system.

FERMILAB-LU-121

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Les Oleksuik – Linac Note #

SCOPE:

It has been observed by Jameson (1), that transverse emittance blowups can occur for injector systems involving severe parameter changes; for a multistage linac system involving frequency , gradient and structure changes, particular attention has to be paid to the sensitivity of the beam dynamics to various effects that contribute to emittance dilution, including space charge, longitudinal -transverse coupling, and non-linear z-phase-plane effects from the large bunch dimensions.

Using three modified codes (DISKZ, TRACEX, DDYNZ) we have attempted to synthesize an 805 Mhz coupled cavity linac representing a useful candidate for the current FERMILAB injector upgrade, and to study systematically the sources of transverse emittance growth that could be predicted from the dynamics codes (TRACEX, DDYNZ).

The candidate was a 40 cavity DAW linac, with EOT=7. Mev/m and a graded synchronous phase (-32 to -26 degrees), plus an upstream transition module. Initial 11-cell accelerating cavities were reduced to 9-cell units, to keep the FODO lens spacing roughly uniform. The FODO period step change produced here was studied to estimate tranvserse emittance growth sensitivity.

Because the 805 MHz system utilizes a transition module, to rebunch the 200 MHz beam to the higher z-plane focusing forces, this abrupt change needed to be studied in its effects on the transverse emittance blow-up. In particular, the synchrotron and betatron frequencies are roughly the same for this linac, so that z-t coupling effects might be sensitive to resonance effects. Figure ___ shows the typical phase advance, including space charge, per FODO period, for both z and t planes, for the DAW linac system simulated here. The step change in the syncrotron tune appears at the 11 to 9 cell fodo period transition, and is not a real tune change.

The minimum transverse beam radii(95%) are predicted using the current knowledge of the 200 MhZ tank #5 beam (ref. 2)phase space.

The design of the transition module is explored to include (i) 5 mev of acceleration, at a synchronous phase of -32 degrees, and (ii) using five 9 cell cavities (design. A) and four 11 cell cavities (Design. B) a study of the FODO quad spacing effects on the tranverse matching for this module . In addition an empty cavity is included as a monitor area, between the transition module and the accelerator proper. Its effects on the z-plane match is also estimated.

The coupled cavity synthesis program (DISKZ) defines quadrupole FODO laws, within the stability region for the beam transport, and transverse input matches are studied , for 3 different phase advance FODO distributions.

Space charge and non-linear emittance blowups for the three cases are monitored, to verify non-resonant transimission of the transverse phase space through the 116-400 Mev linac structure used here for the analysis.
Beam currents of 50 ma. are simulated, assuming the intial 200 MHz bunch population (ie every fourth 805 MHz bucket populated)
A useful transverse acceptance window is defined for the 805 MHz linac, to limit maximum radial beam dimensions, and thus define required 200 MHz tank #5 transverse TWISS parameter range.

FODO transport laws:

I. Design A Transition Module.

This transition design consists of 4 rf cavities, plus an empty cavity, used for a diagnostic center. The fodo quad spacing (1.2 METERS) corresponds to the 11-cell cavity separated by 3-cell bridge couplers.
Transition module quad settings are simply a smooth merge with the accelerating module transverse phase advance.

The FODO channel carrying the beam through a 45 cavity 805MhZ linac is defined during the linac synthesis, by setting up three phase advance laws, two near the mimimum 'beta' function (minimum TWISS beta in F/2-D-F/2 cell matrix) typically near 80 degrees, neglecting space charge and the third at the lowest useful phase advance without excessive TWISS betas, taken as 45 degrees here.

Thus the phase advance quad laws were:

i. (dphix, dphiy) = 60 ->70 degrees
ii. (dphix, dphiy) = 70 ->80 degrees
iii. (dphix, dphiy) = 45 ->53 degrees

without space charge. The net phase advance is typically 10% lower, at 50 ma. of space charge, for the beam conditions studied here.

The same phase advance was used in both planes, with A 10 degree increase through the 116 - 400 mev acceleration process. Such a phase advance distribution was used to reduce the matched beta functions slowly so that, together with adiabatic damping, the transverse beam dimensions could be reduced in the 2nd half of the 805 MhZ linac, hopefully to allow the rf structure design to exploit this feature with smaller bore radii in the 200- 400 Mev cavities.
In addition, because the synchrotron phase advance (per fodo cell) drops, from kinematics, resonant z-t phase relations could be easily avoided, since the z-plane phase advance would be decreasing, while the t-plane would be increasing.

Test I: Fodo at 45-53 degrees phase advance.

Using a 50 ma. beam, three estimates of transverse emittance growth were simulated for (a) a mismatched z-plane , rough tuned transverse plane,
(b) a matched z-plane , rough tuned transverse plane,
(c) a matched z-plane , fine tuned transverse plane,

Table-A- summarizes these results. It is seen that substantial transverse emittance growth occurrs, even for a well matched tune for this choice of transverse phase advance.

TABLE A. Transverse Emittance Growth for FODO = 45-53 degrees phase advance.

z-plane	t-plane	x-growth	y-growth	z-growth
match	rough q-law (x-plane mistuned)	39%	17%	6%
mismatch	fine tuned	39%	32%	7%
match	fine tuned	21%	25%	3%

Test II. Fodo laws near beta minimum.

Two Fodo quad laws are shown in tables B. and C, that are chosen near the minimum TWISS beta, using the half cell splicing algorithm used by DISKZ, to approximate the required quad tune. Emittance damping and space charge are neglected in the raw 'quad law' algorithm ; however, different phase advances (split tunes) in the x-y planes can be requested via the parameters TFADX, TFADY. The 'tilting' of this tune is accomplished by the 'QUPS' parameter, which sets the per cent ramp per momentum interval, for the desired quad law parameter (defined in input momentum units) as:

thus: dk/k = 100.*QUPS *d (bg)/(bgin)

= fractional change in the 'tilted' parameter over the system momentum swing (bgout - bgin)

The raw quadrupole gradients, produced by 'DISKZ', are tuned by the 'TRACEX' linear tuning program, to include space charge and momentum damping. Figure I shows the resulting shape oscillations for the current MCC tank#5 transverse beam output, before any TRACEX tuning- ie. using only the raw quad law tunes, including an accidental match in the x-plane with the raw tune values, at the transition from 9 to 11 cell cavities, beam energy of 200 Mev. Such an accidental match implies that the raw quad law tunes are good approximations for a matched beam transport channel, that involves rf defocusing, acceleration, (ie momentum damping) space charge and non uniform FODO lens spacings. Local fine TRACEX tuning using only 3 quads in the transition module, and 4 in the region of cavities 22-24, achieves a well matched beam, but requires a large radial excursion in the transition module to achieve downstream matching, using the MCC beam model.

Because such a transverse excursion might be cause excessive emittance growth, due to the rapid bunch size change in the transition module, transverse input ellipses were assumed upright, as required for for smooth entry in the FODO Channel. This requires tank #5 quadrupole tuning to create this transverse condition.

The approach to transverse beam matching is proposed below, implying a well-defined acceptance window should be created for the 805 MHz system, which does not allow large radial excursions to exist- thus ensuring maximum radial beam dimensions, within a well defined input beam TWISS range.

FODO Acceptance window: Design A.

For a given raw 'quad law' the 'FODO' input acceptance is first scanned, with TRACEX space charge, by defining the input beta range that transports beams within a limited shape (beta) amplitude excursion, typically 8 -10 mm 95% total beam envelope, including the shape oscillations-using the raw 'quad law' gradients generated by DISKZ. The resulting beta acceptance range thus defines the required tuning range needed from the 200 MHz tank #5 FODO lattice.

Table D shows the defined beta acceptance ranges, for both planes, assuming upright ellipses (alpha=0.)are present at the FODO entrance, using only the raw quad law (60 -->>70 deg. phase advance). Shape oscillations are kept to 8-9 mms radius for the x-y planes, within this acceptance window.

After a TRACEX tuning, involving the transition module and 4 quads at cavities 22-24, the shape oscillations are reduced, with resulting radial envelopes of 5-6 mm, as shown in figure II. A second scan, over the same acceptance window with this TRACEX tuned FODO channel indicated that the acceptance window was increased by about 25% in beta (betax= 1.8-> 5.0). Thus, the operational tune-up procedure for the FODO quad law used here appears to be simple- since the splicing of the 200 MHz quad period (.67meters) to the 1.2 meter 805 MHz quad period is defined by the large beta acceptance window delineated in this study. Both quad phase advance laws indicated similarly large beta acceptance ranges.

TABLE D. TWISS BETA ACCEPTANCES (FODO)
for 8-9 MM RADIUS BEAM ENVELOPE
(95%) LIMIT (DESIGN A.)
(matched envelope range= 6-7 mm)

Quad law	beam	*twiss beta acceptance(meter)		
60-70 deg	50ma.	2.0	- 4.8	bx- raw.tune
60-70 deg	50ma.	0.8	- 2.2	by- raw.tune
70-80 deg	50 ma.	1.8	- 4.4	bx-raw.tune
70-80 deg	50 ma.	1.0	- 2.6	by-raw.tune

* TRACEX fine tunes produced 25% increases in the above TWISS beta ranges, for the same 8-9 mm envelope radius limit.

Emittance Growth Studies.(Design A.)

Non-linear space charge and coupling effects were checked by 1000 particle samples using the DDYNZ dynamics code,using the same linac synthesis data files as TRACEX. The actual beam envelopes are 95% cuttoffs of the original 5xsigma emittances, and so represent the 85% cuttoff of the tank #5 phase spaces.

Initial phase space distributions were uniform 3D charge density, so that only tune perturbations would create charge non-uniformities.
Figures IV and V show the effect of slight mismatches on the y-emittance growth for the 60-70 degree tunes.

A mismatched beam, with alpha=2.0, was simulated with resulting transverse shape oscillations reaching 10 -12 mm (or 13 - 15mm for the 95% envelope)radially. The transverse emittance growth, shown in figures vii and ix_ indicated emittance blowup of 1.3 to 2.0 for this extreme case, for the 50 ma. beam.

Little transverse growth is seen, with tunes within the beta acceptance window, even with raw tuned quad laws.

II. Design B. (6 - 9cell transition cavities)

In this design, the transition module consists of 5 rf cavities plus an empty cavity (diagnostic station). The fodo spacing and phase advance (3 fodo cells), provides a 0.9 meter interquad spacing, and a 180 degree phase advance. Thus the input beam is imaged again (transversely) in the diagnostic 6th empty cavity, to provide simple data for the tank #5 output optics monitoring.

Design B. Study of Emittance growth Sources.

Design B. was set up, with a 66deg. phase advance raw quad law to provide 3x60 degress of 50 ma. space charge depressed phase advance. Figure __ shows the TRACEX beam envelopes, for (betax, betay) of (6.0, 1.0) meters, and raw quad law of 66-73 degress. 3 transition and 2 mid energy quads were fine tuned, to provide this quiet envelope.

