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Reversible Bunch Rotation in the AGS

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Study Date: October 17, 1993

Participants: J.M. Brennan, D.P. Deng, J. Rose

Reported By: J. Rose

Machine: AGS

Beam: Gold 77^+ ions

Tools: LeCroy 7200A scope, 9040 scope, HP3562A Dynamic Signal Analyzer, F20 Wall Current monitor

1 Introduction

Because AGS will inject protons into RHIC close to, but above transition the nominal matching voltage is 19 kV, compared to 12 kV induced by the beam alone. In order to avoid control problems associated with the large transients a bunch rotation in AGS is proposed to increase the momentum spread and hence the matching voltage. A study during a gold ion run was used to prove the feasibility of a reversible bunch rotation. The process involved adiabatically reducing the rf voltage to debunch the beam and then to snap on the rf to the maximum available and letting the bunch rotate in phase space a quarter of a synchrotron period to its minimum length. Since the process takes place in the linear region at the center of the bucket there is no filamentation and hence the process is reversible. By keeping the voltage high for a half of a synchrotron period the bunch goes from its maximum length through a minimum and back to its maximum length. As the bunch returns to its original length the rf is dropped to its original (low) value and the bunch, being matched to the bucket, becomes stationary. The process can be repeated at will. In practice, there will be twelve bunches in the ring and a single bunch will be extracted into RHIC when the bunches are at their minimum length, and the process repeated for the remaining 11 bunches.

Experimental Technique

In preparation for the bunch rotation experiment the synchrotron frequency was first determined for the high and low voltage settings. It was measured by the test setup of figure 1. The dynamic signal analyzer injects a signal into the loop amplifier of the amplitude loop. There is a peak in the beam response at the quadrupole frequency which is twice the synchrotron frequency. The results are shown in figures 2 and 3.

The duration of the voltage step was then adjusted to be a half of a synchrotron period in duration. The repetition frequency was chosen to be 30 Hz which approximates the RHIC injection kicker minimum repetition rate of 33ms. In an initial study on October 6 (1993) this was unfortunately picked to coincide with the synchrotron period at the low voltage and resulted in driving the beam unstable. In the final tests the voltage floor was chosen to avoid this.

Experimental Results

Figure 4 shows the wall current monitor (WCM) (top trace) WCM peak detected (middle trace) and the voltage waveform (bottom trace). The adiabatic decrease in voltage to lengthen the bunch is seen in the voltage waveform, with the corresponding decrease in intensity on the wall current monitor. The pulses were programmed off line with 5 ms widths and 30 ms separation. The pulse widths were then adjusted online to 4.5 ms corresponding to the half synchrotron period. In figure 5 the first two pulses have been corrected, but the bunch is seen tumbling after the third pulse since it has continued to rotate past the starting point and is mismatched to the bucket.

Figures 6 and 7 show the first and second, and eleventh and twelfth bunches respectively after all the pulses had been adjusted. A high resolution trace of the twelfth rotation is shown in figure 8, showing that the bunch has maintained its shape and does not display any filamentation effects from the process.

The bunch lengths before and after the bunch rotations are shown in table 1. The scatter in the data is primarily due to the difficulty in measuring the width of irregularly shaped bunches. Using the quadrupole (synchrotron) frequencies of 223.7 (111.9) Hz and 75 (37.5) Hz and knowing $\gamma=10.1$ the rf voltages were calculated to be 280 kV_{rf} and 32 kV_{rf} respectively. From the data an average bunch length at 32 kV of 38.25 ns and 15.7 ns at 280 kV was calculated. If the 280 kV rf were used to adiabatically squeeze (focus) the bunch the resulting bunch length would be 22.1 ns, so the experiment resulted in a 30 % reduction of the minimum bunch length. The bunch and bucket parameters are shown in figures 9-11. If rf voltage alone were used to shorten the bunch adiabatically then it would require 1100 kV to achieve a bunch length of 15.7 ns, clearly impossible with the existing systems. Mountain range plots of the first and twelfth rotation are shown in figures 12 and 13. It is interesting to note the bunch shape asymmetry is preserved and flips left for right as the bunch undergoes a half synchrotron revolution between the bottom of the plots and the top.

