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PS/LEA/Note 87-11
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STUDY OF THE ULTRASLOW EXTRACTION IN LEAR BY TRACKING

J. Bengtsson

1. INTRODUCTION

We study the ultraslow extraction in LEAR by tracking with DIMAT. Due to the introduction of sextupoles for chromaticity correction and excitation of the extraction resonance $3Q_H = 7$, the motion in the two transverse planes are no longer independent. It is found that this coupling increases the emittance of the extracted particles and the apparent thickness of the electrostatic septum and therefore the losses due to limited acceptances in the vertical plane. It is also found that this coupled motion is mainly due to the systematic resonance $Q_H + 2Q_V = 8$ which is close to the working point $(Q_H + 2Q_V - 8 = -0,25)$, so that the coupling may be reduced by compensating this resonance.

2. THE ULTRASLOW EXTRACTION

Due to the long spill times (typically 1 hour) in LEAR, one is using stochastic extraction[1]. This method reduces the modulation of the spill rate due to ripple on the power supplies.

The extraction is done by exciting the resonance $3Q_H = 7$. However the working point is kept around 2.325 for the stack. The particles are moved to the resonance by having nonzero horizontal chromaticity and accelerating the particles longitudinally with noise so that they make a random walk towards the resonance.

By tuning correctly the horizontal chromaticity together with amplitude and phase of the resonance, it is possible to get an alignment of the outgoing horizontal separatrices for different horizontal emittances[2], [3], [4].

3. TRACKING AT THE EXTRACTION WORKING POINT

The working point at extraction is :

$$Q_H = 2.325, \ Q_V = 2.725$$

The chromaticities are tuned to :

$$\text{Horizontal plane } \xi_H = 0.53$$
$$\text{Vertical plane } \xi_V = 0$$

and the extraction resonance $3Q_H = 7$ is excited.

The particles are also given a horizontal bump to approach them to the electromagnetic septum used for extraction. However this also means that they are going off center in some of the sextupoles. The particle will then be more influenced by the nonlinear fields.

We have done tracking with DIMAT[5], during these conditions. One particle has been tracked 1024 turns for different horizontal- and vertical amplitudes. We have then applied Fourier analysis[6], [7], [8] to the horizontal and vertical position to obtain the frequency spectra and tune shift with amplitude.

The "action J" has been varied by :

$$\text{Horizontal plane } (2J_H) : 1 \longrightarrow 30 \text{ mm.mrad}$$
$$\text{Vertical plane } (2J_V) : 0 \longrightarrow 30 \text{ mm.mrad}$$

The results are shown in Appendix A.

In the frequency spectra we find big amplitudes for the frequencies.

$$\text{Horizontal motion} \quad 2Q_H, \ 2Q_V$$
$$\text{Vertical motion} \quad Q_H + Q_V, \ Q_H - Q_V$$

The corresponding resonances are[9], [10] :

Resonance	Observed frequency Horizontal plane	Vertical plane
$3Q_H = 7$	$2Q_H$	-
$Q_H + 2Q_V = 8$	$2Q_V$	$Q_H + Q_V$
$Q_H - 2Q_V = -3$	$2Q_V$	$Q_H - Q_V$

We conclude that the systematic resonance $Q_H + 2Q_V = 8$ is excited as is expected from the arrangement of the sextupoles. The other frequencies are due to the second order effects by sextupoles.

In appendix B we show the tune shift as a function of horizontal- and vertical action due to the nonlinear fields. We compare with calculated values from the HARMON[11], [12], [13] module in MAD[14].

The reason of the bad correspondance is probably the coupling between the two transverse planes due to the excitation of the resonance $Q_H + 2Q_V = 8$. It also seems that HARMON does not recalculate the closed orbit with the bump.

However the error in the tune shift as a function of amplitude when neglecting the bump is expected to be small.

4. SIMULATION OF THE STOCHASTIC EXTRACTION

The tracking is in this case done under the same conditions as in chapter 3. However we now add an increment $\Delta p/p$ to the particles longitudinal momenta for each turn. This simulates the longitudinal acceleration of the particle by noise, so it moves towards the extraction resonance. It is then following the separatrices of the extraction resonance $3Q_H = 7$ and is assumed to be extracted when it's horizontal position is bigger than the position of the electromagnetic septum.

We have simulated the extraction for 35 particles where the "action" has been varied in equidistant steps as :

$$2J_H : 1\text{-}10 \text{ mm.mrad, 5 steps}$$
$$2J_V : 0\text{-}10 \text{ mm.mrad, 7 steps}$$

The result is shown in appendix C.

In the first case without compensation of the resonance $Q_H + 2Q_V = 8$. Due to the coupling between the horizontal planes, the outgoing separatrices are not overlapping for different vertical "actions".

In the second case with the resonance $Q_H + 2Q_V = 8$ compensated by adding two sextupoles, the coupling is reduced so that we recover the alignment of the outgoing separatrices.

Finally in appenix D we show tracking of one particle around the machine just before extraction ($Q_H + 2Q_V = 8$ not compensated).

5. CONCLUSIONS

We conclude from the tracking that the systematic resonance $Q_H + 2Q_V = 8$ is excited in LEAR as expected from the arrangement of the sextupoles for the chromaticity correction. This leads to coupled motion in the transverse plane.

This coupling leads to an increase of the emittance of the extracted beam. The coupling may be reduced by compensation of the resonance with two extra sextupoles.

6. ACKNOWLEDGEMENT

The LEAR-lattice for DIMAT was created by A. Mosnier * , who also adopted DIMAT for the simulation of the ultraslow extraction in LEAR. It has also been improved by M. Chanel. I would like to thank M. Chanel for many helpfull discussions and suggestions during this work.

Finally I would like to thank E. Asséo for providing the algorithms for the FFT-analysis.

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* Scientific Associate in the LEAR group form CEA Sacley during 1983-1984.

List of references:

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[2] R. Giannini, Beam Envelope in LEAR at Third Order Resonant Extraction, PS/CD/Note 81-4.

[3] W. Hardt, Ultraslow extraction out of LEAR, PS/DL/Note 82-06.

[4] R. Giannini, Ultraslow extraction out of LEAR, Comparison of measure-ments with theory, PS/LEA/Note 83-3.

[5] R. Servranckx, K.L. Brown, SLAC Report 270 UC-28 (1984).

[6] E. Asséo, Causes et corrections des erreurs dans la mesure des caractéristiques des oscillations bétatroniques obtenues à partir d'une transformation de Fourier, CERN/PS 85-9 (LEA).

[7] E. Asséo, Possibilité de mesure précise de la phase des oscillations bétatroniques à partir d'une transformée de Fourier en introduisant un algorithme de modulation d'amplitude, PS/LEA/Note 86-14.

[8] E. Asséo, Moyens de calcul pour la mesure des force et phase des effets perturbateurs des resonances sur le faisceau, PS/LEA/Note 87-01.

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[10] J. Bengtsson and M. Chanel, Resonance measurements using Fourier spectrum analysis of beam oscillations, PS/LEA/Note 86-15.

[11] M. Donald, User's Guide to HARMON, RL-76-052 Rutherford Laboratory (1976).

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[13] M. Donald, D. Schofield, A User's Guide to the HARMON Program, LEP Note 420 (1982).

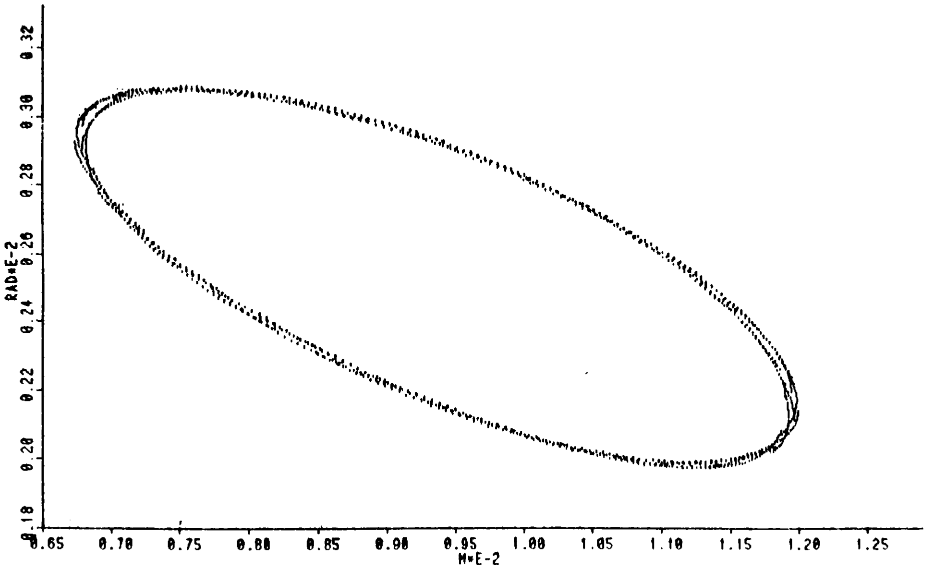
[14] C. Iselin, J. Niederer, The MAD Program (Methodical Accelerator Design) Version 6. User's Reference Manual CERN/LEP/TH/87-33.

APPENDIX A

Tracking at extraction in LEAR

VD12 H1V1 $2J_H = 1$, $2J_V = 1$

HORIZONTAL PHASE SPACE



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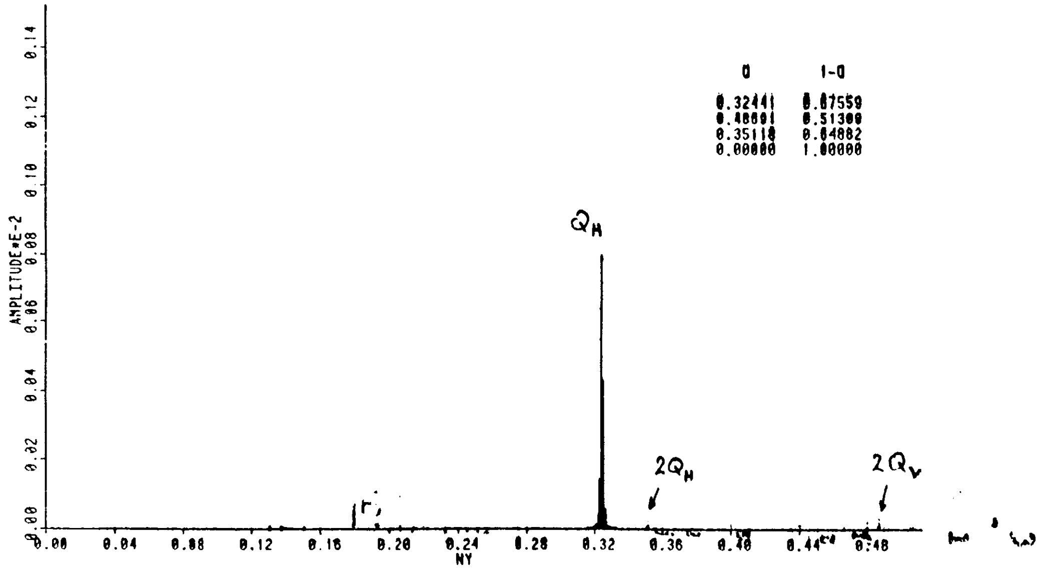
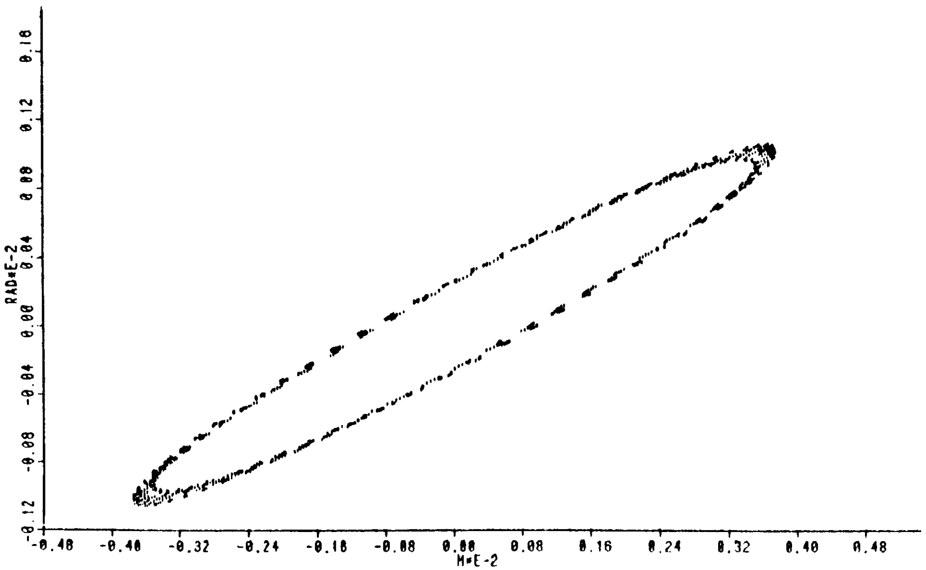