The transverse emittance growth is less than 1-2%. Mismatched beams, with alphas of 1.0 - 2.0, were placed into the design B. fodo channel, to monitor the emittance growth dependence on the channel mismatch. Even with severe mismatch (alpha=1.0), emittance growths were typically 6-12 %, while severe mismatches (alpha=2.0), produced growths of 20-25%, much lower than those seen in the design A transition module.

Particle simulations with no space charge for the same mismatched input beams, indicated that the non-linear longitudinal to transverse coupling (from quad chromatics, and phase dependent rf defocusing) were the dominant local transverse emittance dilution sources. However, the z-t coupling effects were being cancelled, to first order, because the local synchrotron frequency is close to the betatron frequency, and reverses (in 180 degrees) the z-t coupling effects, with a resulting 1st order cancellation of the phase space dilution.
The addition of 50 ma. of space charge to the overall phase space growth showed little additional dilution, even at these large mismatch conditions.

Conclusions.

The synthesis of this linac, involving 45 coupled cavity 805Mhz structures indicated that the quadrupole FODO transport design could provide reasonably well behaved tranverse beam optics, including non=linear and space charge effects.

By defining an acceptance FODO window, it is clear that beam radii of 6-8 mm are stably available for this design, based on the present knowledge of the 200 MHz tank #5 beam output.

Particle simulations, with 1000 particle samples indicated that:

a. transverse emittance blowups of typicaly 25% were predicted for the 45-53 degree FODO law, under mildy mismatched conditions.(figure X)

b. low (1-2 %) transverse emittance blowups were available for the 60 - 70 degree FODO laws, with small sensitivity to both z- and t- plane mismatches.

Previous emittance growth studies, indicate that for large tune depressions, (75% or greater) phase advance should be held below 60 degrees (uncharged tune). However, at the current space charge conditions (10% tune depression), the 60 - 70 degree phase advance laws appear to be useful, since they appear to have less sensitivity to emittance growth from transverse mismatched beams,while providing smaller twiss betas in the fodo channel. Presumably the z-t coupling is cancelled by selecting this fodo tune range.

c. A transition module design B. consisting of five 9.cell cavities, and tuned to 180 degress of FODO phase advance gave low transverse emittance dilution, even for high TWiss mismatches.

d. Operating the transition module at -32 degrees phase advance produces about 5-% z-plane dilution, from the non-linear bucket motion.

e. Input energy error can produce z-plane dilution, from excursions in the small transition module bucket. This is shown in figure _XI_, indicating that input beam energy must be kept to with in 0.2 Mev of the design figure (116.54 Mev)

The transition module has the smallest constraining bucket for a 'pure bunching' mode, and thus is most sensitive to the input energy error.

The actual z-plane rms emittance growth for a 0.8 mev input energy error is shown in figure XII, The resulting bunch shape oscillations are seen in figure XIII.

Summary.

Transverse emittance growth can be controlled by selective FODO and z-plane tune design.

In all cases studied here, z-plane emittance growth was held below 10%, matched, and 15%, for a 50% z-plane beta mismatch in the transition module, (assuming correct input energy)

Further 200 MHz parmila simulations should delineate the tank #5 FODO retuning requirements to produce the 805MHz system acceptance matching.

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lwo.may.24.88.

References.

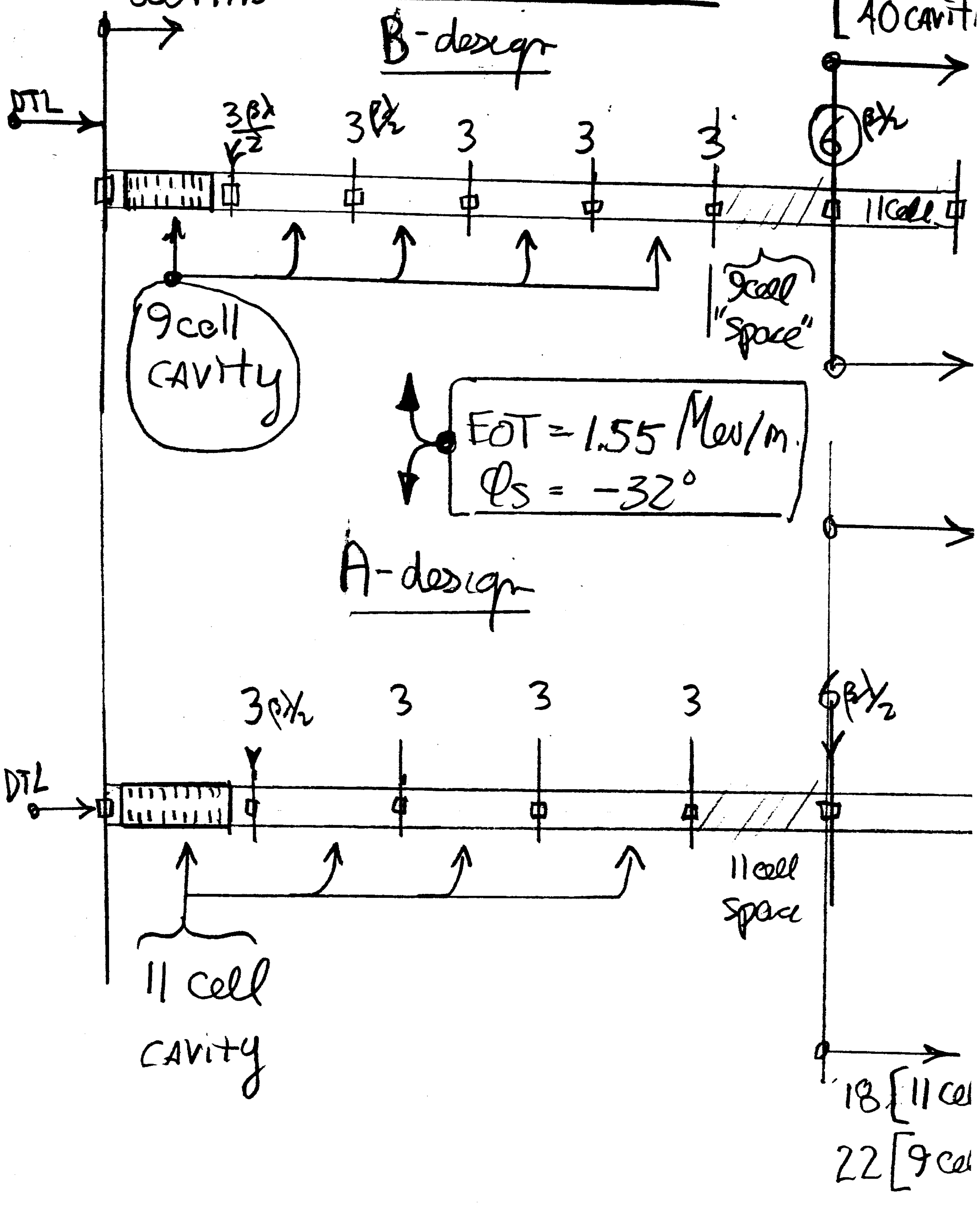
1. R.A. JAMESON, Proceedings of 1983 Fermi Accelerator Conference, p497.
2. E.McCrory,Private communication,(Parmila study of Fermilab linac tank#5 beam output)
3. J.A.MacLachlan, Evolution of the 400 Mev Linac design. Fermilab TM -1503.

____tm31=file__________

.........apr.1.88.

11.49.13.UCLP, GG, TB11, 0.494KLNS. ** END OF LISTING **

TRANSITION MODULES:



Input to Linac synthesis code

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[illegible]=0.5,  [illegible]=1.,  [illegible]
SYNSP=140.,  [illegible]=400.,  [illegible]
DCMA=50.,[illegible]=1.,  [illegible]
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$REXION NC=11, [illegible]        EZ=7.[illegible]
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$REXION NC=11, NTAX=6.           EZ=7.00,PHIS=-[illegible], [illegible]
$REXION NC=9,  NTAX=6.        EZ=7.00,PHIS=-26.,[illegible]=4., [illegible]
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$DESIGN NREC=0  $END
1-DISKZ. (MAR. 3. 88. ).....EXECUTING------->>>
```

Thim (425) 2?8-721.5

(20) ->

45 cavity linac r.f Table

- energies
- EoT's
- cavity ΔL's
- bridge ΔL's
- Syn. phase's
- power/module

```
$DESIGN.GLOBALS------->
    FREQ= 808.0MHZ, WIN= 116.540MEV
 QBION =    1.000 BCMA= 50.000 MA.
MODE= 0 KBUX= 4 LATTO=  1
 GLDEG.IN=      8.000
 NT  NC  LENGTH  TOTL L  ENERGY   EOT   EZ     PHID     BRIDG   NBRIDE  RSPACE  CE
  1  11   93.79   119.4  117.78 1.550  1.550 -32.093  25.637  3      .00  8.524
  2  11   94.21   239.4  119.03 1.550  1.550 -32.093  25.750  3      .00  8.564
  3  11   94.62   359.9  120.28 1.550  1.550 -32.092  25.863  3      .00  8.602
  4  11   95.04   480.9  121.54 1.550  1.550 -32.091  25.975  3      .00  8.639
  5  11   95.24   628.1  121.54  .000   .000 -90.000  51.949  0     6.00  8.658
   ...END KLYSTRON MODULE       #     1
 TOTAL POWER(PWALL+PBEAM) MOD #    1=    .431MW

  6  11   96.19   750.8  127.44 7.000  7.000 -32.054  26.490  3      .00  8.744
  7  11   98.06   875.8  133.45 7.000  7.000 -32.052  26.995  3      .00  8.914
  8  11   99.90  1003.2  139.57 7.000  7.000 -32.051  27.492  3      .00  9.081
  9  11  101.70  1132.9  145.79 7.000  7.000 -32.050  27.980  3      .00  9.245
 10  11  103.47 .1264.8  152.11 7.000  7.000 -32.049  28.459  3      .00  9.406
 11  11  105.21  1418.2  158.53 7.000  7.000 -32.047  48.215  0     5.00  9.564
   ...END KLYSTRON MODULE       #     2
 TOTAL POWER(PWALL+PBEAM) MOD #    2=   7.773MW

 12  11  106.94  1554.6  165.18 7.000  7.000 -30.044  29.399  3      .00  9.721
 13  11  108.65  1693.1  171.93 7.000  7.000 -30.042  29.861  3      .00  9.877
 14  11  110.32  1833.7  178.78 7.000  7.000 -30.041  30.314  3      .00 10.029
 15  11  111.97  1976.4  185.72 7.000  7.000 -30.040  30.758  3      .00 10.178
 16  11  113.58  2121.2  192.76 7.000  7.000 -30.039  31.193  3      .00 10.325
 17  11  115.16  2289.1  199.90 7.000  7.000 -30.038  52.701  0     5.00 10.469
   ...END KLYSTRON MODULE       #     3
 TOTAL POWER(PWALL+PBEAM) MOD #    3=   8.600MW

 18  11  116.73  2437.9  207.25 7.000  7.000 -28.034  32.047  3      .00 10.611
 19  11  118.27  2588.6  214.70 7.000  7.000 -28.033  32.465  3      .00 10.752
 20  11  119.79  2741.3  222.24 7.000  7.000 -28.031  32.875  3      .00 10.890
 21  11  121.28  2895.8  229.87 7.000  7.000 -28.030  33.276  3      .00 11.025
 22  11  122.74  3052.2  237.59 7.000  7.000 -28.029  33.670  3      .00 11.157
 23  11  124.17  3233.2  245.39 7.000  7.000 -28.028  56.759  0     5.00 11.287
   ...END KLYSTRON MODULE       #     4
 TOTAL POWER(PWALL+PBEAM) MOD #    4=   9.360MW

 24   9  102.64  3370.2  251.92 7.000  7.000 -26.067  34.369  3      .00 11.404
 25   9  103.57  3508.4  258.50 7.000  7.000 -26.064  34.676  3      .00 11.507
 26   9  104.49  3647.9  265.13 7.000  7.000 -26.060  34.979  3      .00 11.609
 27   9  105.39  3788.5  271.82 7.000  7.000 -26.057  35.277  3      .00 11.709
 28   9  106.27  3930.4  278.57 7.000  7.000 -26.054  35.570  3      .00 11.808
 29   9  107.14  4085.3  285.37 7.000  7.000 -26.052  47.811  0     4.00 11.904
   ...END KLYSTRON MODULE       #     5
 TOTAL POWER(PWALL+PBEAM) MOD #    5=   8.168MW

 30   9  108.00  4229.5  292.22 7.000  7.000 -26.049  36.141  3      .00 12.000
 31   9  108.84  4374.7  299.13 7.000  7.000 -26.046  36.419  3      .00 12.093
 32   9  109.67  4521.1  306.09 7.000  7.000 -26.044  36.693  3      .00 12.185
 33   9  110.48  4668.5  313.10 7.000  7.000 -26.041  36.962  3      .00 12.276
 34   9  111.28  4817.0  320.15 7.000  7.000 -26.038  37.226  3      .00 12.364
 35   9  112.07  4979.1  327.26 7.000  7.000 -26.036  49.982  0     4.00 12.452
   ...END KLYSTRON MODULE       #     6
 TOTAL POWER(PWALL+PBEAM) MOD #    6=   8.566MW

 36   9  112.84  5129.7  334.41 7.000  7.000 -26.033  37.742  3      .00 12.538
 37   9  113.60  5281.3  341.61 7.000  7.000 -26.031  37.993  3      .00 12.622
 38   9  114.35  5433.9  348.86 7.000  7.000 -26.029  38.240  3      .00 12.705
 39   9  115.09  5587.4  356.15 7.000  7.000 -26.027  38.483  3      .00 12.787
 40   9  115.81  5754.9  363.49 7.000  7.000 -26.025  51.629  0     4.00 12.867
   ...END KLYSTRON MODULE       #     7
 TOTAL POWER(PWALL+PBEAM) MOD #    7=   7.414MW

 41   9  116.52  5910.4  370.87 7.000  7.000 -26.023  38.957  3      .00 12.946
 42   9  117.22  6066.8  378.29 7.000  7.000 -26.021  39.187  3      .00 13.024
 43   9  117.90  6224.1  385.75 7.000  7.000 -26.100  39.414  3      .00 13.100
 44   9  118.58  6382.3  393.26 7.000  7.000 -26.090  39.637  3      .00 13.175
 45   9  119.24  6554.7  400.80 7.000  7.000 -26.080  53.141  0     4.00 13.248
   ...END KLYSTRON MODULE       #     8
 TOTAL POWER(PWALL+PBEAM) MOD #    8=   7.642MW
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DAW31D

z & t plane phase advance / FODO
at 50ma sp.ch

figure

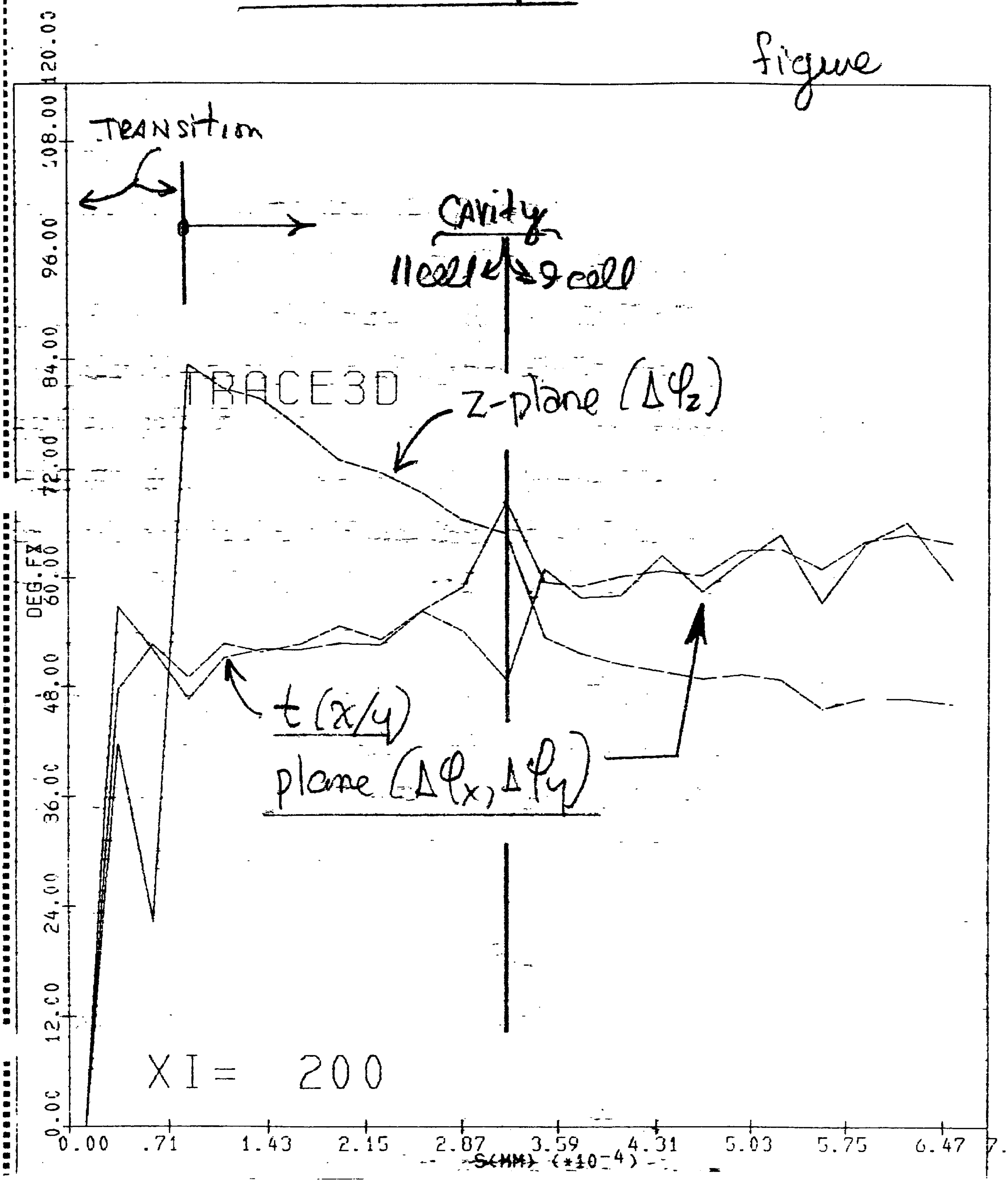


TABLE B.

1 TRANSVERSE LINEAR DYNAMICS
HP1.2..GRADIENTS.SHOWN

QUAD LATTICE -->> LATTG= 1
GLAW= 2.000

NT	XMUT	YMUT	BETAX	BETAY	HP1	HP2	GLA	GLB
1	70.034	70.033	422.025	104.520	2.126	2.138	8.000	8.000
2	70.091	70.091	423.713	105.014	2.129	2.140	8.000	8.000
3	70.149	70.149	425.396	105.509	2.131	2.143	8.000	8.000
4	70.207	70.207	427.073	106.003	2.134	2.145	8.000	8.000
5	70.238	70.238	446.606	121.524	1.798	1.798	8.000	8.000
6	70.256	70.366	578.208	107.561	2.284	2.391	8.000	8.000
7	70.645	70.637	516.370	99.791	2.521	2.579	8.000	8.000
8	70.921	70.913	522.150	101.131	2.525	2.582	8.000	8.000
9	71.195	71.188	527.864	102.500	2.530	2.585	8.000	8.000
10	71.468	71.462	533.507	103.896	2.535	2.590	8.000	8.000
11	71.814	71.748	585.043	110.457	2.409	2.427	8.000	8.000
12	71.964	72.020	583.489	113.233	2.359	2.438	8.000	8.000
13	72.299	72.293	543.668	108.028	2.530	2.582	8.000	8.000
14	72.573	72.568	549.279	109.611	2.539	2.590	8.000	8.000
15	72.847	72.842	554.789	111.209	2.548	2.598	8.000	8.000
16	73.120	73.115	560.196	112.821	2.558	2.608	8.000	8.000
17	73.436	73.391	612.925	121.570	2.428	2.448	8.000	8.000
18	73.644	73.670	611.387	123.561	2.391	2.460	8.000	8.000
19	73.965	73.961	569.526	115.664	2.570	2.618	8.000	8.000
20	74.239	74.236	574.777	117.399	2.583	2.630	8.000	8.000
21	74.532	74.528	579.150	116.964	2.597	2.643	8.000	8.000
22	74.806	74.802	584.195	118.705	2.611	2.657	8.000	8.000
23	75.104	75.071	637.442	129.139	2.474	2.497	8.000	8.000
24	75.314	75.333	534.305	114.602	2.754	2.811	8.000	8.000
25	75.569	75.567	493.265	106.478	2.997	3.039	8.000	8.000
26	75.806	75.805	496.572	106.364	3.014	3.056	8.000	8.000
27	76.029	76.028	500.097	107.796	3.032	3.073	8.000	8.000
28	76.266	76.265	503.317	107.682	3.050	3.091	8.000	8.000
29	76.513	76.501	529.449	111.976	2.955	2.986	8.000	8.000
30	76.724	76.733	532.584	112.322	2.965	3.012	8.000	8.000
31	76.962	76.961	512.962	108.888	3.106	3.147	8.000	8.000
32	77.198	77.196	516.052	108.786	3.126	3.166	8.000	8.000
33	77.420	77.419	519.197	110.197	3.145	3.185	8.000	8.000
34	77.655	77.654	522.197	110.093	3.165	3.205	8.000	8.000
35	77.903	77.893	548.695	113.999	3.066	3.097	8.000	8.000
36	78.115	78.123	551.581	114.457	3.079	3.124	8.000	8.000
37	78.346	78.346	531.026	111.294	3.227	3.266	8.000	8.000
38	78.581	78.580	533.888	111.198	3.248	3.287	8.000	8.000
39	78.815	78.814	536.726	111.107	3.269	3.308	8.000	8.000
40	79.051	79.042	563.487	116.227	3.166	3.196	8.000	8.000
41	79.264	79.271	566.149	116.758	3.181	3.224	8.000	8.000
42	79.503	79.503	544.928	112.306	3.335	3.373	8.000	8.000
43	79.736	79.736	547.699	112.247	3.358	3.396	8.000	8.000
44	79.970	79.969	550.358	112.160	3.381	3.418	8.000	8.000
45	80.207	80.199	577.392	116.889	3.274	3.303	8.000	8.000

1 Z-PLANE+POWER.SUMMARY-->>>

"Raw" Quad Law → (FODO) (No space charge).