VERTICAL PHASE SPACE



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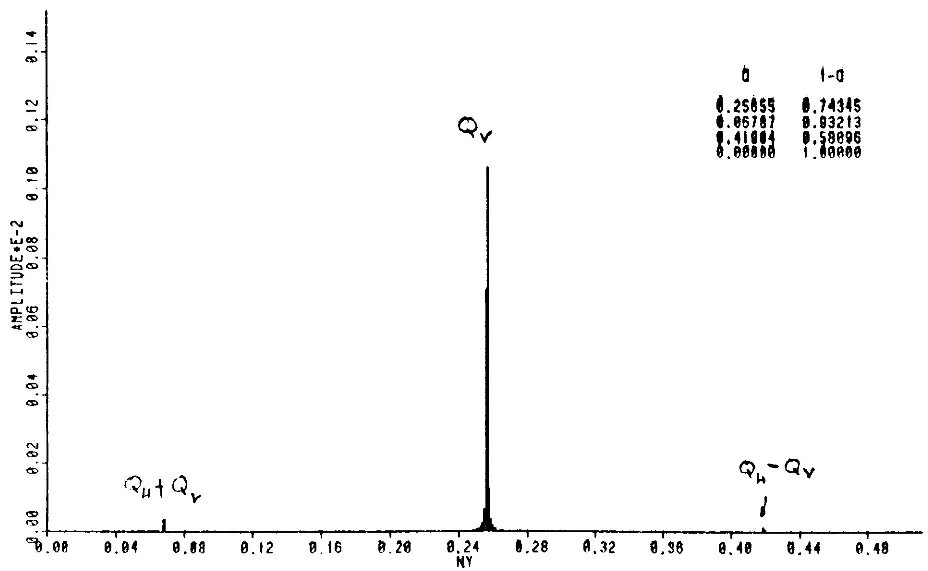
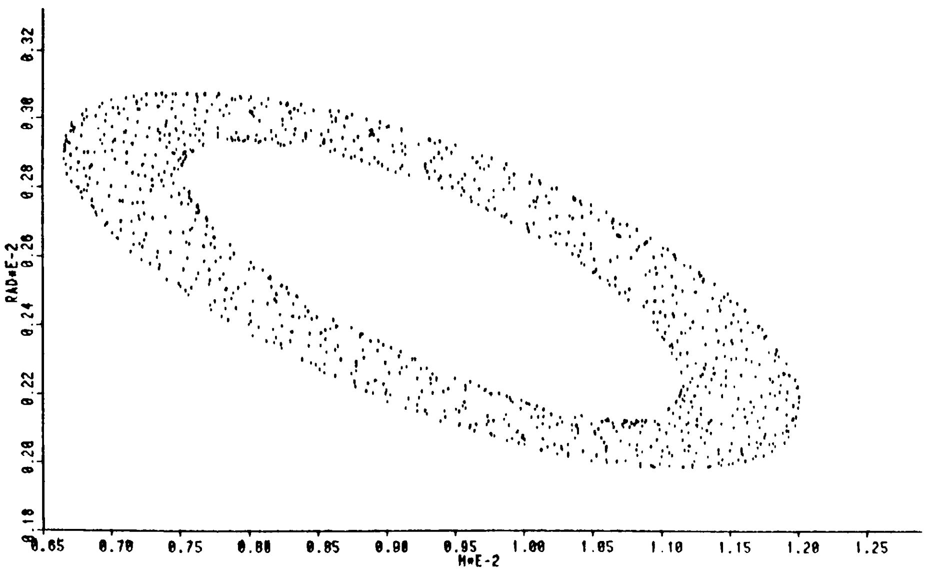


VD12:H1V10 $2J_H = 1$, $2J_V = 10$

HORIZONTAL PHASE SPACE



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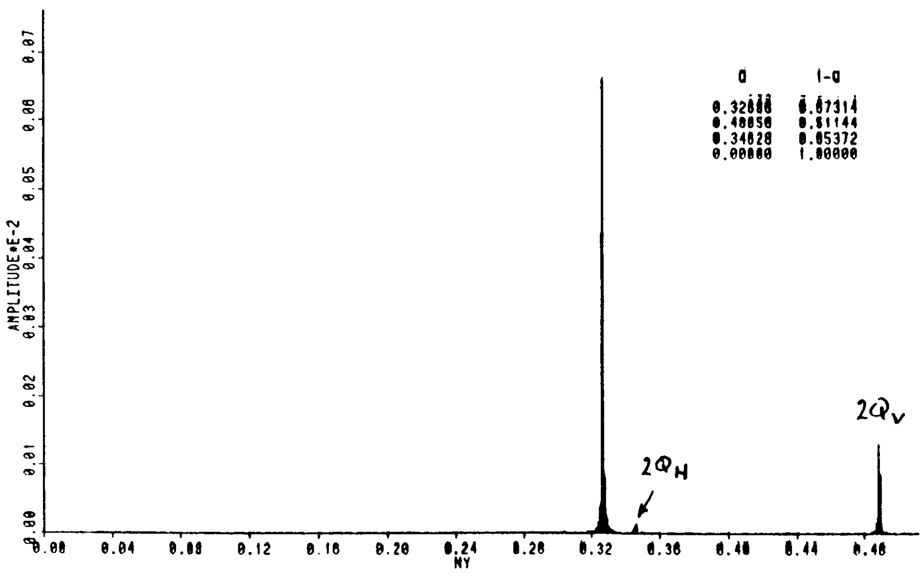
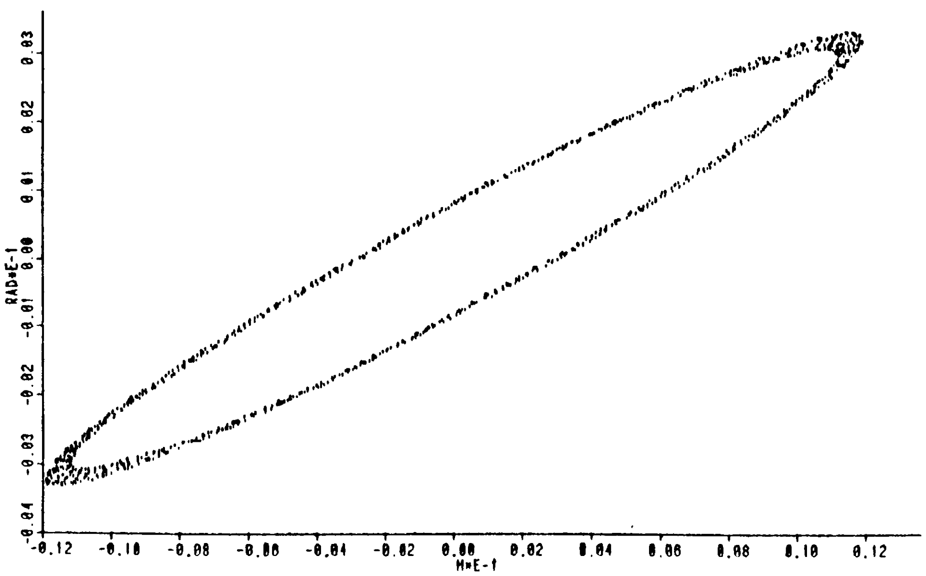


VERTICAL PHASE SPACE



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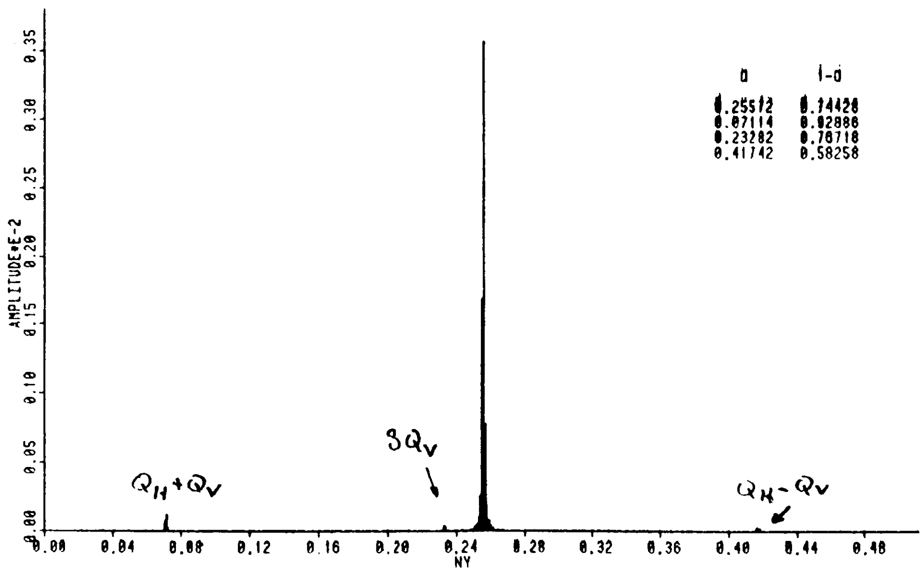
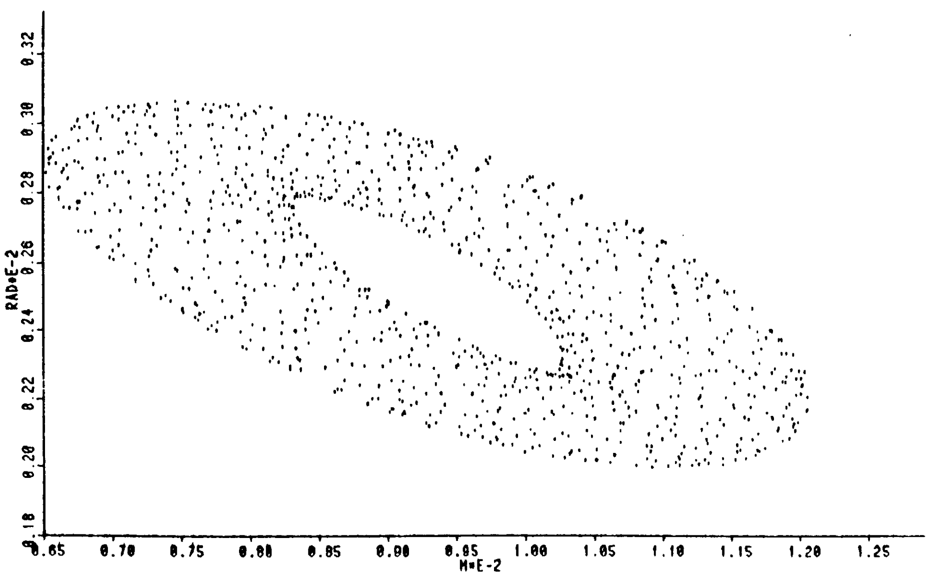
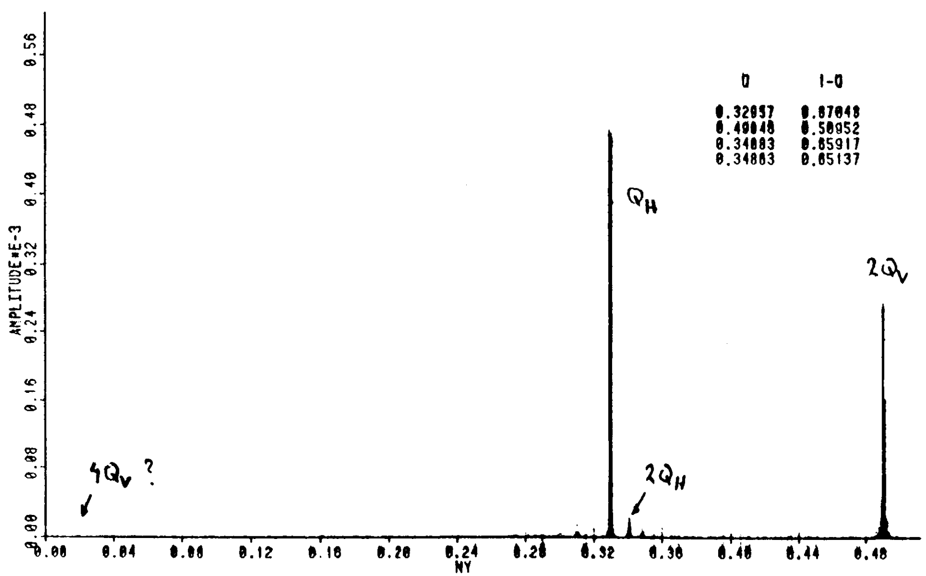
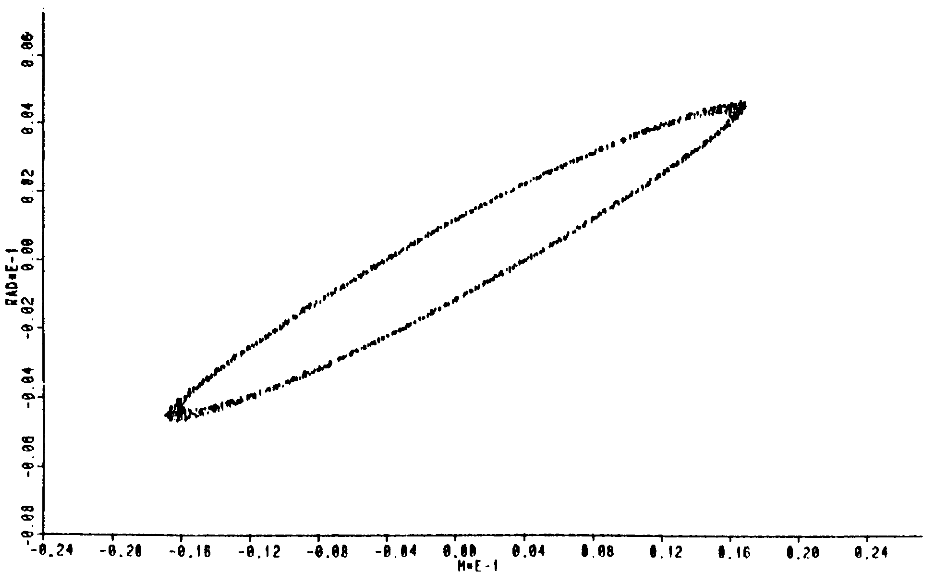
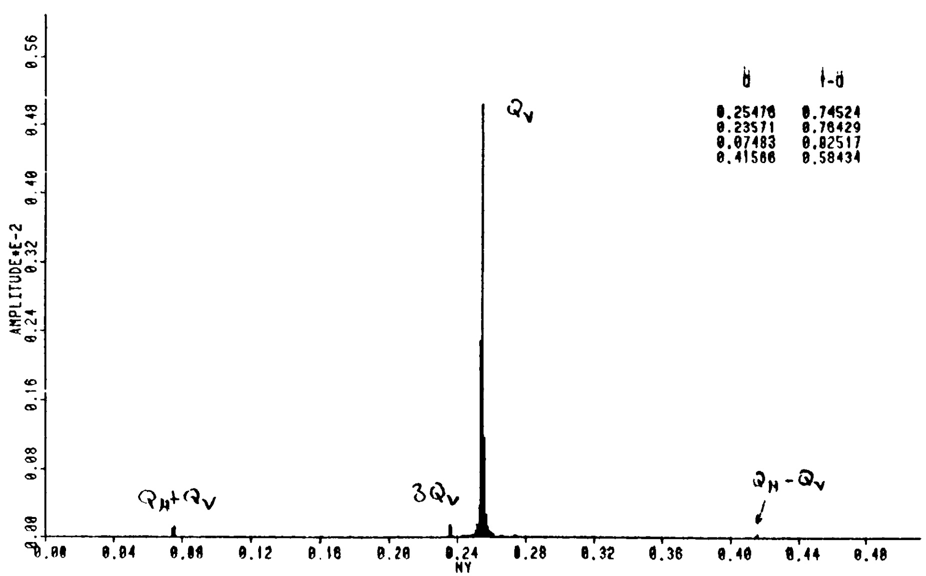