TABLE Q.

2 TRANSVERSE LINEAR DYNAMICS

HP1.2..GRADIENTS.SHOWN

Kg/cm (HP1, HP2) — cm (QLA, QLB)

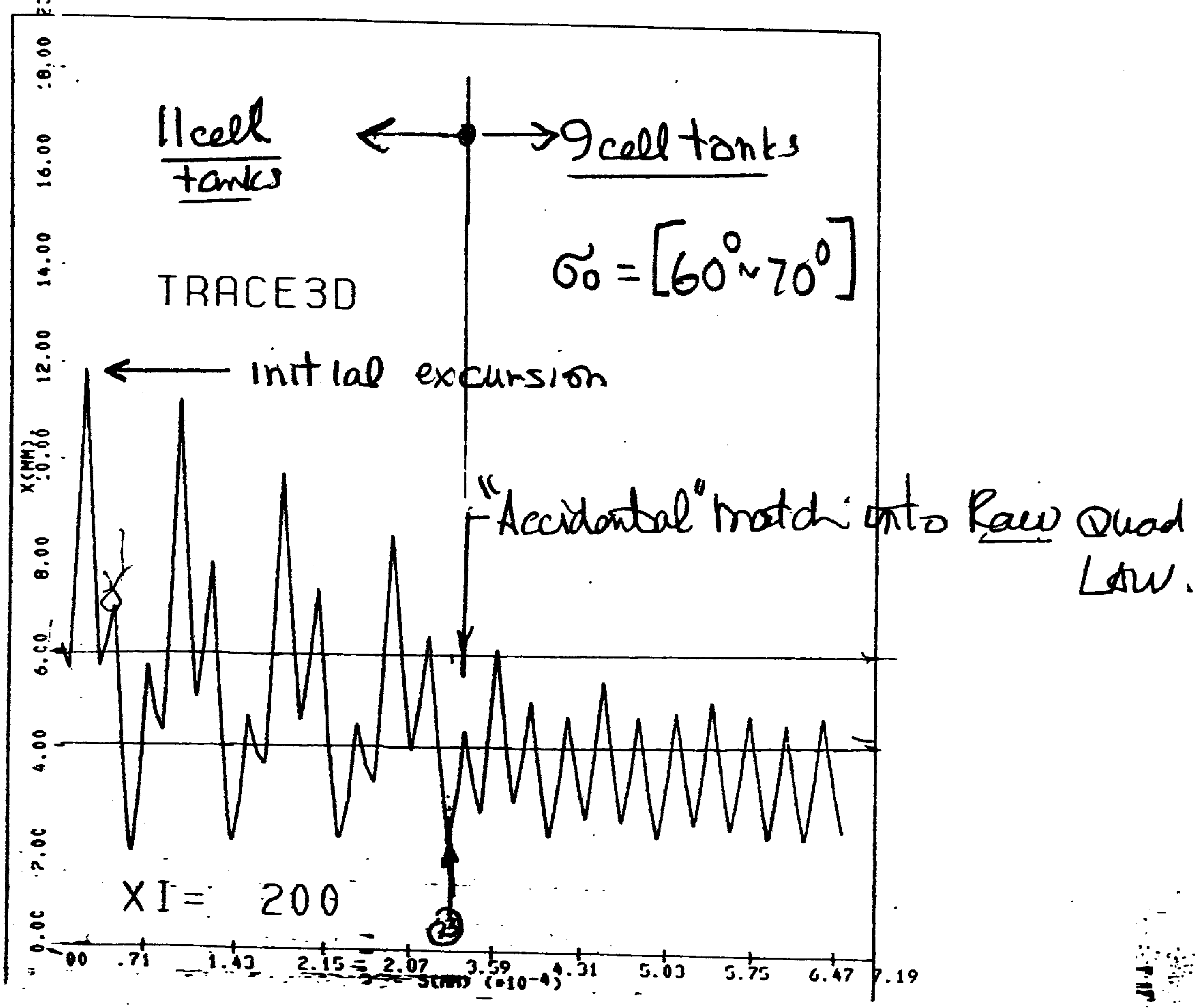
QUAD LATTICE -->> LATTQ= 1

QLAW= 2.000

NT	XMUT	YMUT	BETAX	BETAY	HP1	HP2	QLA	QLB
1	60.039	60.038	439.280	131.768	1.899	1.909	8.000	8.000
2	60.105	60.105	440 975	132.340	1.901	1.911	8.000	8.000
3	60.172	60.171	442.664	132.912	1.903	1.914	8.000	8.000
4	60.238	60.238	444.349	133.483	1.906	1.916	8.000	8.000
5	60.274	60.273	461.514	153.965	1.569	1.569	8.000	8.000
6	60.324	60.426	609.779	133.247	2.133	2.233	8.000	8.000
7	60.747	60.739	541.888	122.843	2.344	2.398	8.000	8.000
8	61.064	61.056	546.516	124.077	2.346	2.399	8.000	8.000
9	61.379	61 371	551.184	125.360	2.349	2.401	8.000	8.000
10	61.673	61.667	559.451	129.628	2.353	2.403	8.000	8.000
11	62.057	61.994	610.471	136.676	2.240	2.256	8.000	8.000
12	62.288	62.293	610.932	142.634	2.187	2.260	8.000	8.000
13	62.629	62.624	564.985	133.104	2.339	2.387	8.000	8.000
14	62.945	62.940	569.967	134.699	2.346	2.393	8.000	8.000
15	63.260	63.255	574.902	136.317	2.354	2.400	8.000	8.000
16	63.574	63.569	579.787	137.956	2.362	2.408	8.000	8.000
17	63.934	63.888	633.125	147.631	2.246	2.264	8.000	8.000
18	64.174	64.194	632.864	152.566	2.207	2.270	8.000	8.000
19	64.527	64.524	587.532	142.795	2.366	2.410	8.000	8.000
20	64.844	64.841	592.489	144.609	2.378	2.422	8.000	8.000
21	65.177	65.173	595.061	143.657	2.391	2.434	8.000	8.000
22	65.492	65.489	599.900	145.485	2.403	2.446	8.000	8.000
23	65.834	65.802	654.648	157.505	2.282	2.302	8.000	8.000
24	66.083	66.106	545.810	139.196	2.517	2.570	8.000	8.000
25	66.363	66.362	504.082	130.822	2.735	2.774	8.000	8.000
26	66.634	66.633	506.555	130.450	2.752	2.791	8.000	8.000
27	66.892	66.891	510.197	132.015	2.769	2.807	8.000	8.000
28	67.162	67.161	512.627	131.653	2.786	2.824	8.000	8.000
29	67.432	67.421	539.290	137.965	2.702	2.730	8.000	8.000
30	67.680	67.688	541.892	138.155	2.712	2.755	8.000	8.000
31	67.958	67.957	520.937	132.516	2.840	2.877	8.000	8.000
32	68.215	68.214	524.316	134.060	2.858	2.895	8.000	8.000
33	68.484	68.483	526.652	133.724	2.877	2.914	8.000	8.000
34	68.752	68.751	528.988	133.402	2.897	2.933	8.000	8.000
35	69.024	69.015	555.550	139.151	2.808	2.836	8.000	8.000
36	69.272	69.279	558.080	139.500	2.821	2.862	8.000	8.000
37	69.544	69.543	536.765	134.303	2.956	2.992	8.000	8.000
38	69.812	69.811	539.035	134.006	2.977	3.012	8.000	8.000
39	70.067	70.067	542.053	135.509	2.997	3.032	8.000	8.000
40	70.340	70.332	568.634	140.880	2.905	2.933	8.000	8.000
41	70.589	70.595	571.054	141.329	2.919	2.960	8.000	8.000
42	70.868	70.868	548.655	134.651	3.061	3.096	8.000	8.000
43	71.123	71.122	551.577	136.166	3.083	3.118	8.000	8.000
44	71.389	71.389	553.692	135.884	3.105	3.140	8.000	8.000
45	71.664	71.657	580.315	140.769	3.010	3.037	8.000	8.000
	$\Delta\varphi_x$	$\Delta\varphi_y$	β_x	β_y	G_1	G_2	QL_1	QL_2
	(degree)		(cm)					

1 Z-PLANE+POWER.SUMMARY-->>>

Figure I



MCC TANK #5 beam into a FODO channel with $\sigma_0 = 60^\circ \rightarrow 70^\circ$ (origin of TRANSITION module radial excursion) figure II DAW31B