VD12 H1V20 $2J_H = 1$, $2J_V = 20$



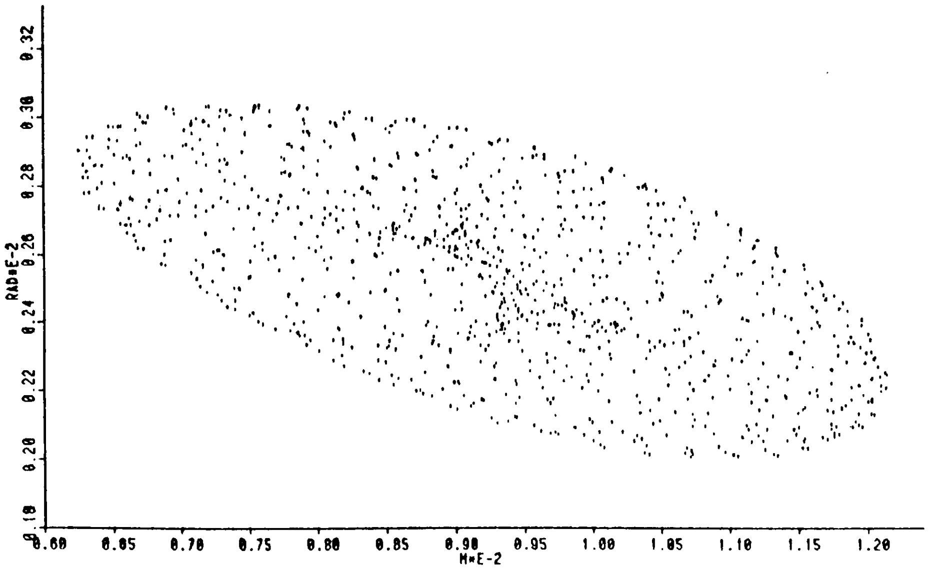






VD12 H1V30 $2J_H = 1$, $2J_V = 30$

HORIZONTAL PHASE SPACE



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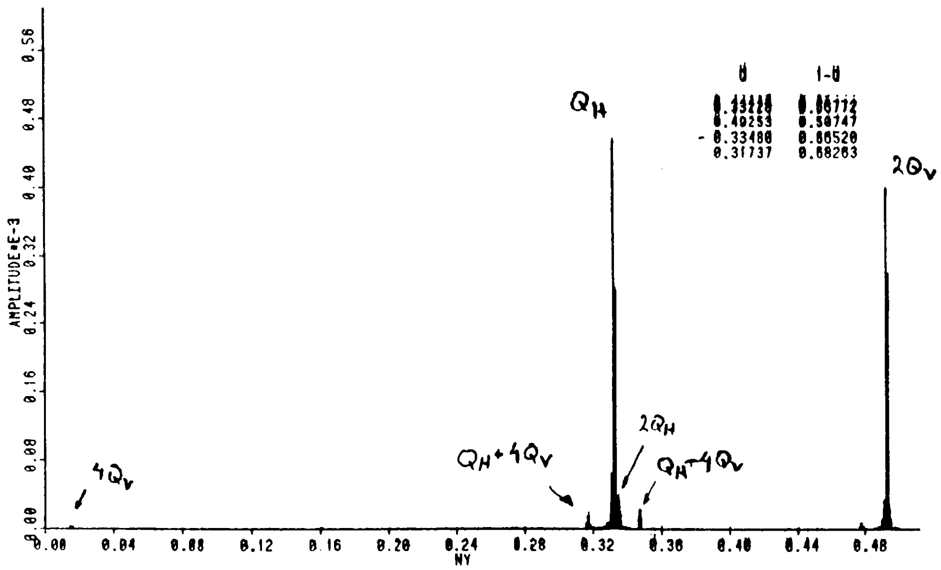
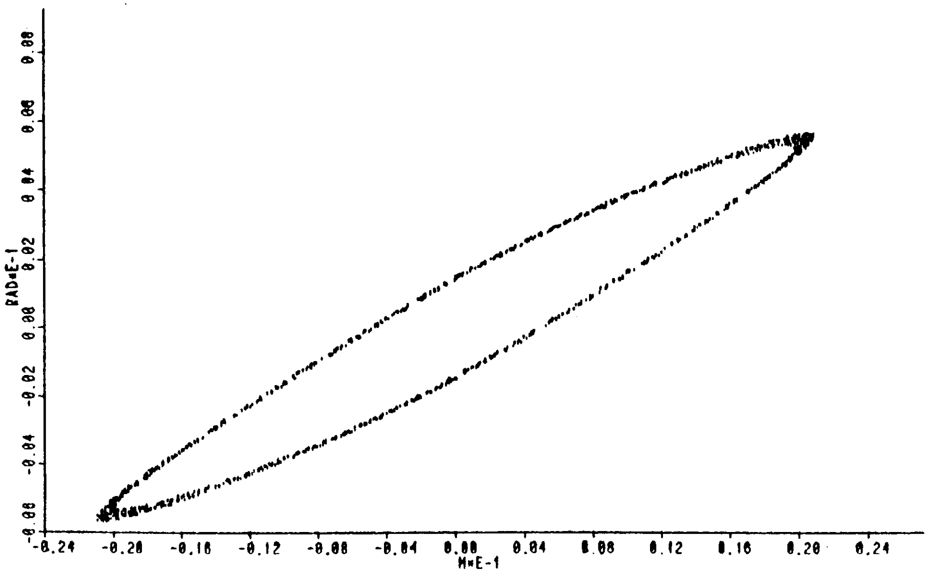


VERTICAL PHASE SPACE



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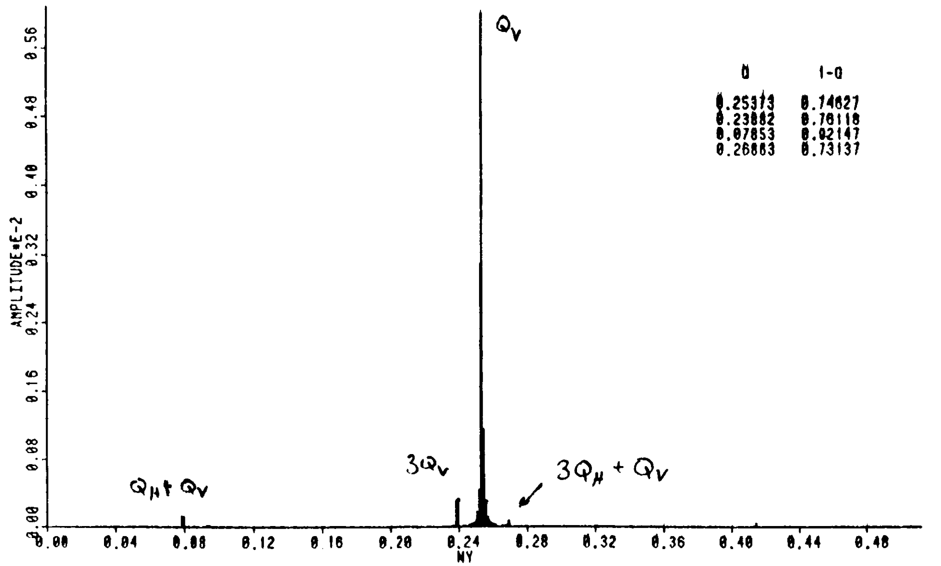
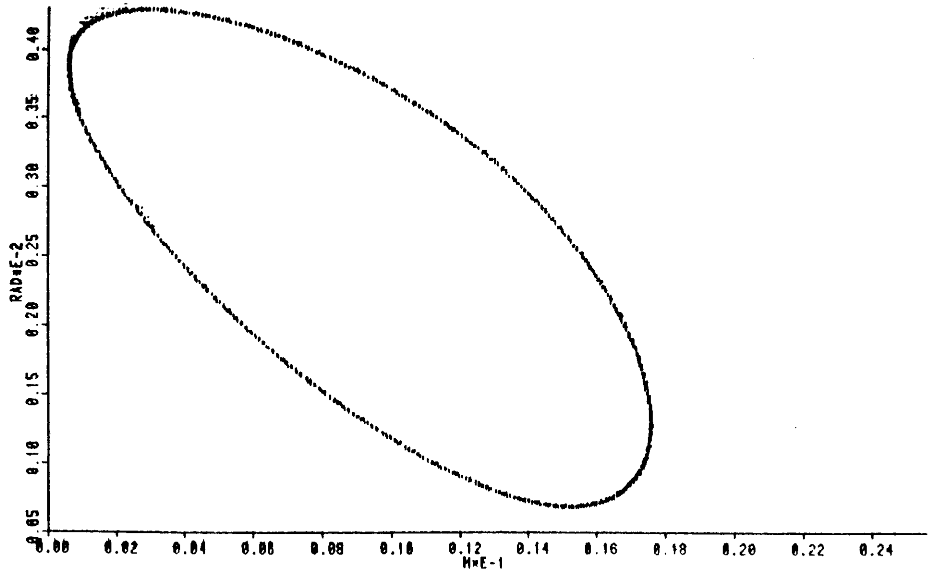


VD12 H10V1 $2J_H = 10,\ 2J_V = 1$

HORIZONTAL PHASE SPACE



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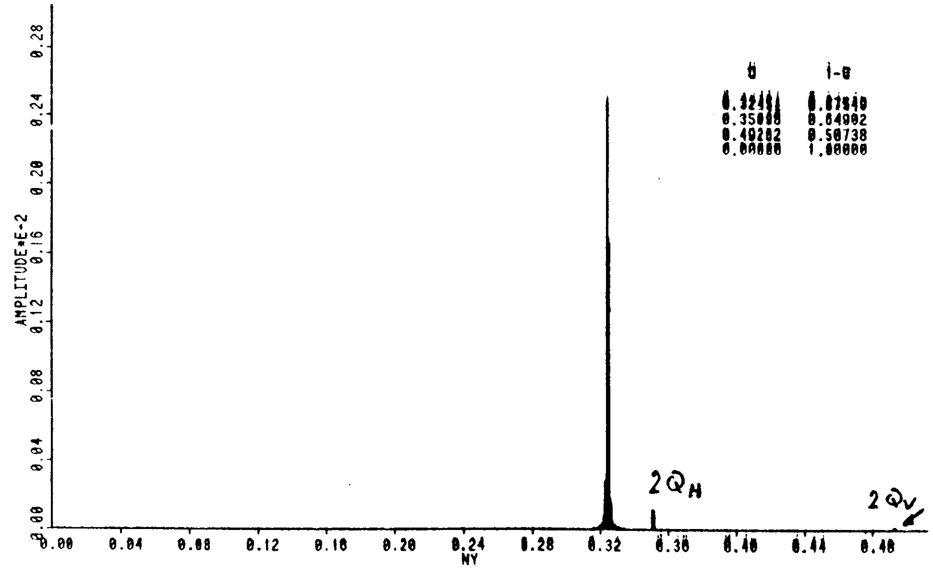

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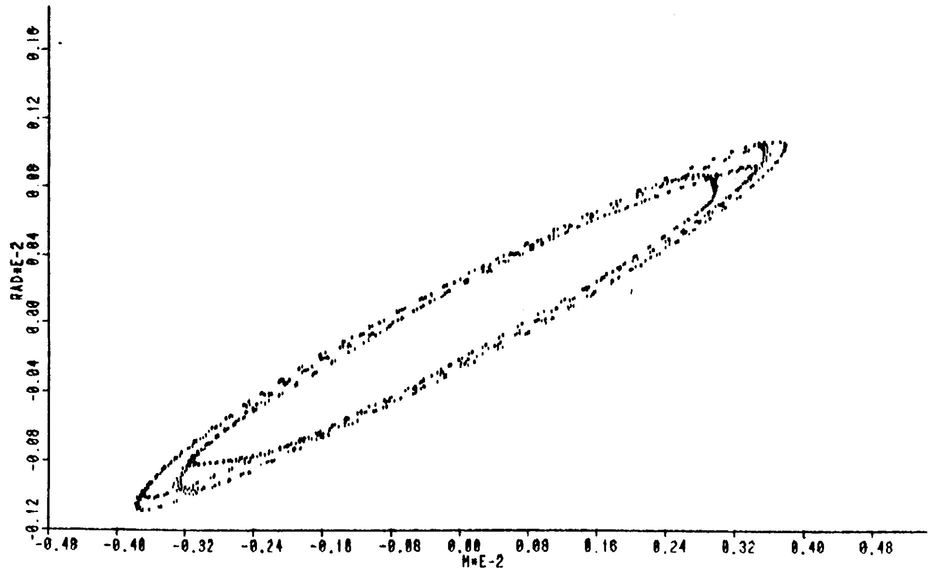

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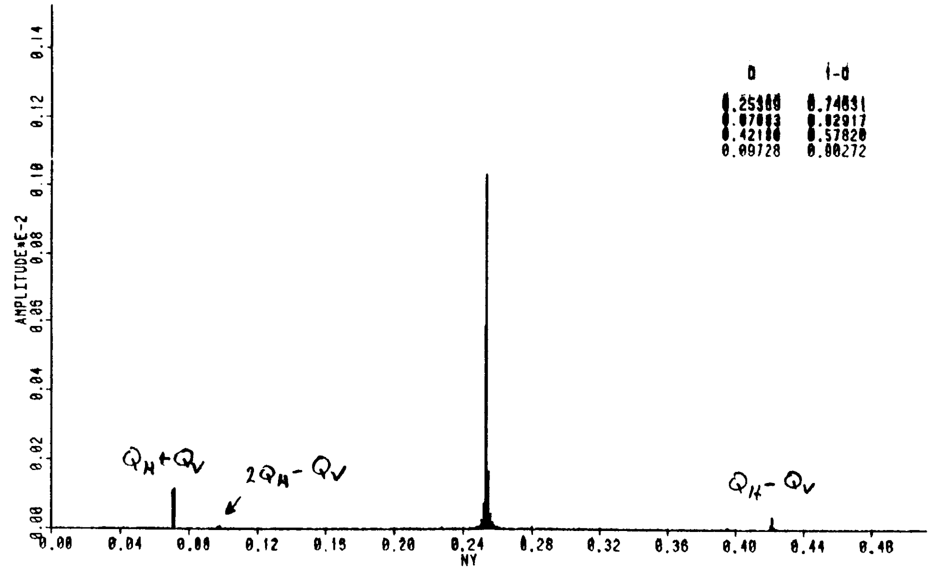
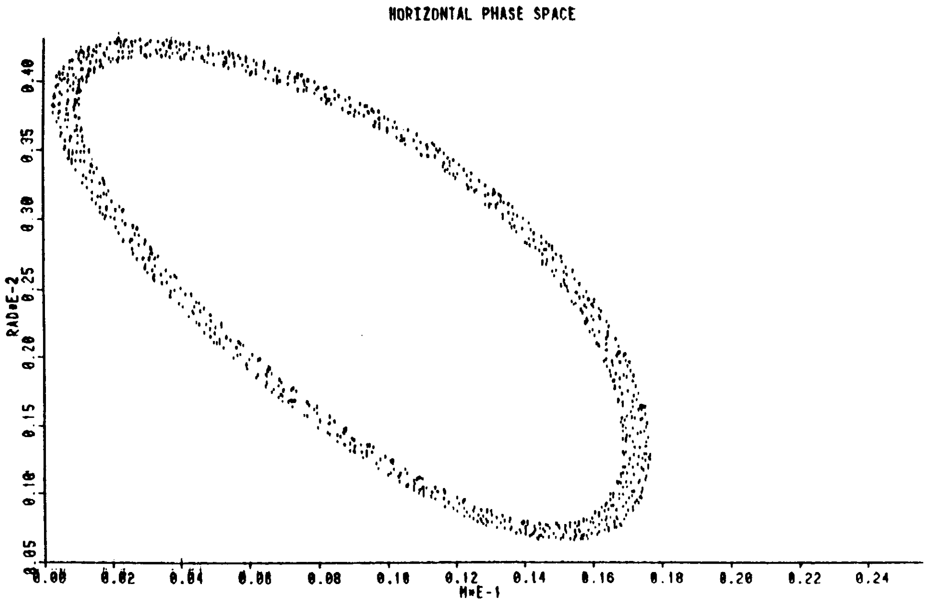
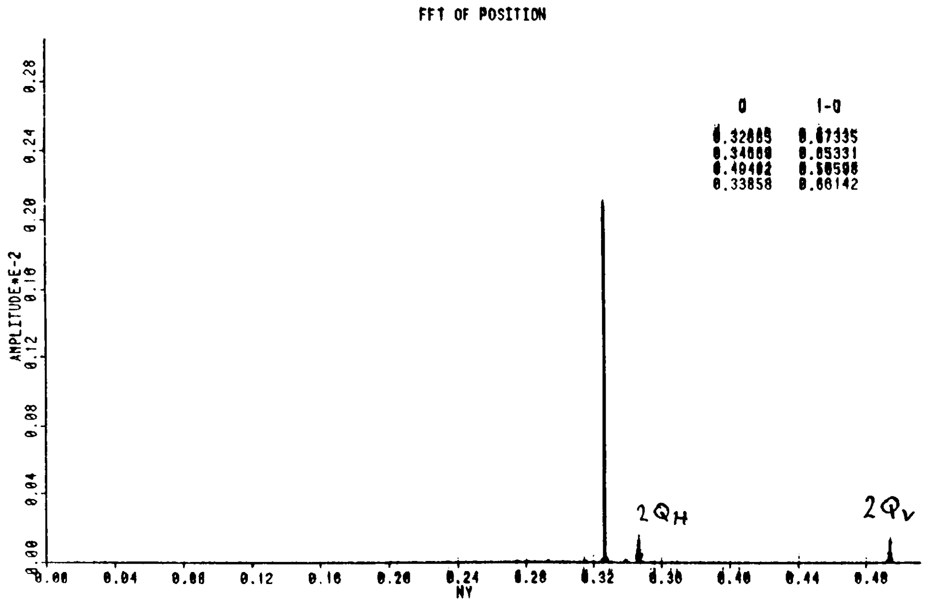
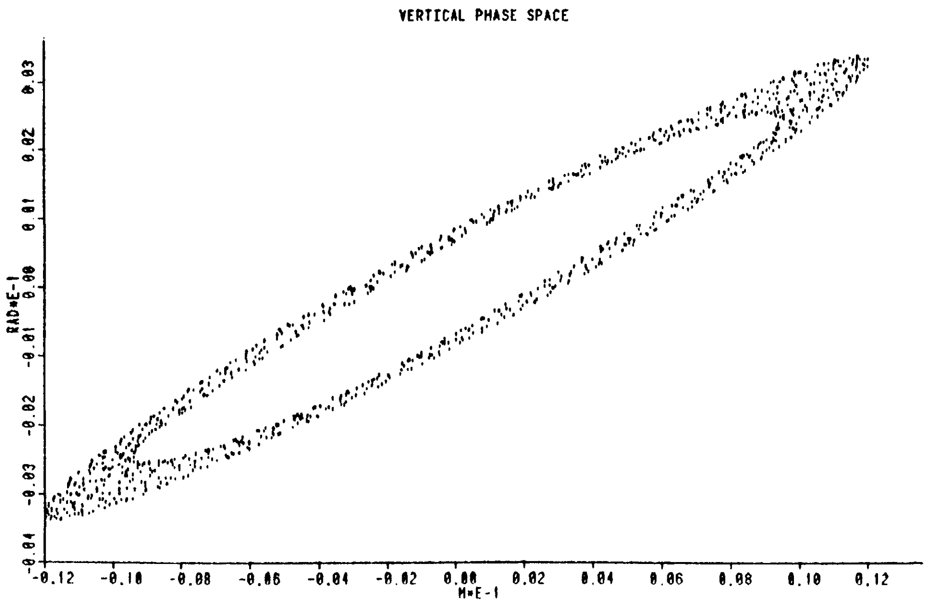
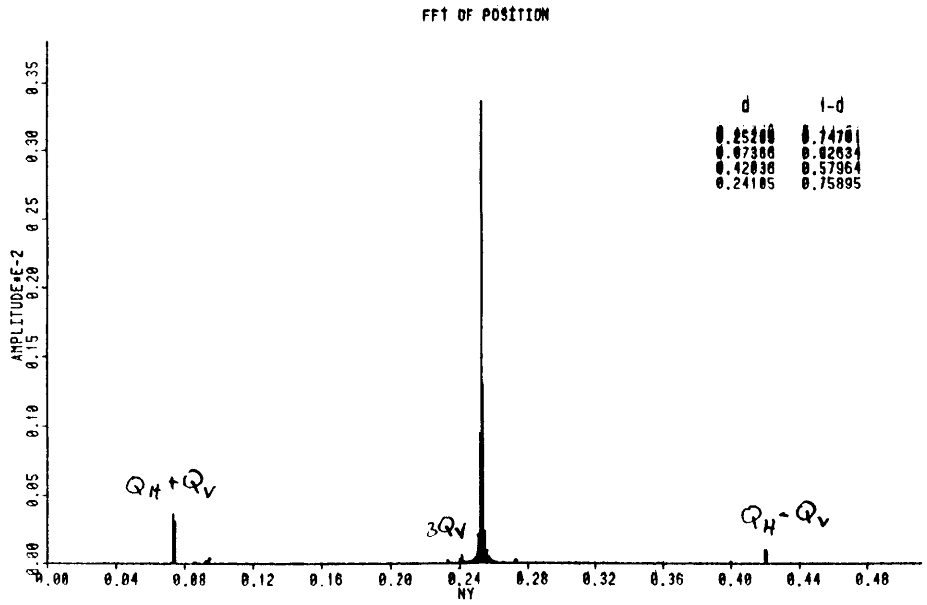