Y (rms) beam envelope

FODO ( ) = 60° → 70°

fine tuned quads

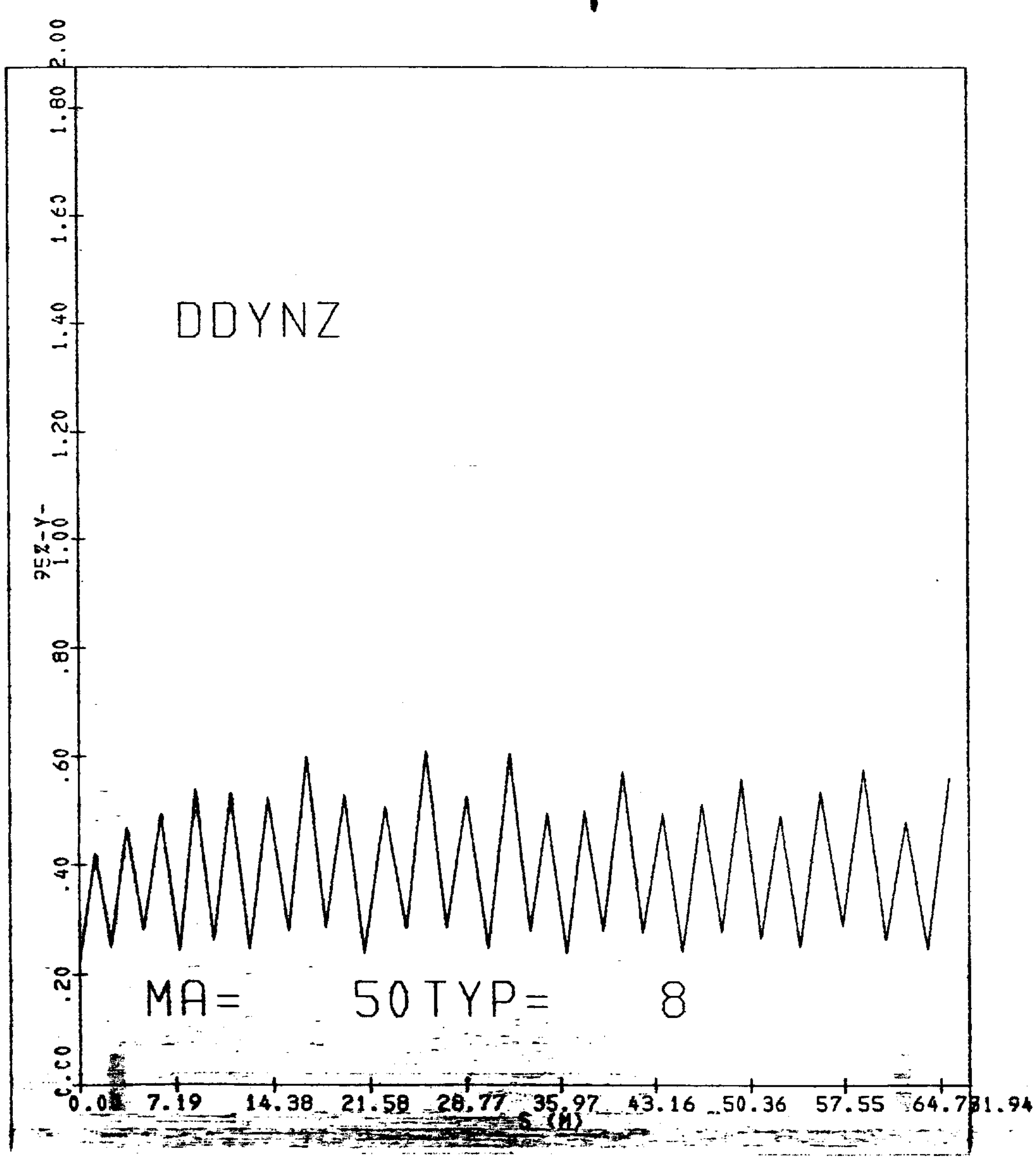
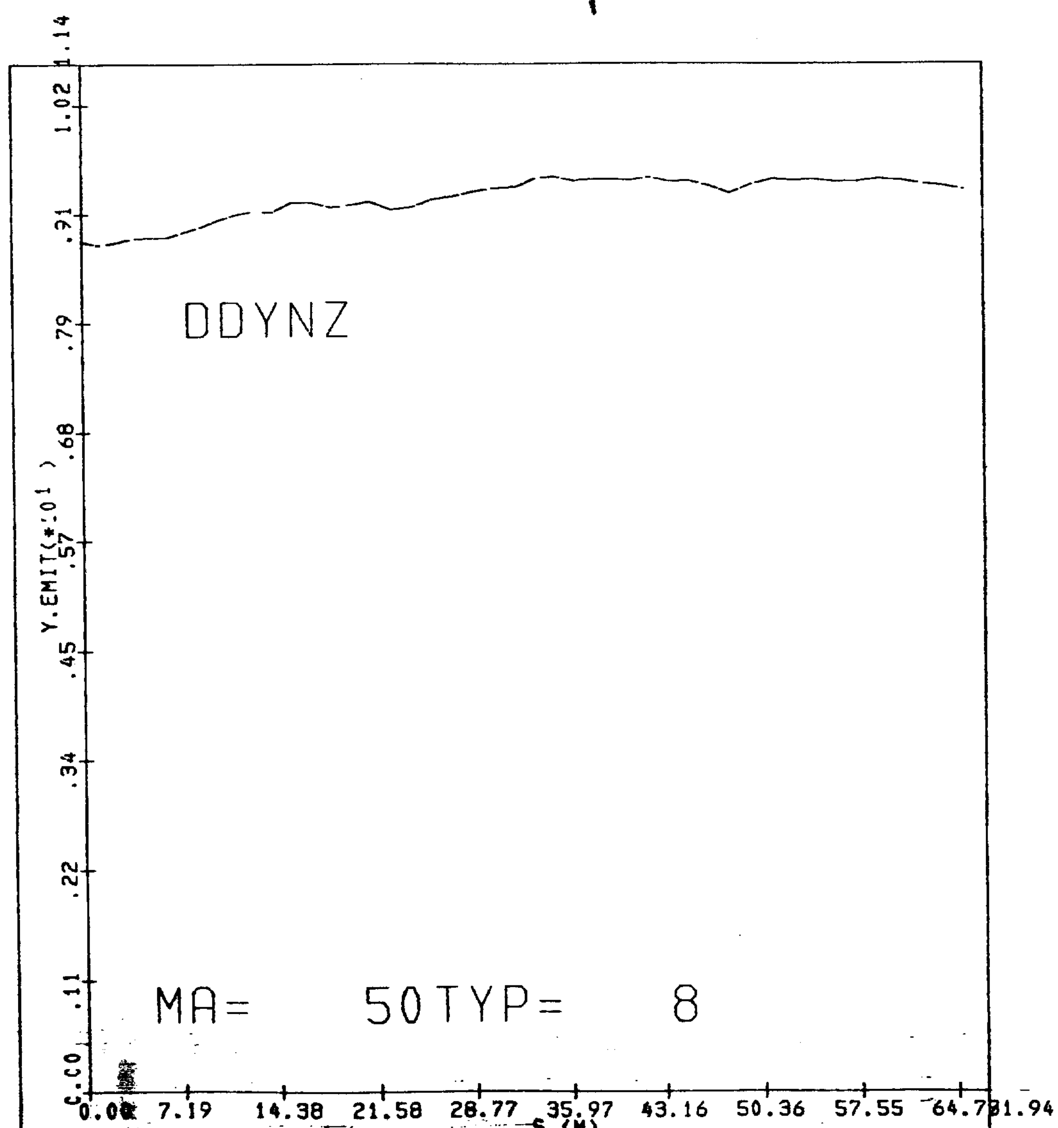


figure III

DAW31B

Ey ([illegible]ms)
FODO (σ_0) = 60° → 70°
fine tuned quads. (no mismatch).

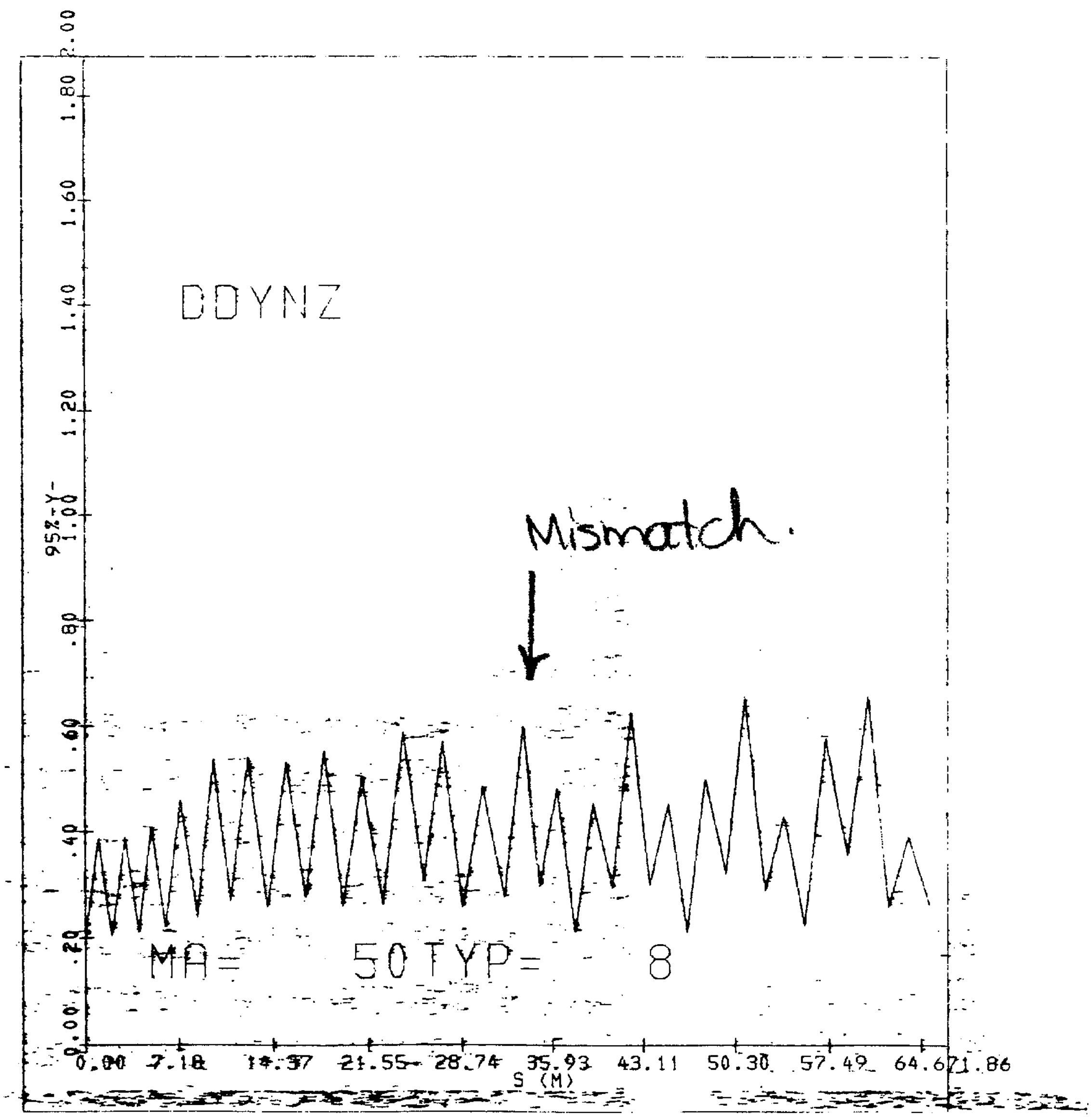


(fig IV)