VD12 H10V10 $2J_H = 10$, $2J_V = 10$

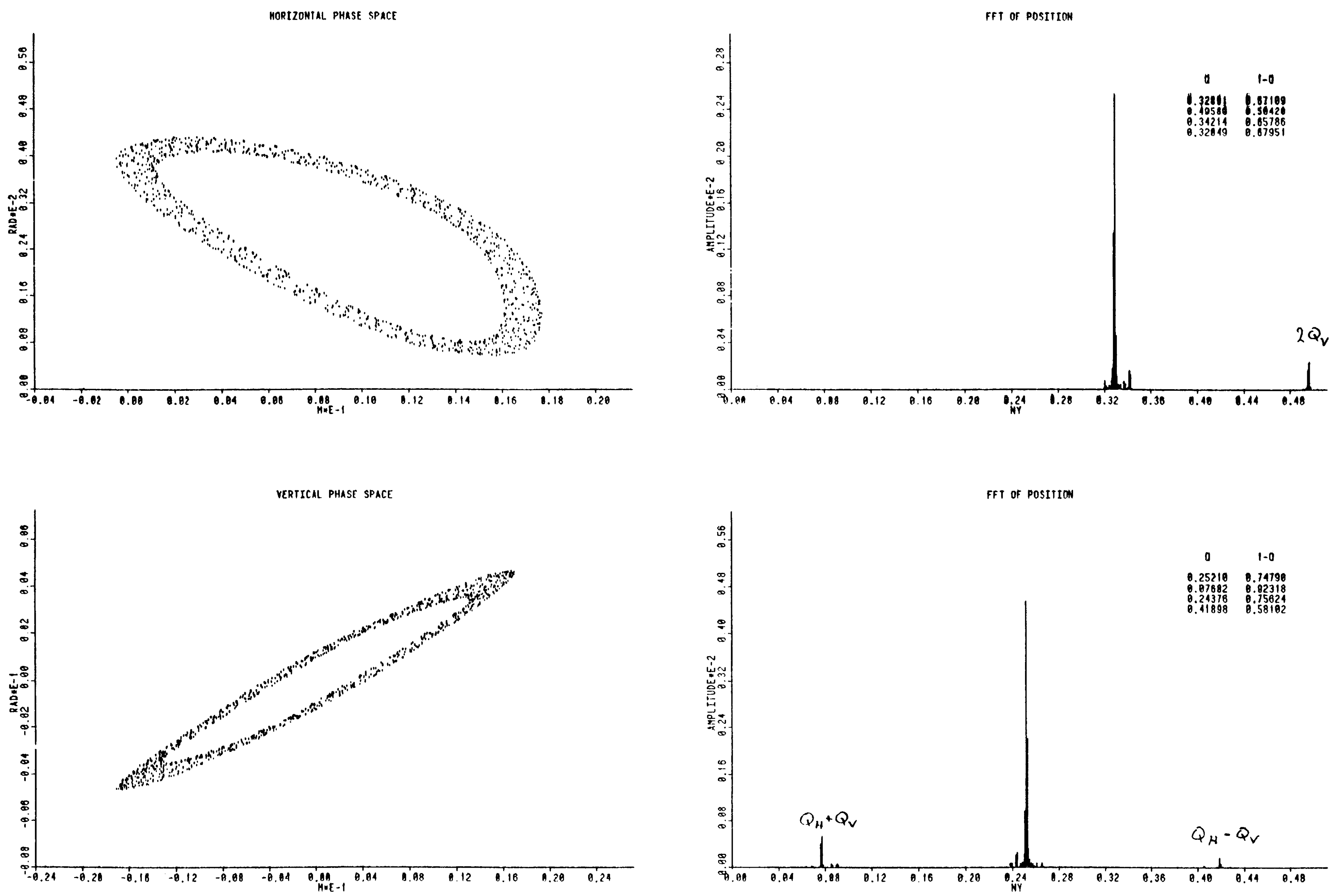






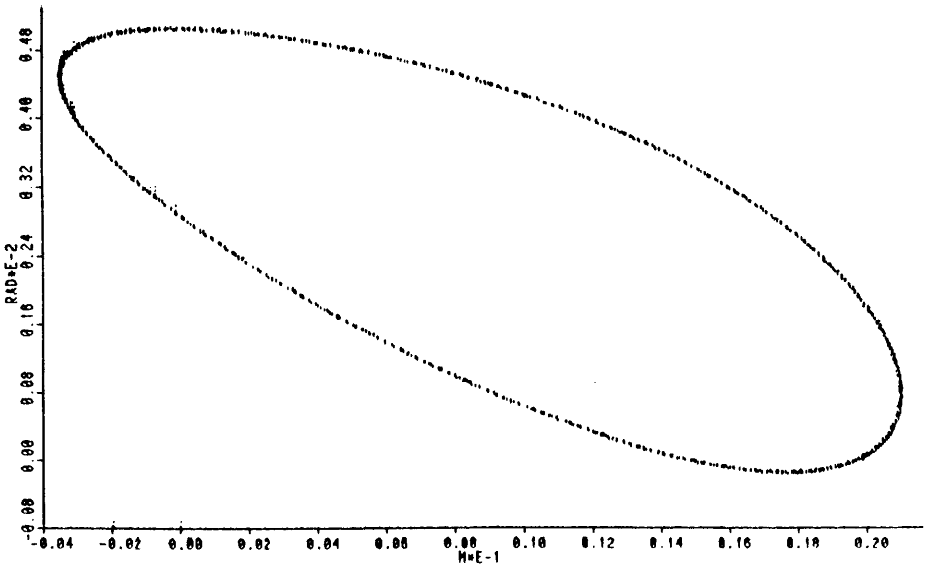


VD12 H10V20 $2J_H = 10$, $2J_V = 20$



VD12 H20V1 $2J_H = 20,\ 2J_V = 1$

HORIZONTAL PHASE SPACE



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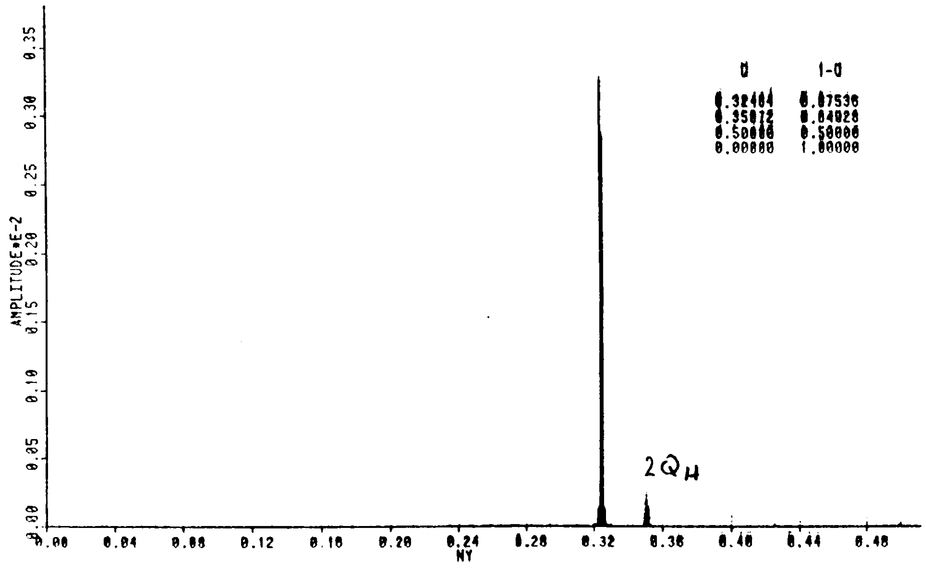
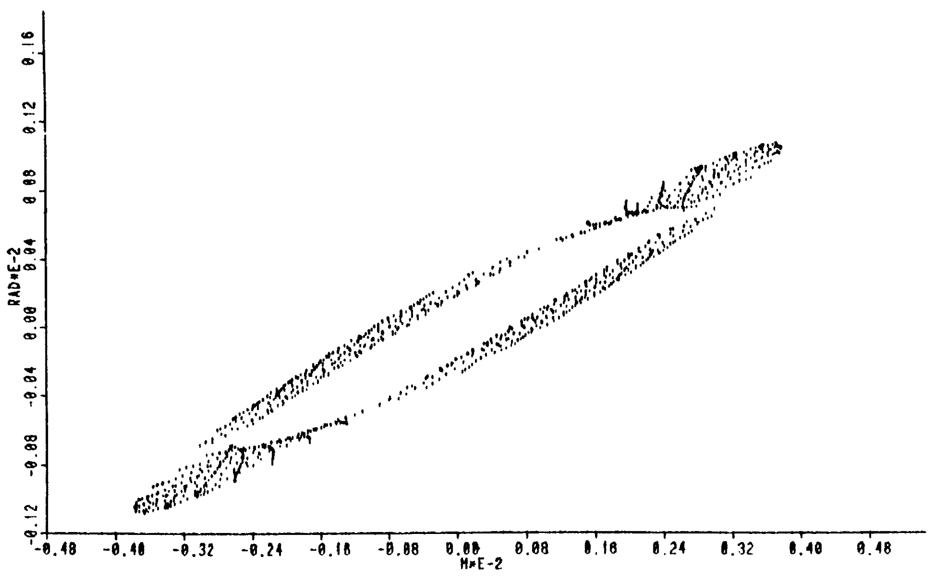


VERTICAL PHASE SPACE



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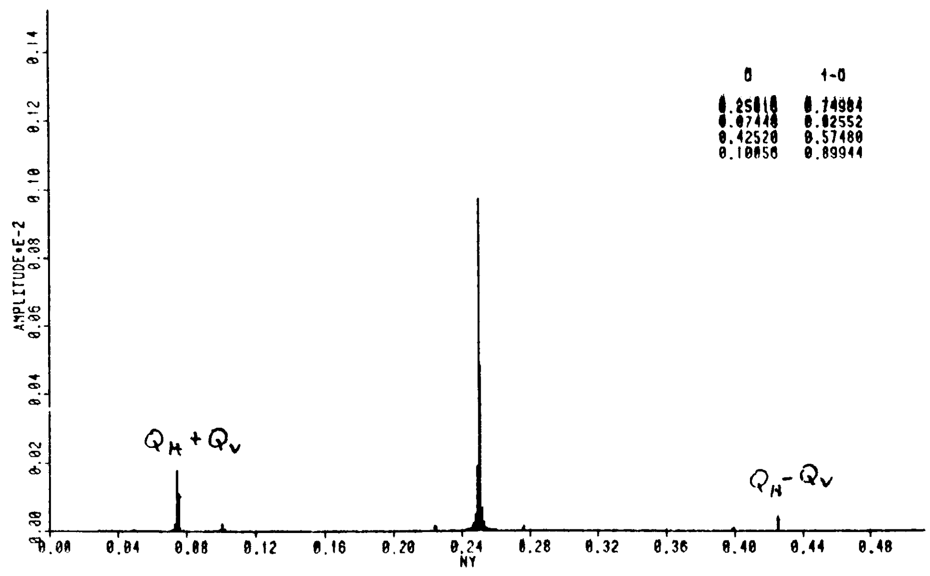
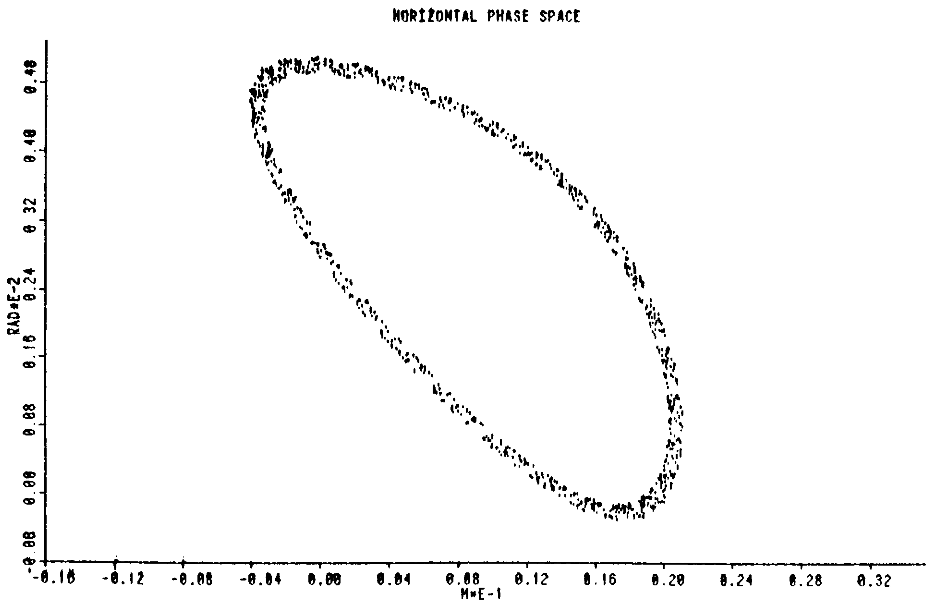
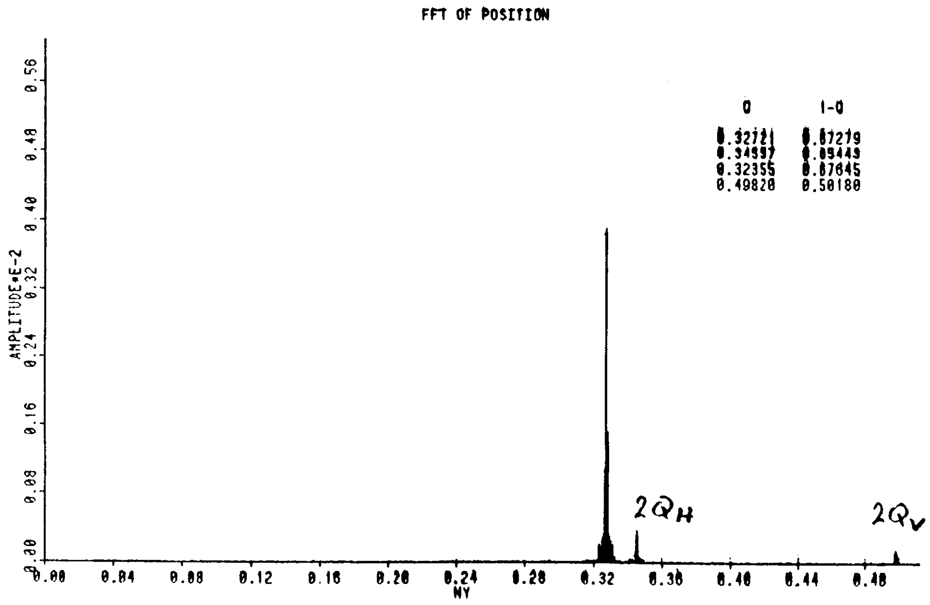
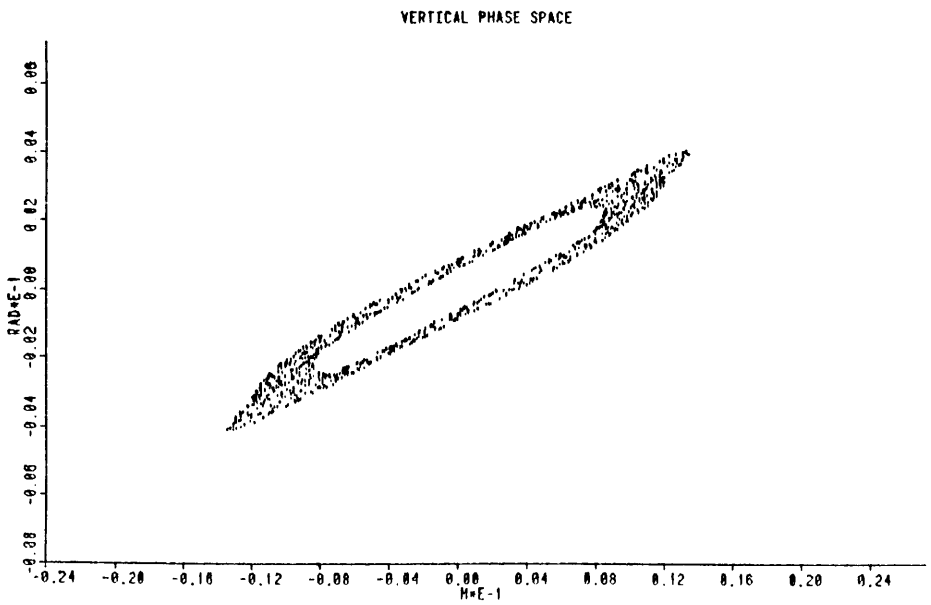
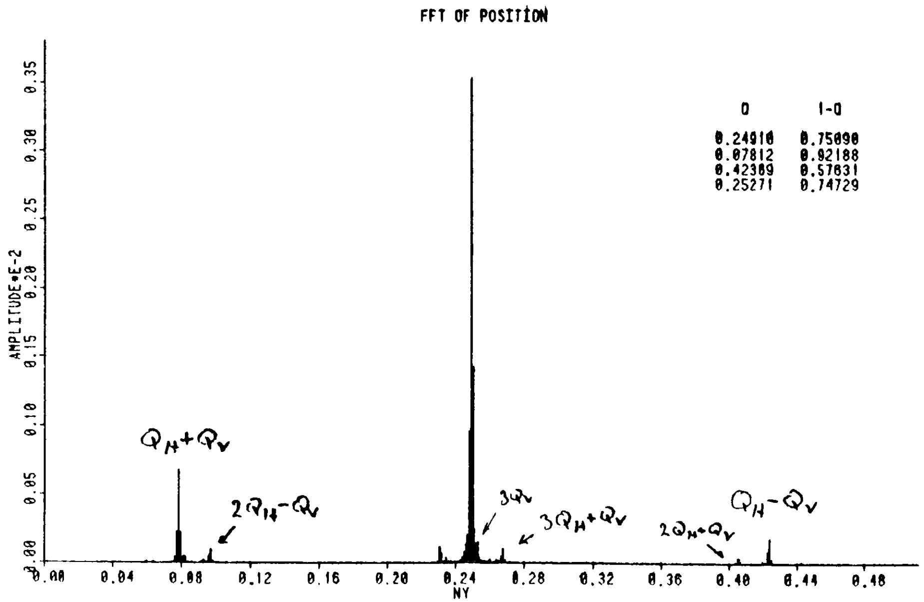