Y (RMS) beam envelope

FODO (σ_0) = $60^0 \rightarrow 70^0$

y - Mismatch at 33 meters



ε_y (RMS)
FODO(σ_0) = 60° → 70°
Y - Mismatched at 33 meters

fig. V

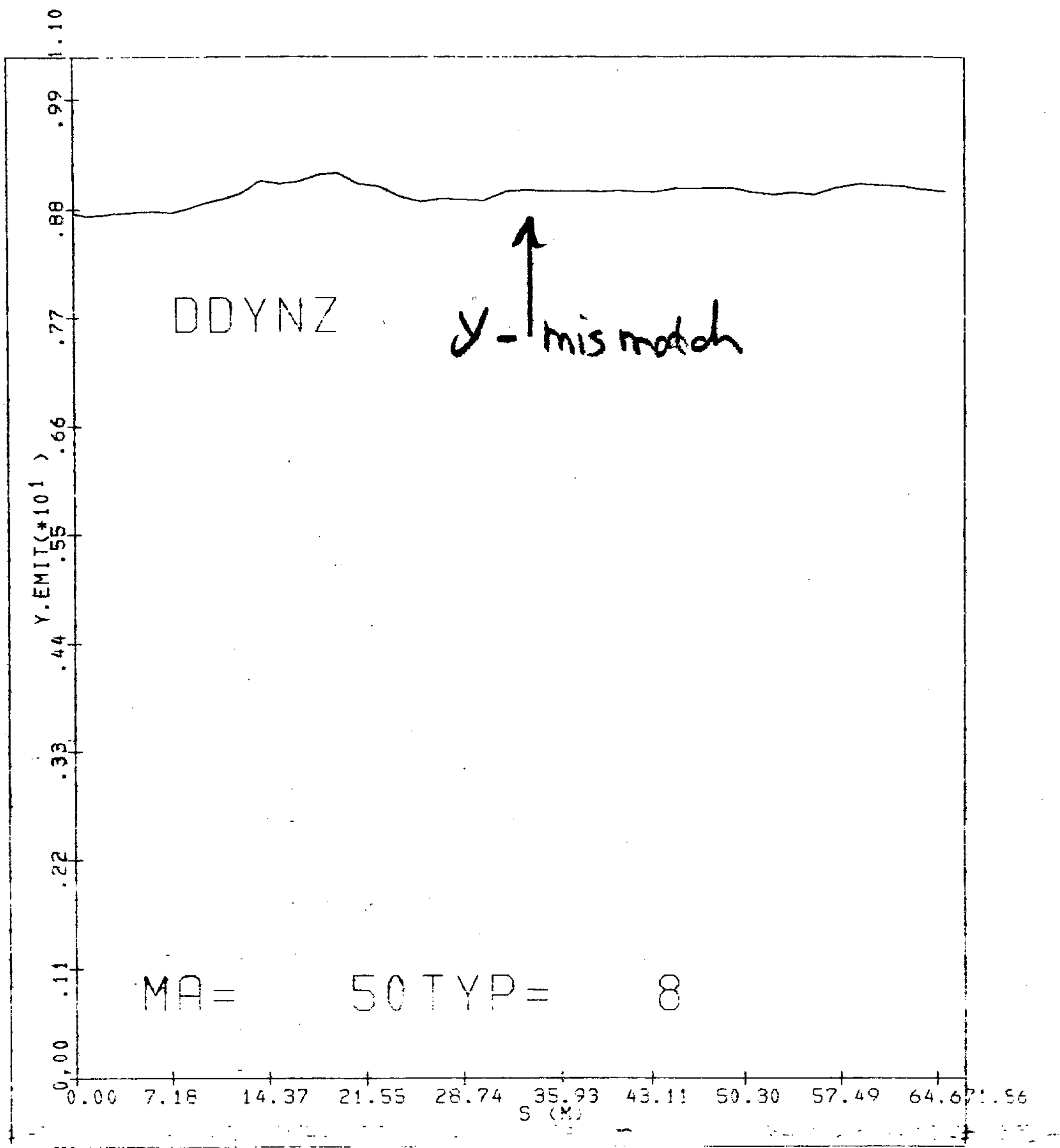


fig VI

DRW 31B

FODO(σ_0) = 60^0-70^0 $(\beta,\alpha)_x$ = (3.0 0.0) (MATCH)

x - Mismatch (α = 2.0)

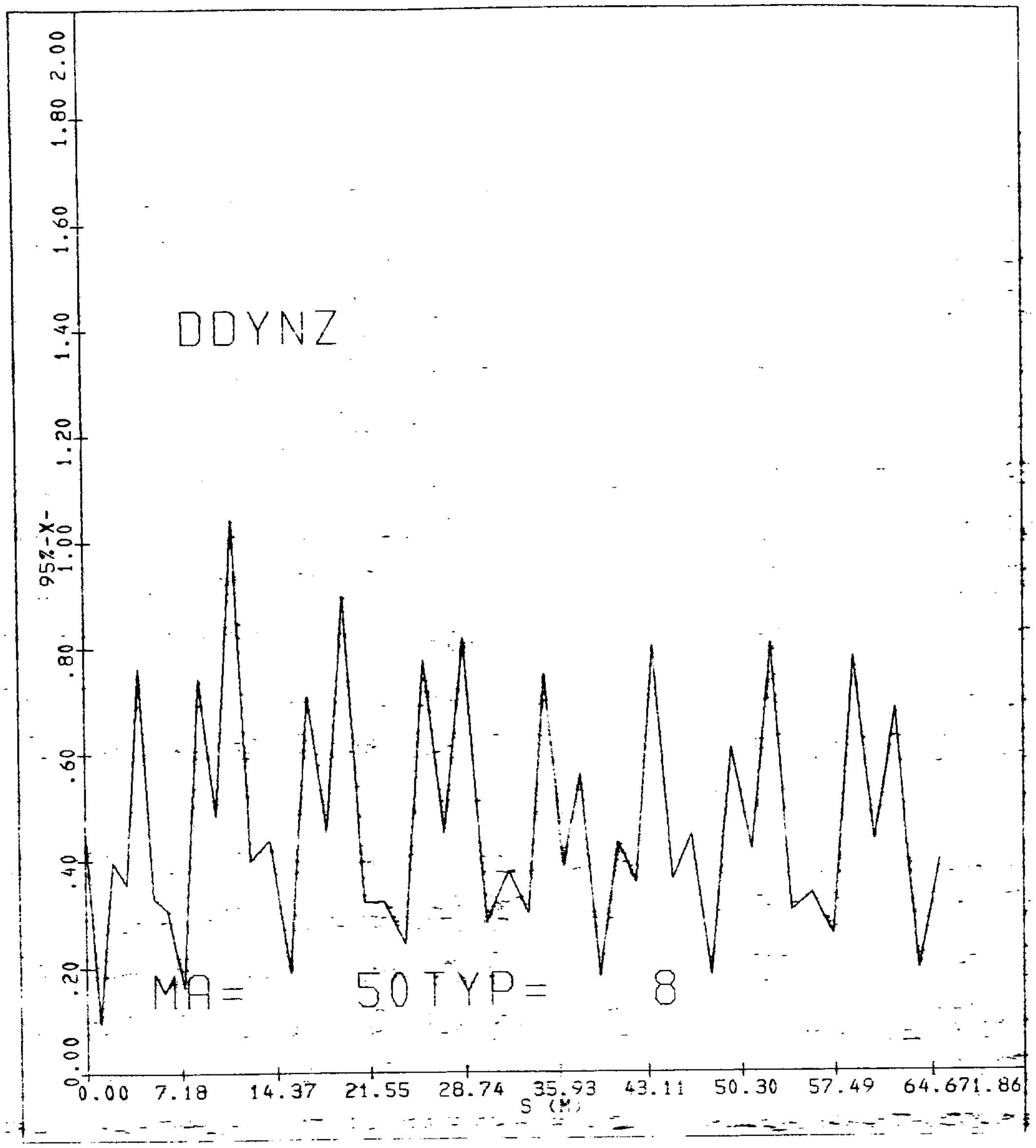
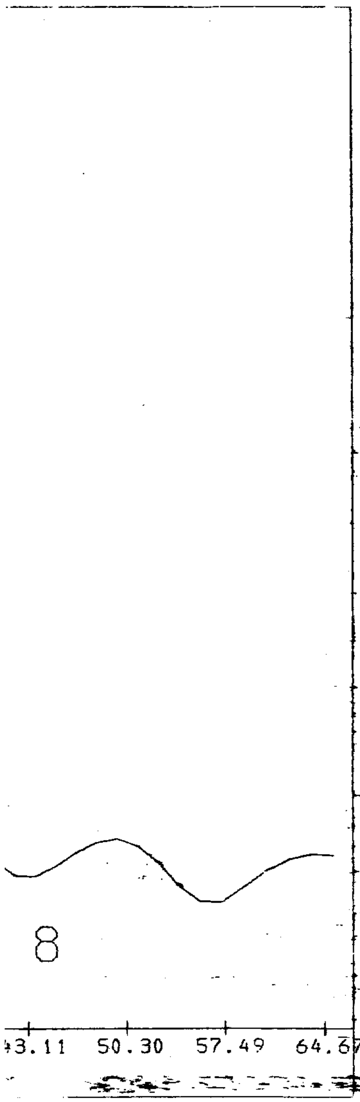


fig VII

DAW31B

ε_x (RMS). growth ($\sigma_0 = 60^\circ - 70^\circ$)

x-mismatch ($\alpha = 2.0$)