VD12 H20V10 $2J_H = 20$, $2J_V = 10$



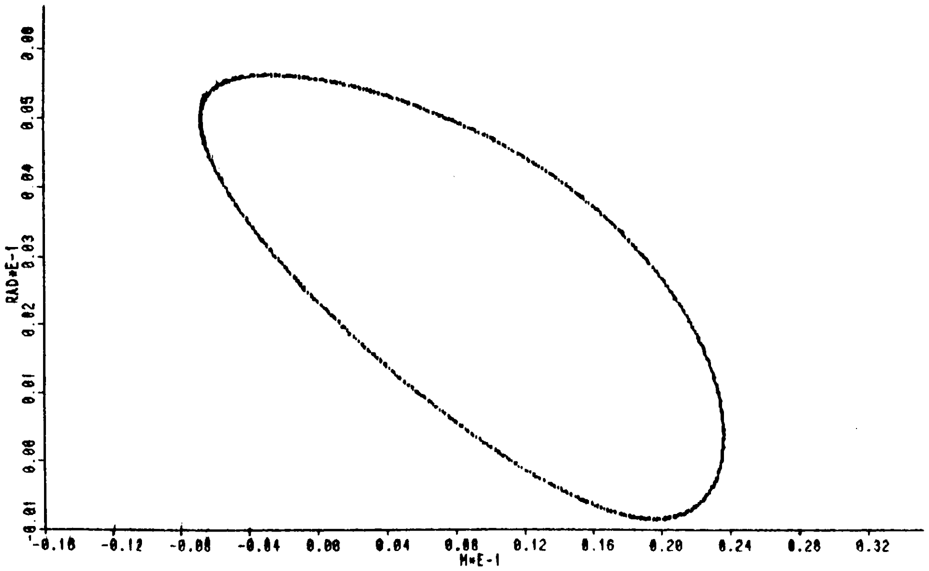






VD12:H30V1 $2J_H = 30,\ 2J_V = 1$

HORIZONTAL PHASE SPACE



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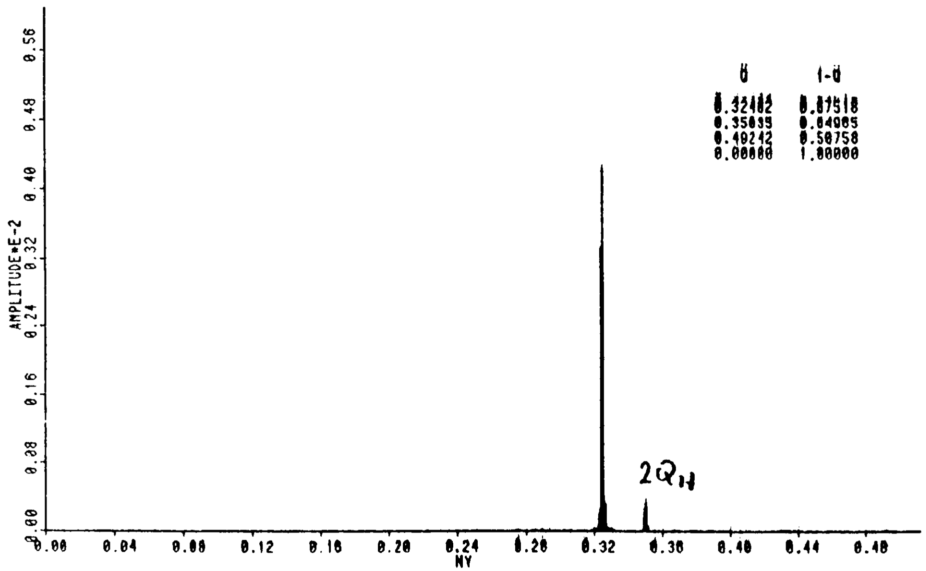
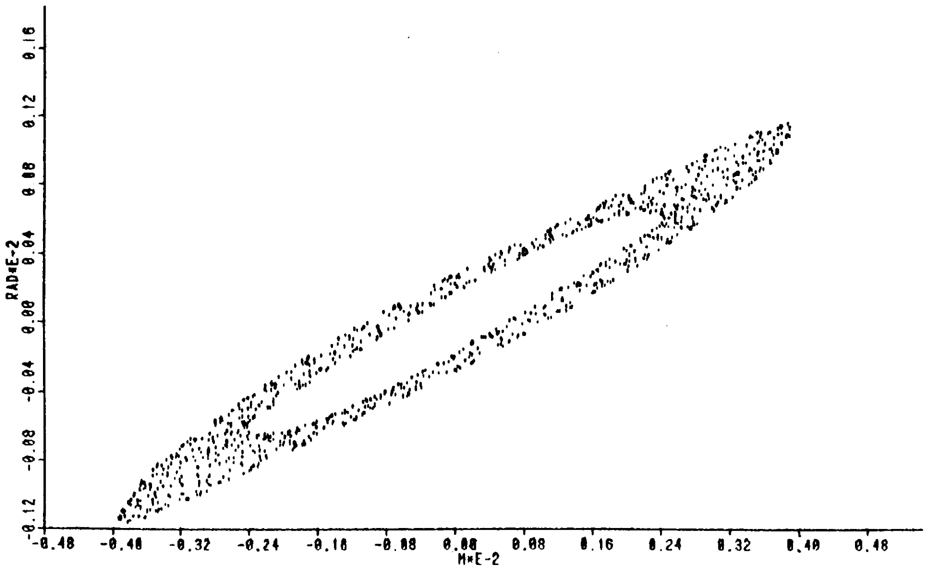


VERTICAL PHASE SPACE



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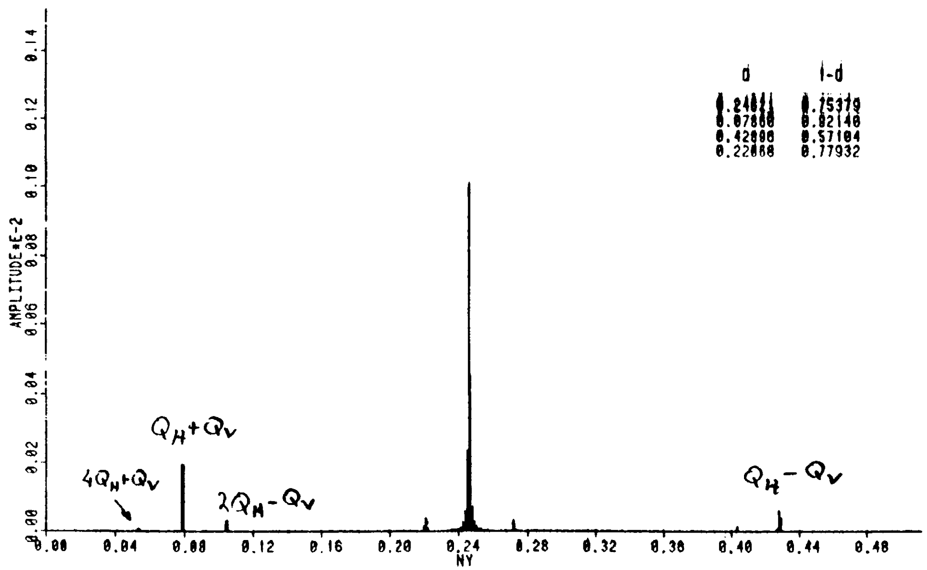
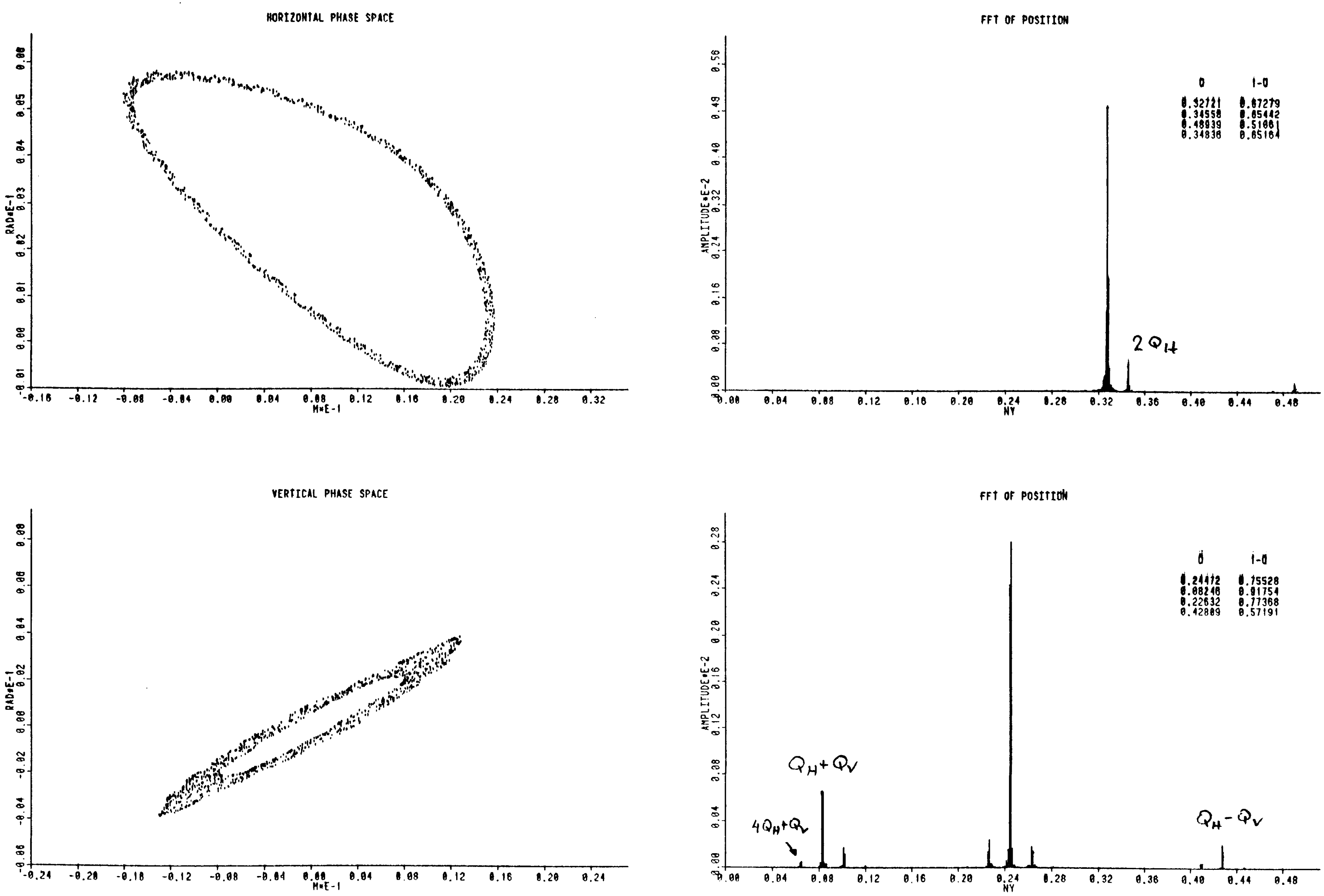


VD12 H30V10 $2J_H = 30$, $2J_V = 10$



APPENDIX B

Tune shift as a function of horizontal- and vertical action.

Q_H

J_V \ J_H	0,5	5	10	15
0.5	2.3244	2.3245	2.3246	2.3248
5	2.3269	2.3267	2.3272	2.3272
10	2.3296	2.3290		
15	2.3323			

Q_V

J_V \ J_H	0,5	5	10	15
0.5	2.7435	2.7463	2.7498	2.7538
5	2.7443	2.7470	2.7509	2.7553
10	2.7452	2.7479		
15	2.7463			

Where the unit for J is [J] = π.mm.mrad.

The tune shifts due to a given sextupole configuration are given by[11], [12], [13] :

$$\delta Q_H = 4 \cdot g_{22000} \, J_H + 2 \cdot g_{11110} \cdot J_V$$

$$\delta Q_V = 2 \cdot g_{11110} \, J_H + 4 \cdot g_{00220} \cdot J_V$$

Calculated values from HARMON

$$\delta Q_H = 2.118 \cdot 10^{-5} \cdot J_H + 2.538 \cdot 10^{-4} \cdot J_V$$

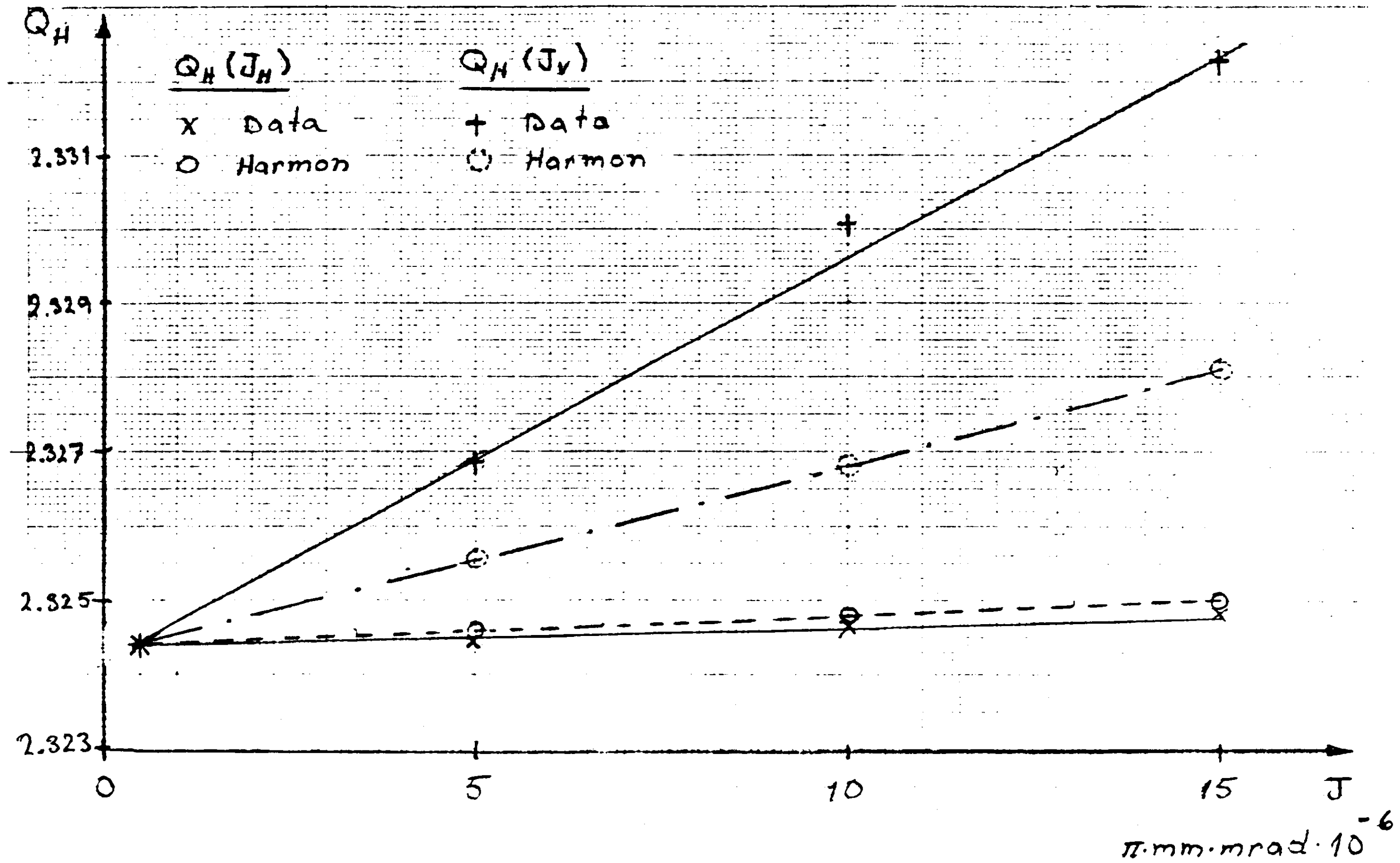
$$\delta Q_V = 2.538 \cdot 10^{-4} - J_H + 1.061 \cdot 10^{-4} \cdot J_V$$