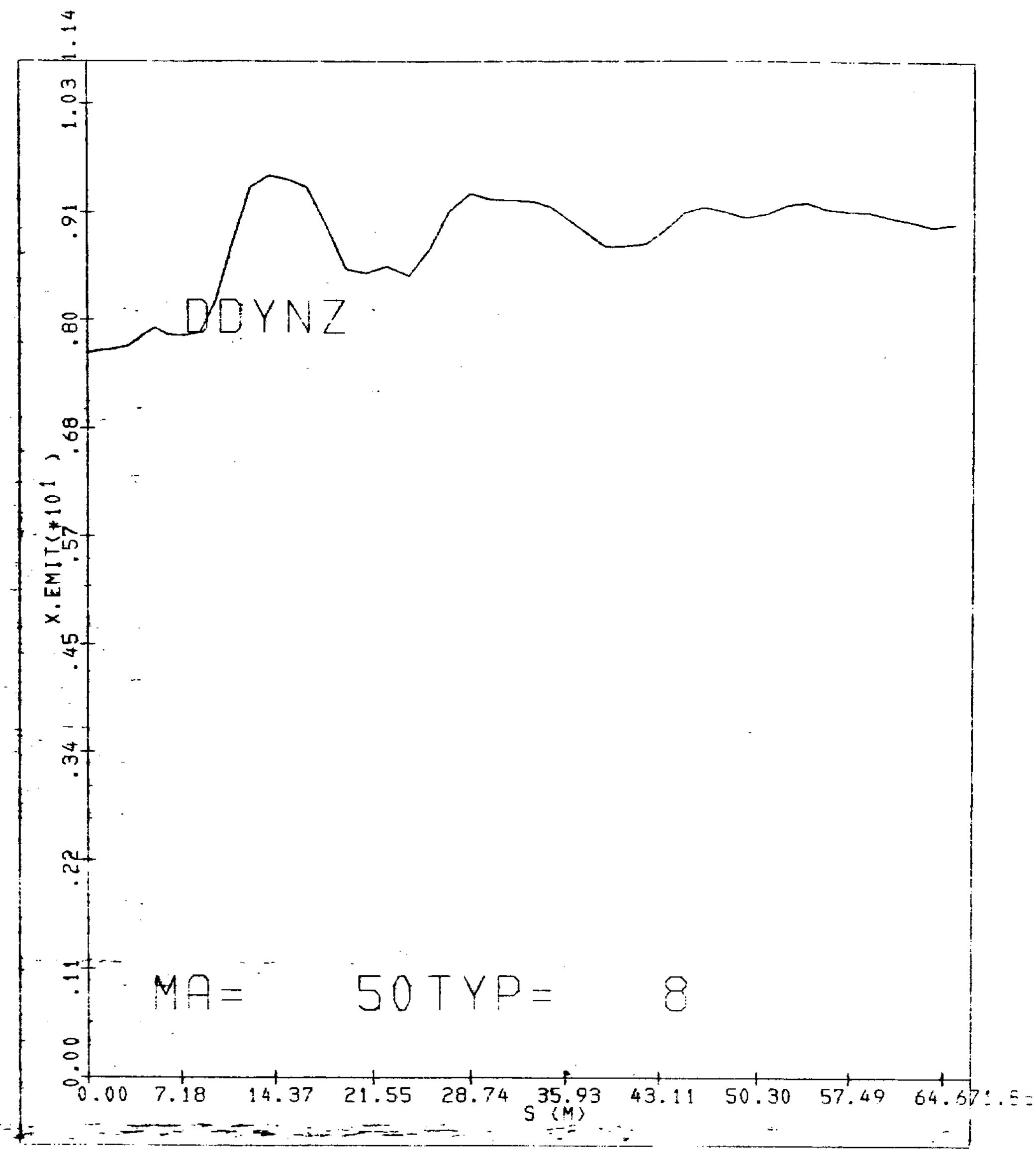
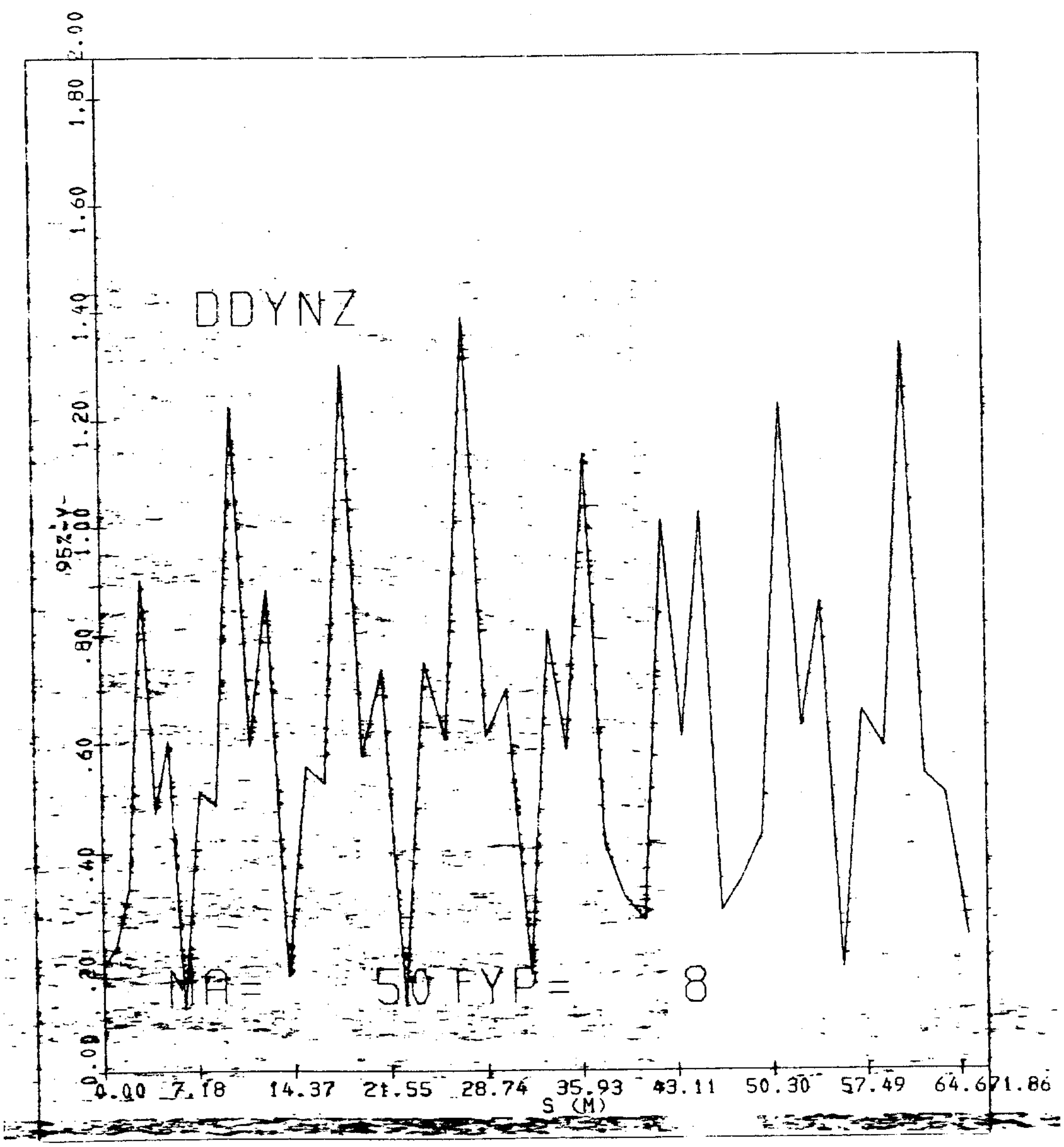


fig VIII

DAW31B

FODO (σ_0) = 60°-70° $(\beta\alpha)_y$ = (1.0, 0.0) Match

y- Mismatch (α = 2.0)



6

DAW31B

(fig 1X) ε_y (rms) growth ($\sigma_0 = 60° - 70°$)

y-mismatch ($\alpha = 2.0$).

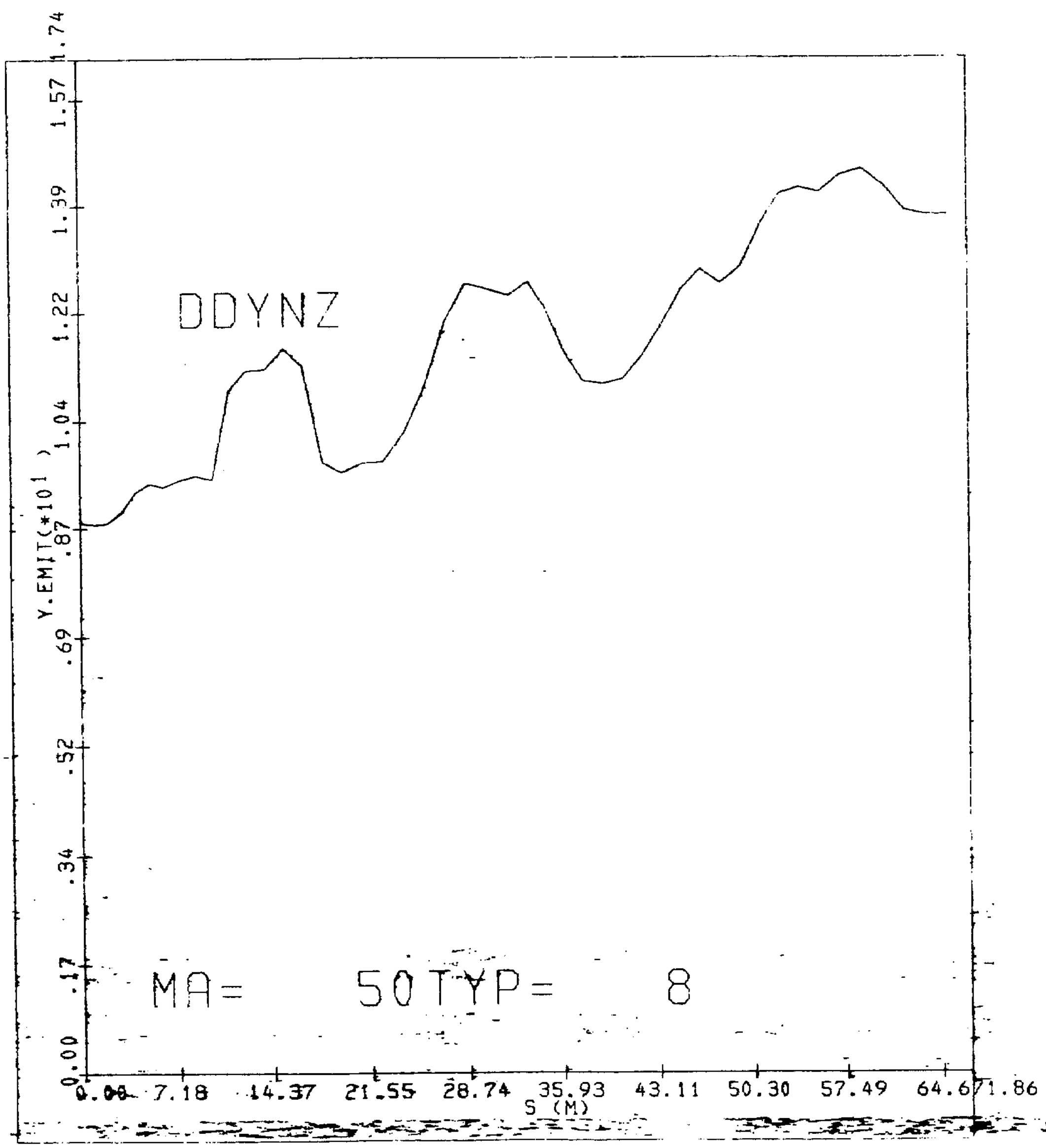
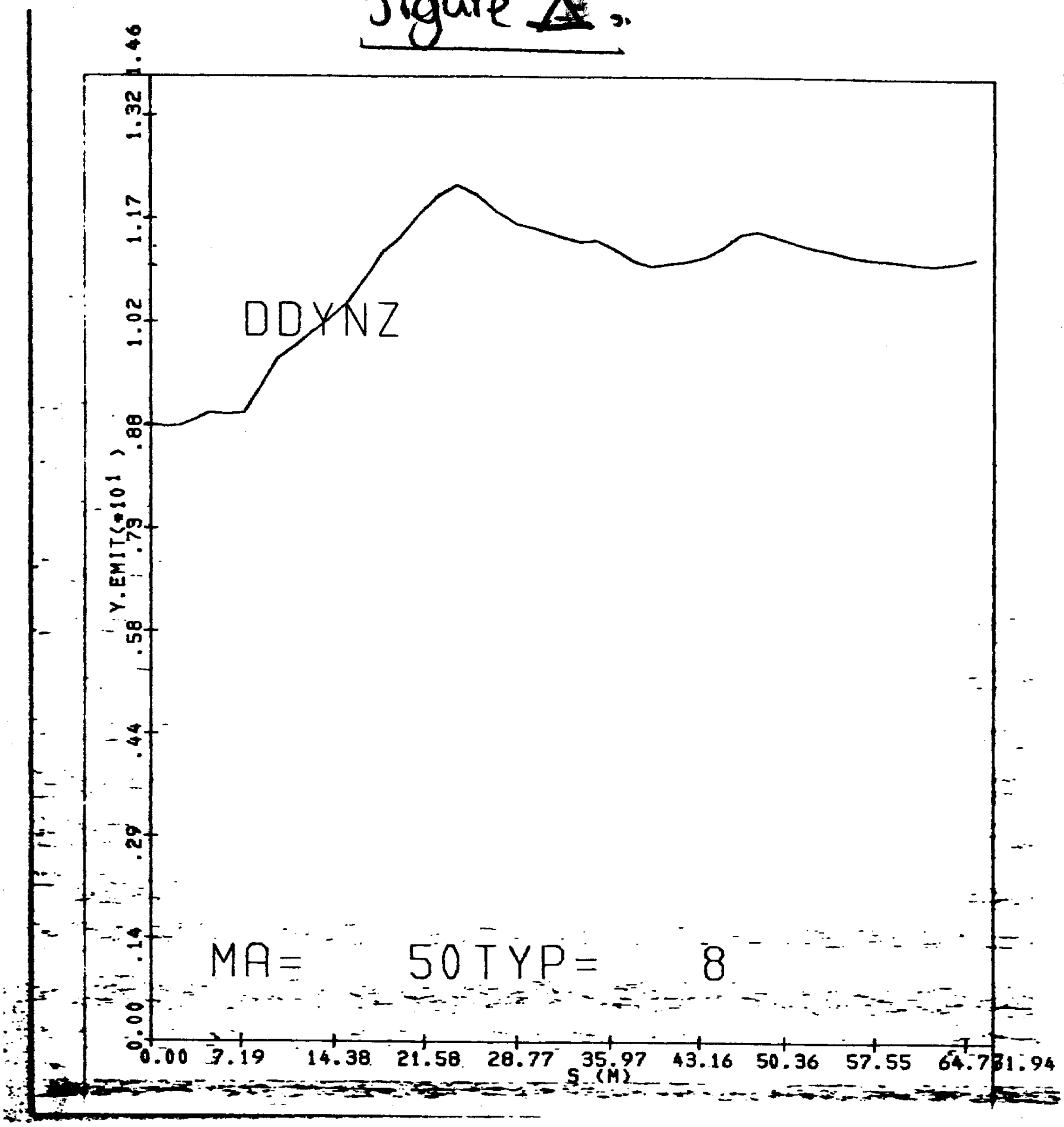


figure X.



y-plane emittance growth (1000 particle)
for fine tuned FODO channel

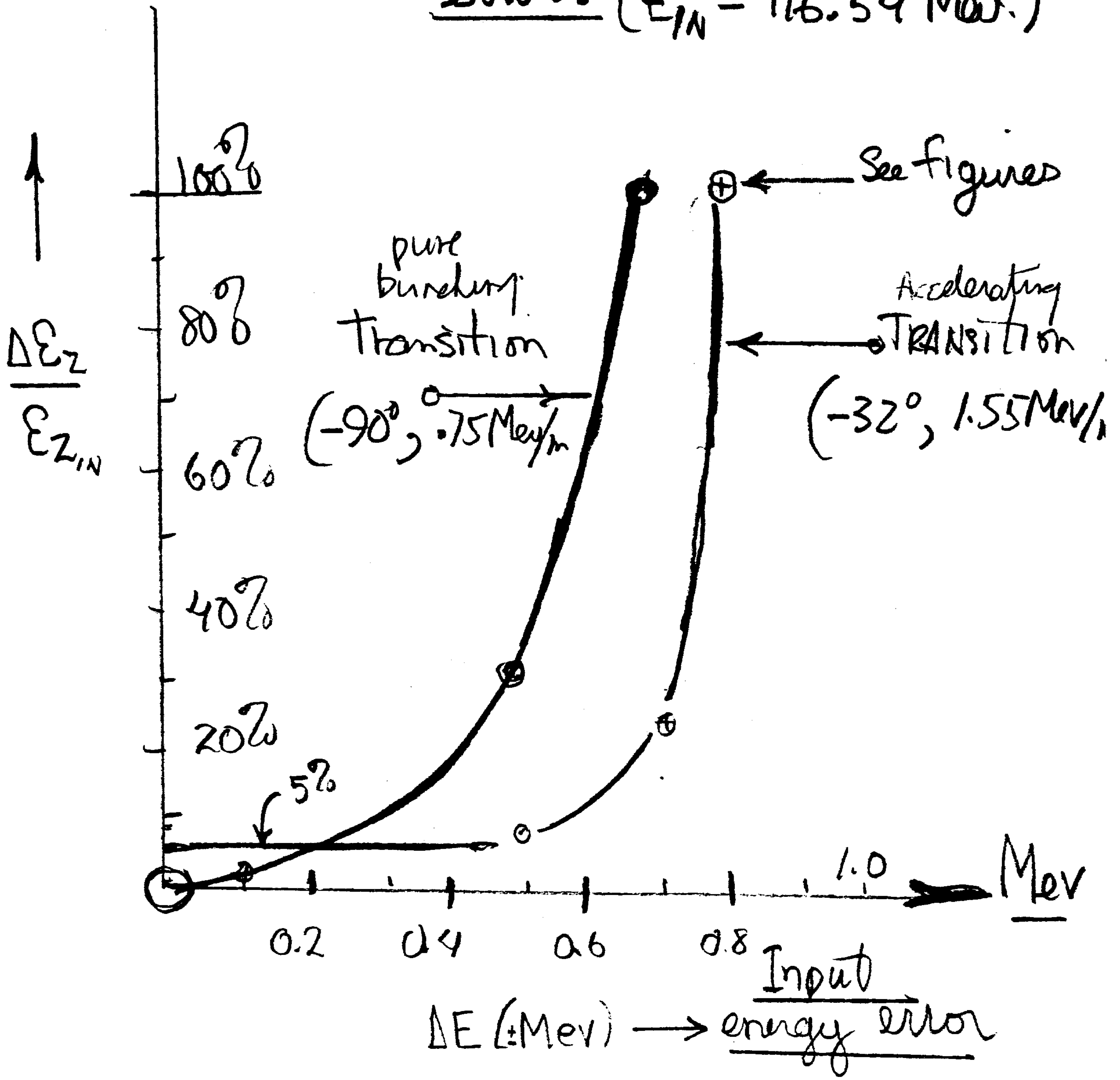
$\Delta\varphi_{x/y} = 45^\circ \rightarrow 53^\circ \ (\sigma_0)$

ε_{oRMS} (NORMALIZED) = .09 π cm.mrad.

$\varepsilon_o(95\%) \simeq 5 \times \varepsilon_o(RMS)$

(fig. XI)

Ez dilution from energy error. (E_{IN} = 116.54 Mev.)



['Bucket' edge dilution from input energy mismatch]

figure

DAW31D.

fig XII E_z (~~[illegible]~~) distribution from 0.8 Mev. input energy error.

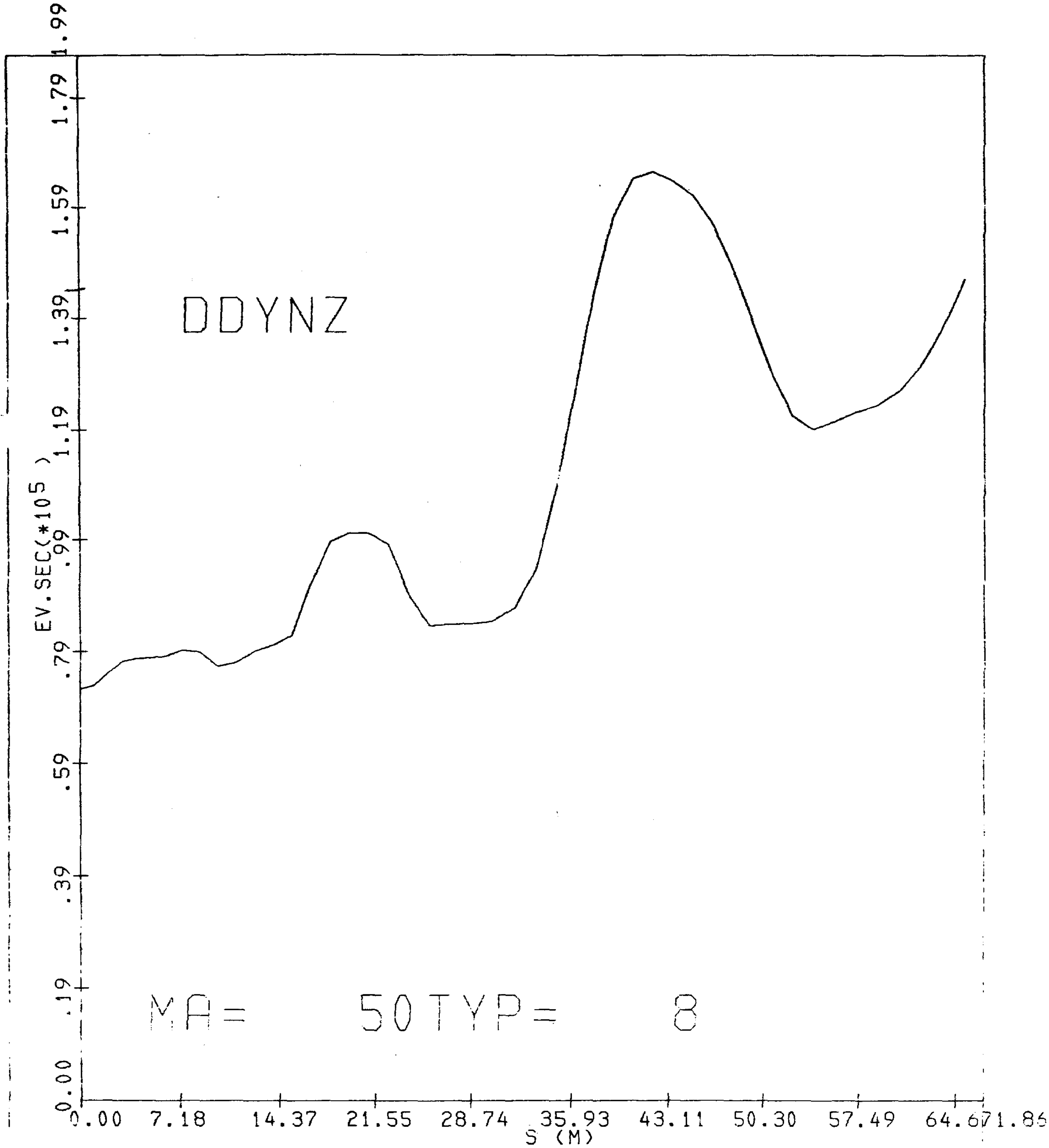


fig XIII Bunch oscillations from 0.8 Mev. energy error

$E_{IN} = (116.54 + .8)$ Mev.