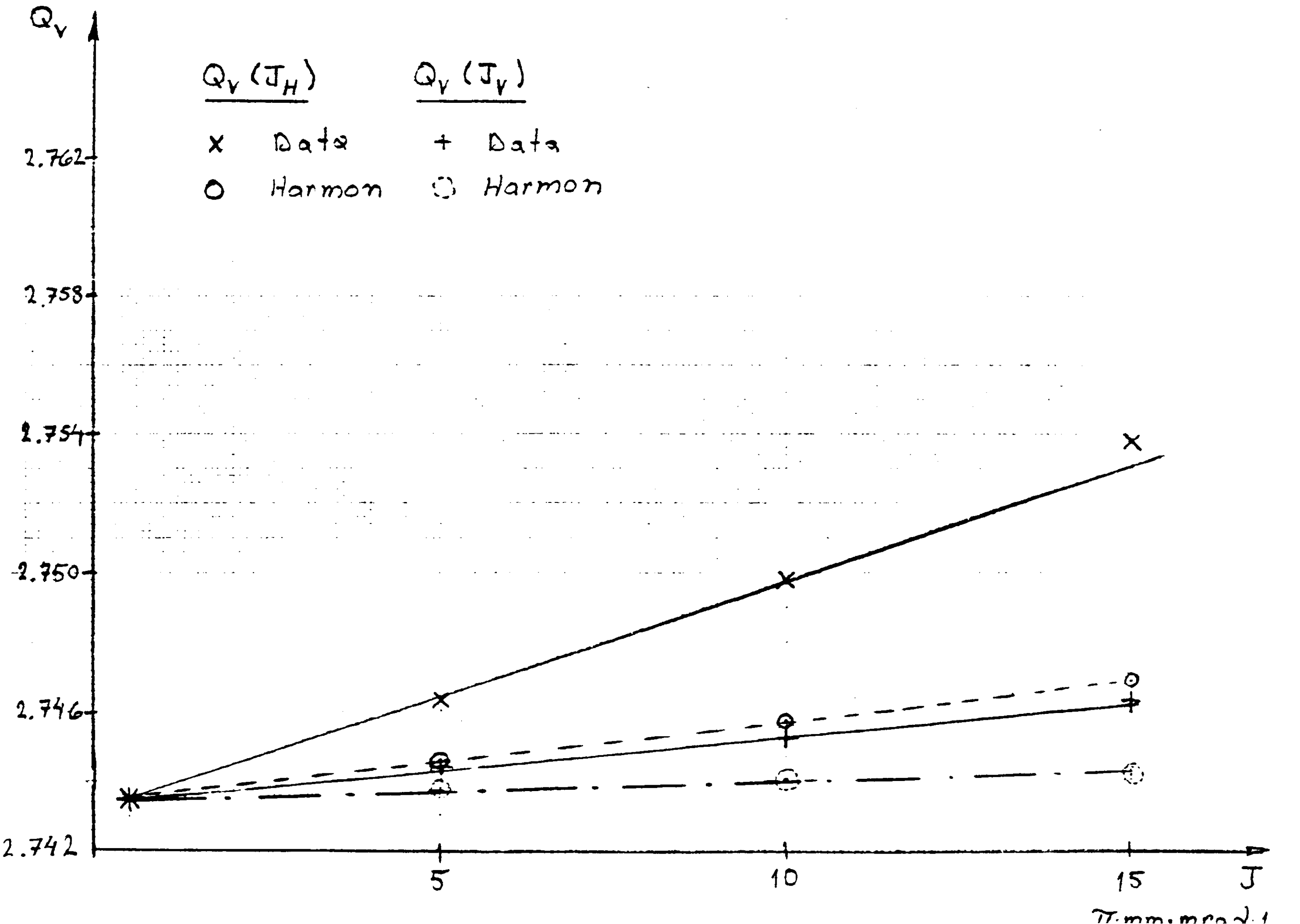
Least square fit of the data gives :

$$\delta Q_H = 2.81 \cdot 10^{-5} \cdot J_H + 5.43 \cdot 10^{-4} \cdot J_V$$

$$\delta Q_V = 7.13 \cdot 10^{-4} \cdot J_H + 1.94 \cdot 10^{-4} \cdot J_V$$

Tune dependence on action





APPENDIX C

Simulation of the stochastic extraction in LEAR :

1) Without compensation of $Q_H + 2Q_V = 8$

2) $Q_H + 2Q_V = 8$ compensated

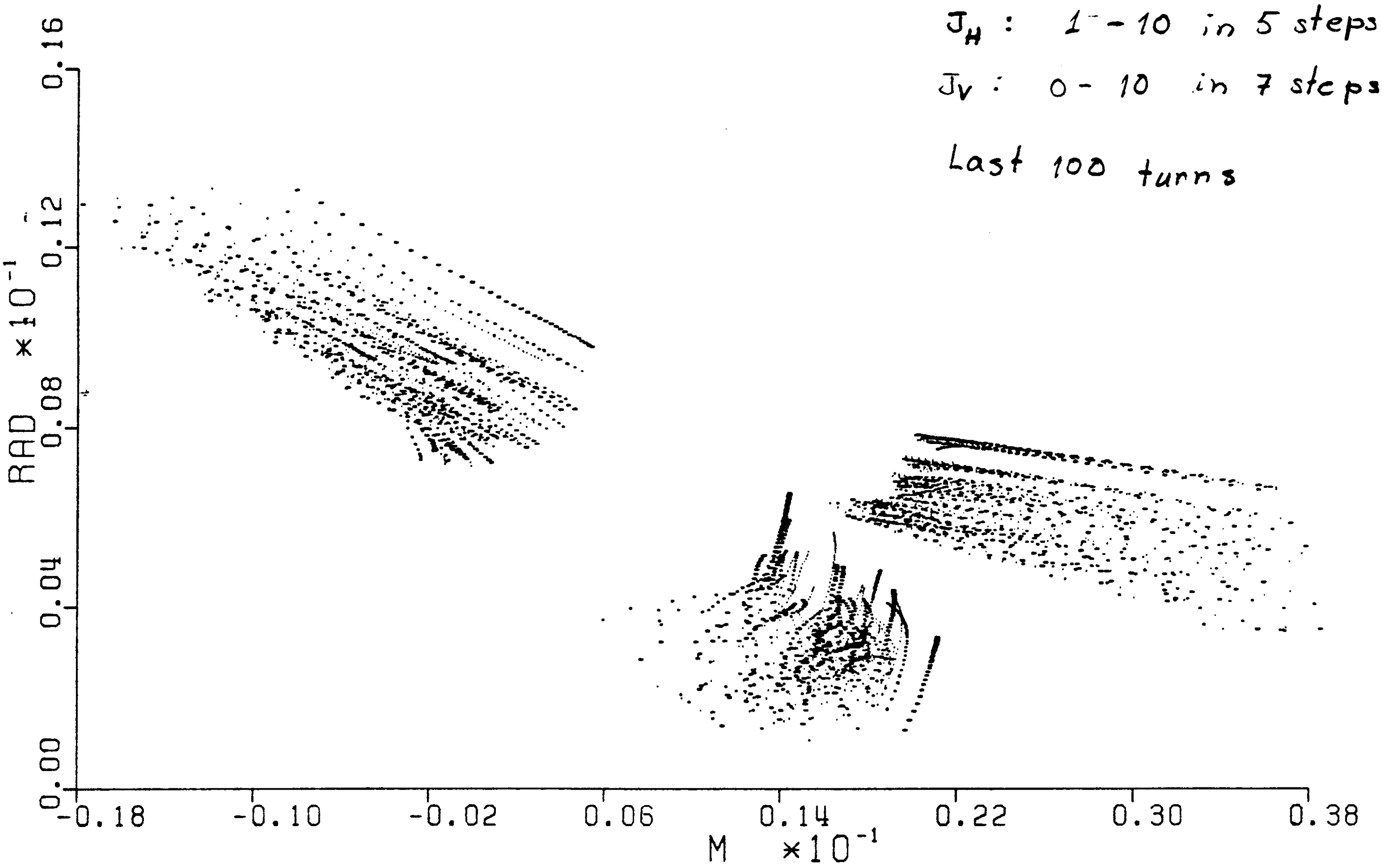
$Q_H + 2Q_V = 8$ not compensated

J_H : 1 - 10 in 5 steps

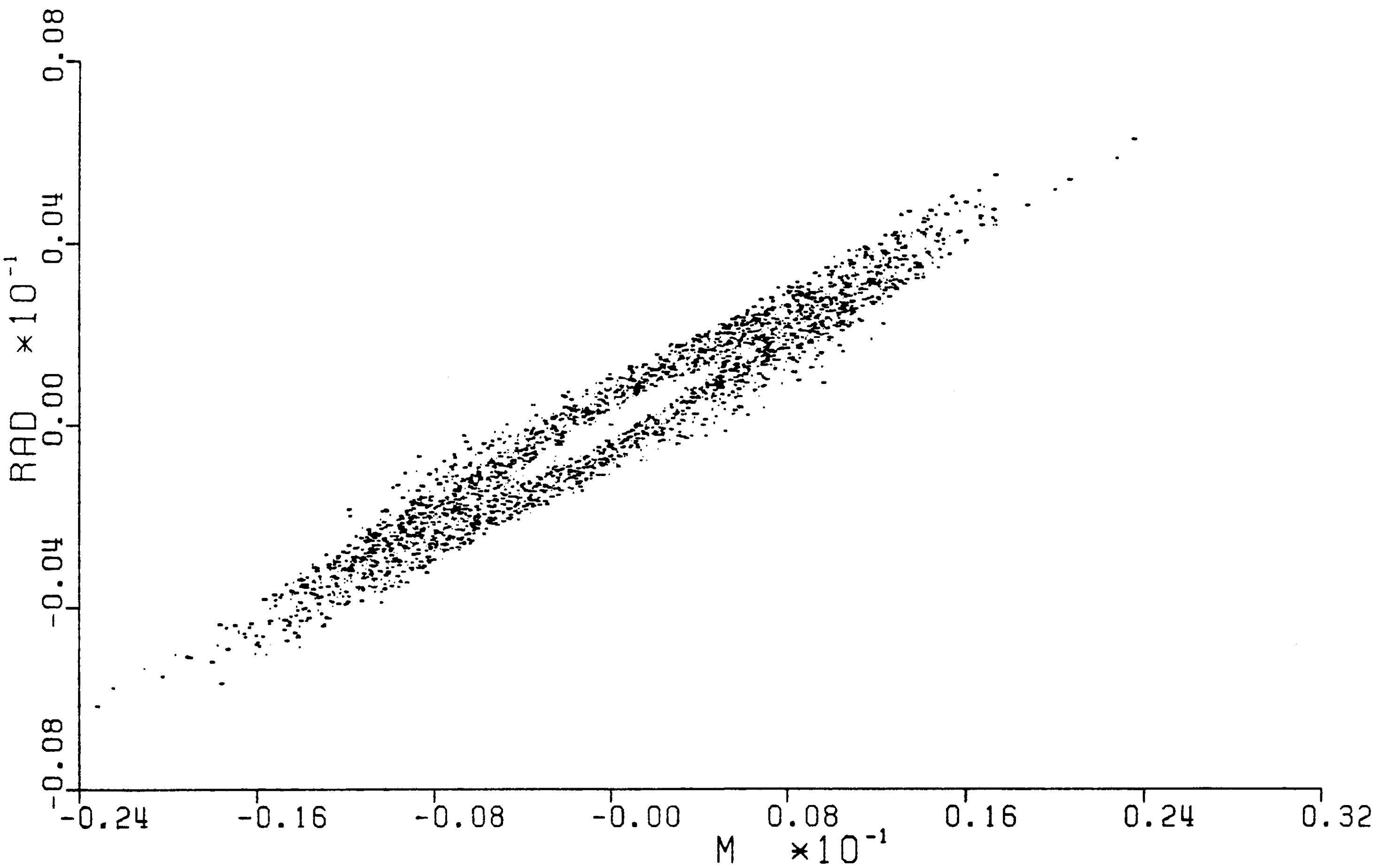
J_V : 0 - 10 in 7 steps

Last 100 turns

HORIZONTAL PHASE SPACE



VERTICAL PHASE SPACE



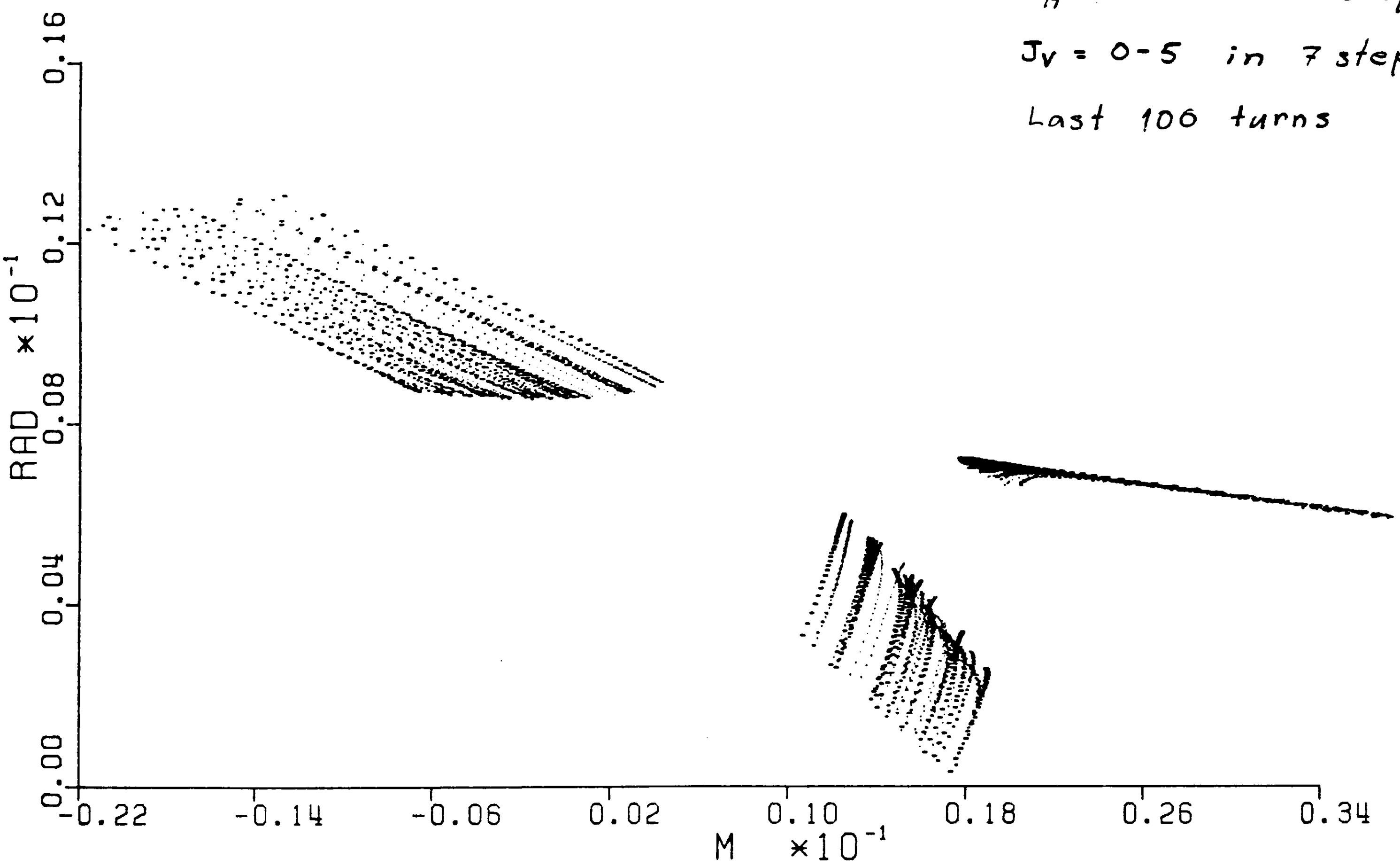
$Q_H + 2Q_V = 8$ compensated

$J_H = 0.5-5$ in 5 steps

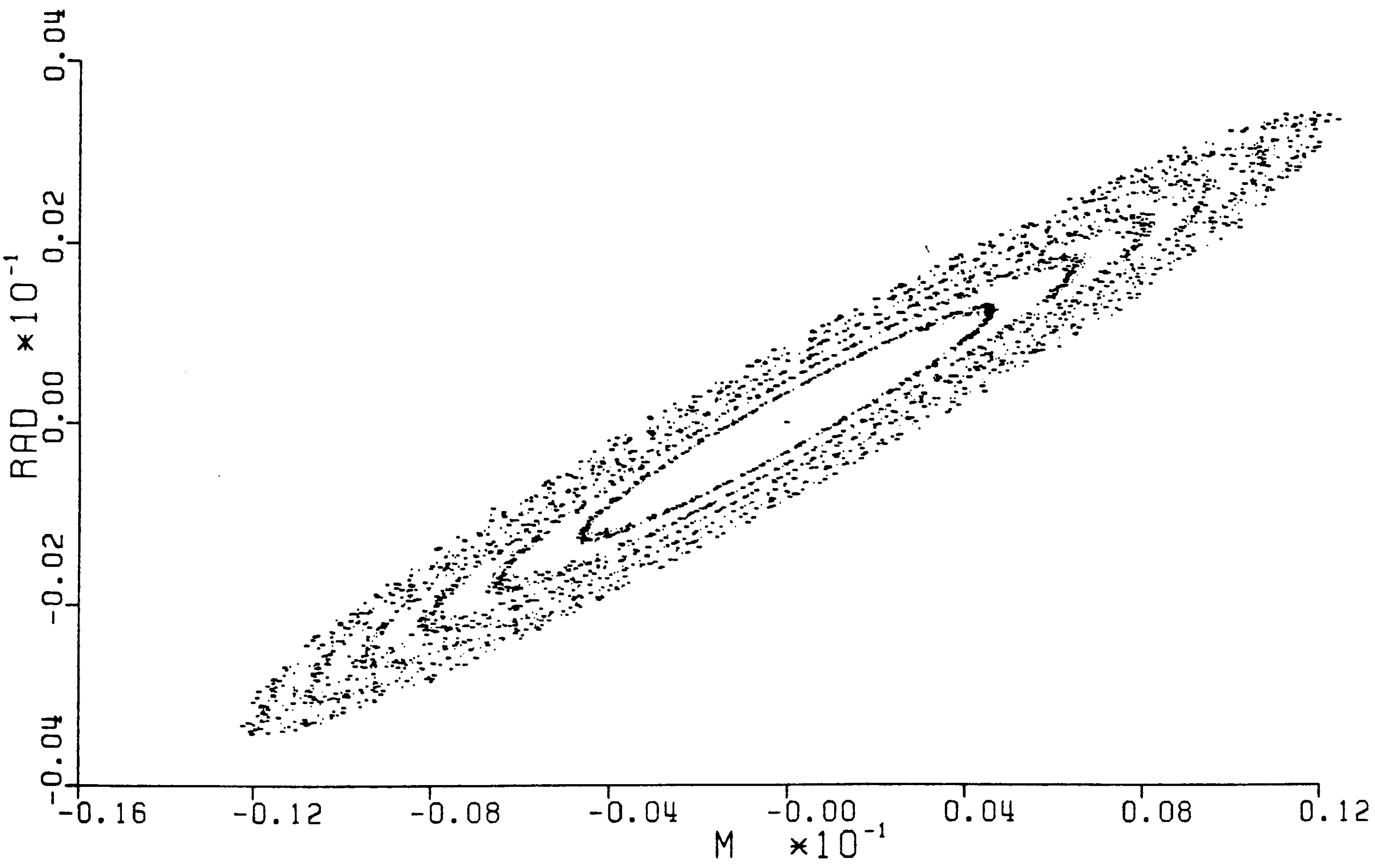
$J_V = 0-5$ in 7 steps

Last 100 turns

HORIZONTAL PHASE SPACE

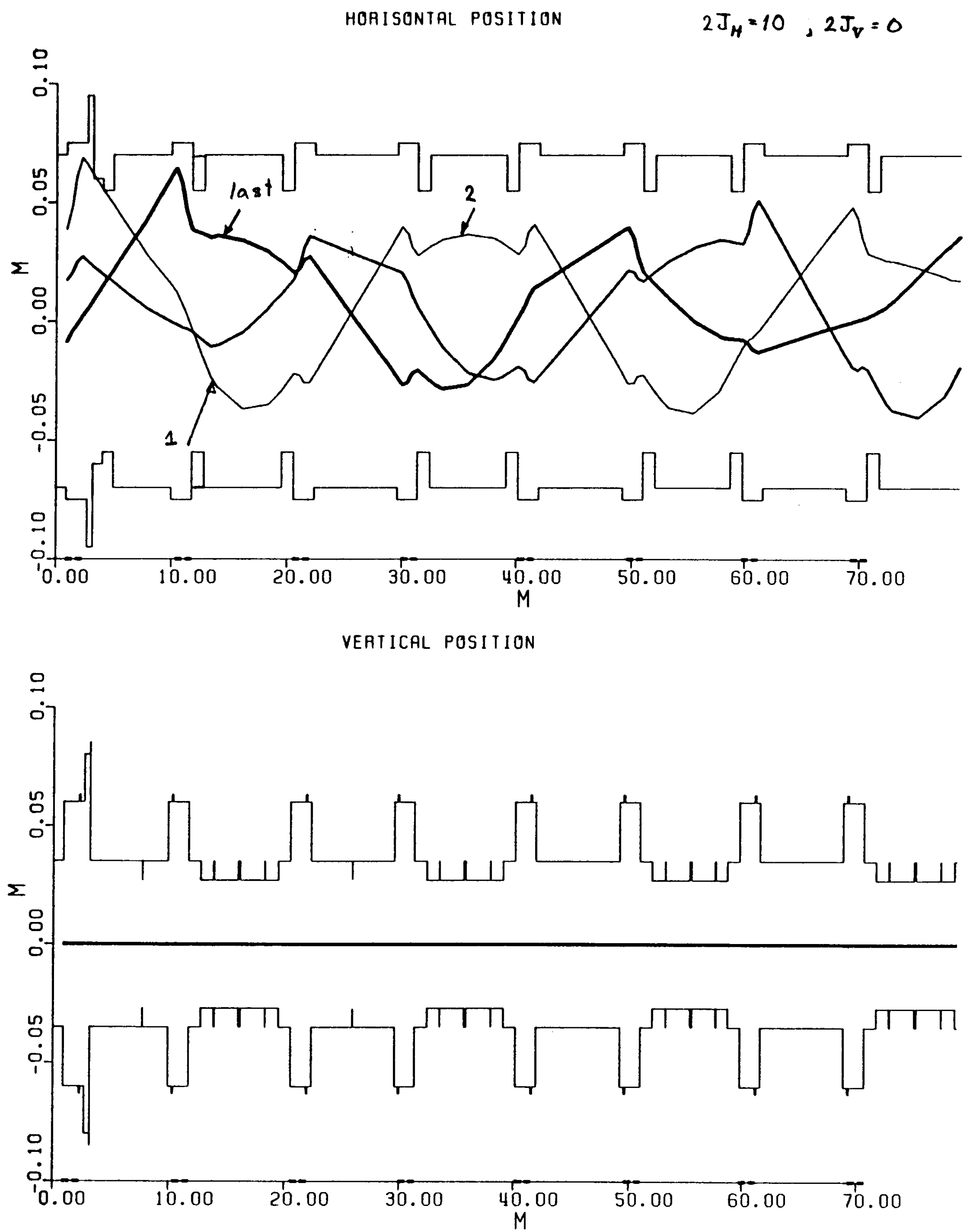


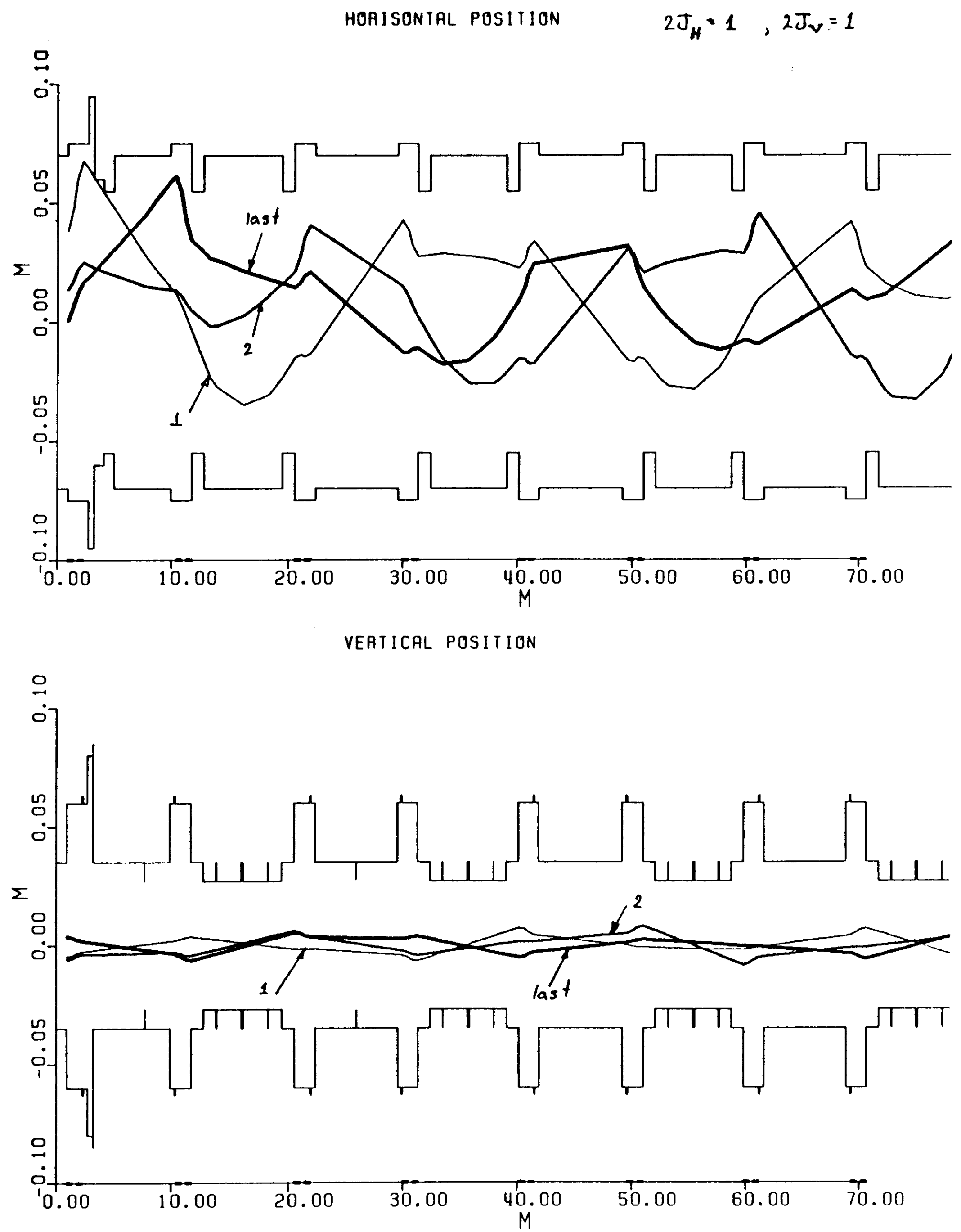
VERTICAL PHASE SPACE



APPENDIX D

Tracking of the last three turns before extraction along the machine.


HORISONTAL POSITION
2J_H = 10 , 2J_V = 0
last
2
1
M
VERTICAL POSITION
M


HORISONTAL POSITION
2J_H = 1 , 2J_V = 1
last
2
1
M
VERTICAL POSITION
2
1
last
M