Conclusion

The bunch rotation has been shown to be reversible, without ill effects on the beam emmittance and is therefore can be used to increase the momentum spread in proton bunches allowing the matching voltage in RHIC to be raised. Lessons learned were to avoid matching the repetition rate to the synchrotron frequency by proper choice of the voltage floor, and the sensitivity of the bunch to the duration of the rf voltage pulse. It should be noted that this experiment was performed before the AGS upgrade was implemented with the rf feedback, separate tuning servos and power supplies which would allow the high level rf to better track the drive signal without overshoot, as well allow a lower voltage floor.

Table I

Bunch Lengths During Rotation Study			
Rotation #	Before (32 kV)	After (280 kV)	Adiabatic Equivalent (280 kV)
1	40	14	22
2	37	13	
3	38	16	
4	28	16	
5	39	14	
6	36	14	
7	33	21	
8	41	18	
9	33	15	
10	56	14	
11	43	18	
12	35	15	

Quadrupole Frequency Measurement
Test Setup

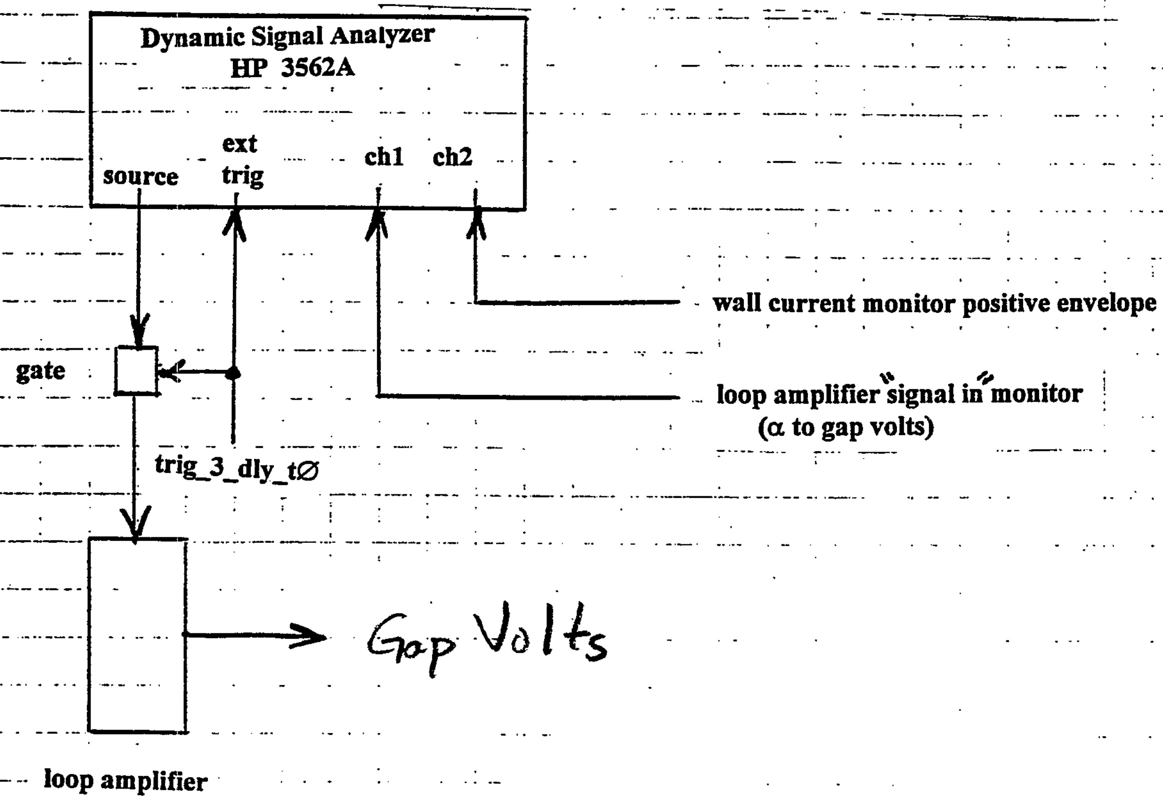

Figure 1

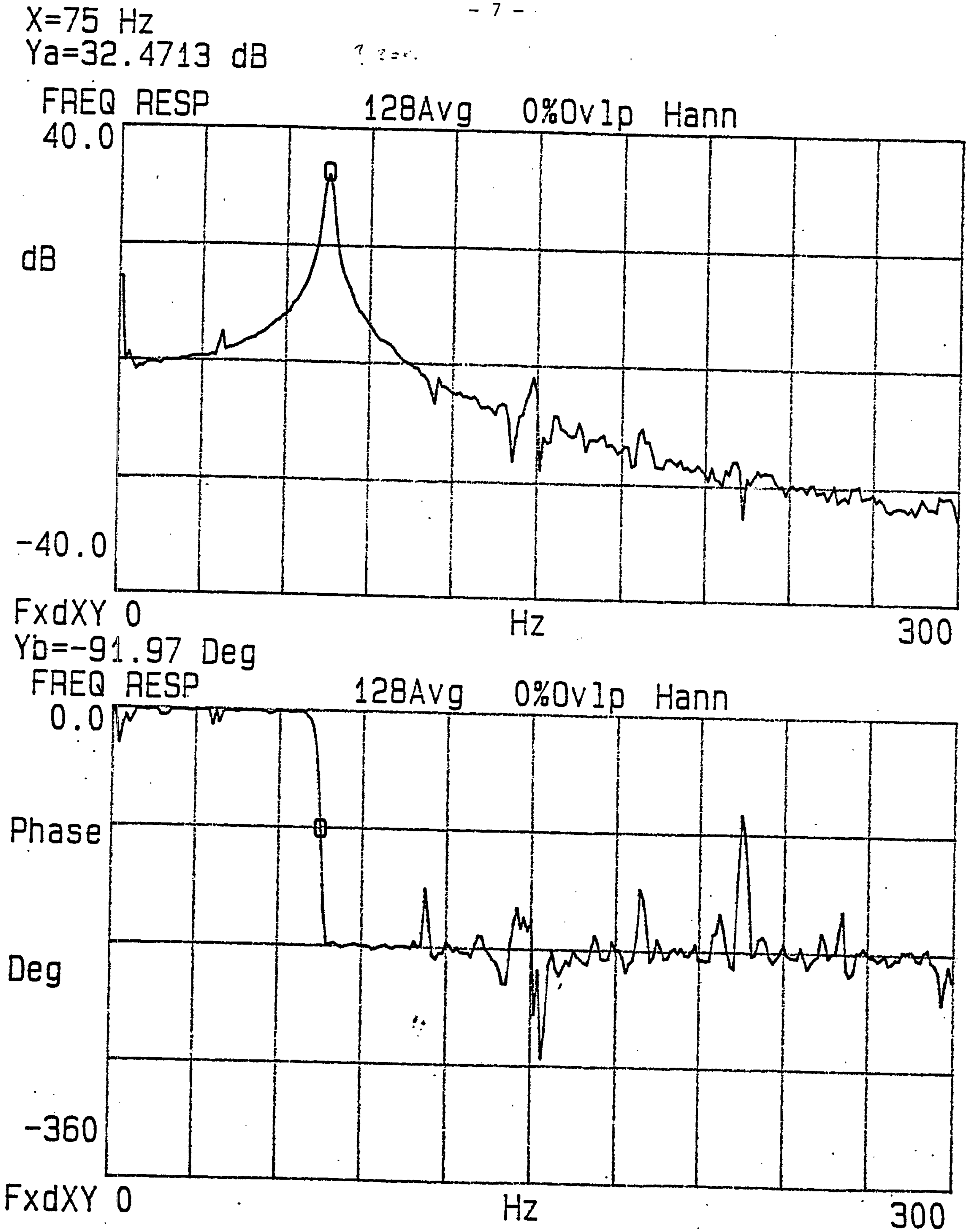
X=75 Hz
Ya=32.4713 dB
FREQ RESP
128Avg 0%Ovlp Hann
40.0
dB
-40.0
FxdXY 0
Hz
300
Yb=-91.97 Deg
FREQ RESP
128Avg 0%Ovlp Hann
0.0
Phase
Deg
-360
FxdXY 0
Hz
300

Figure 2

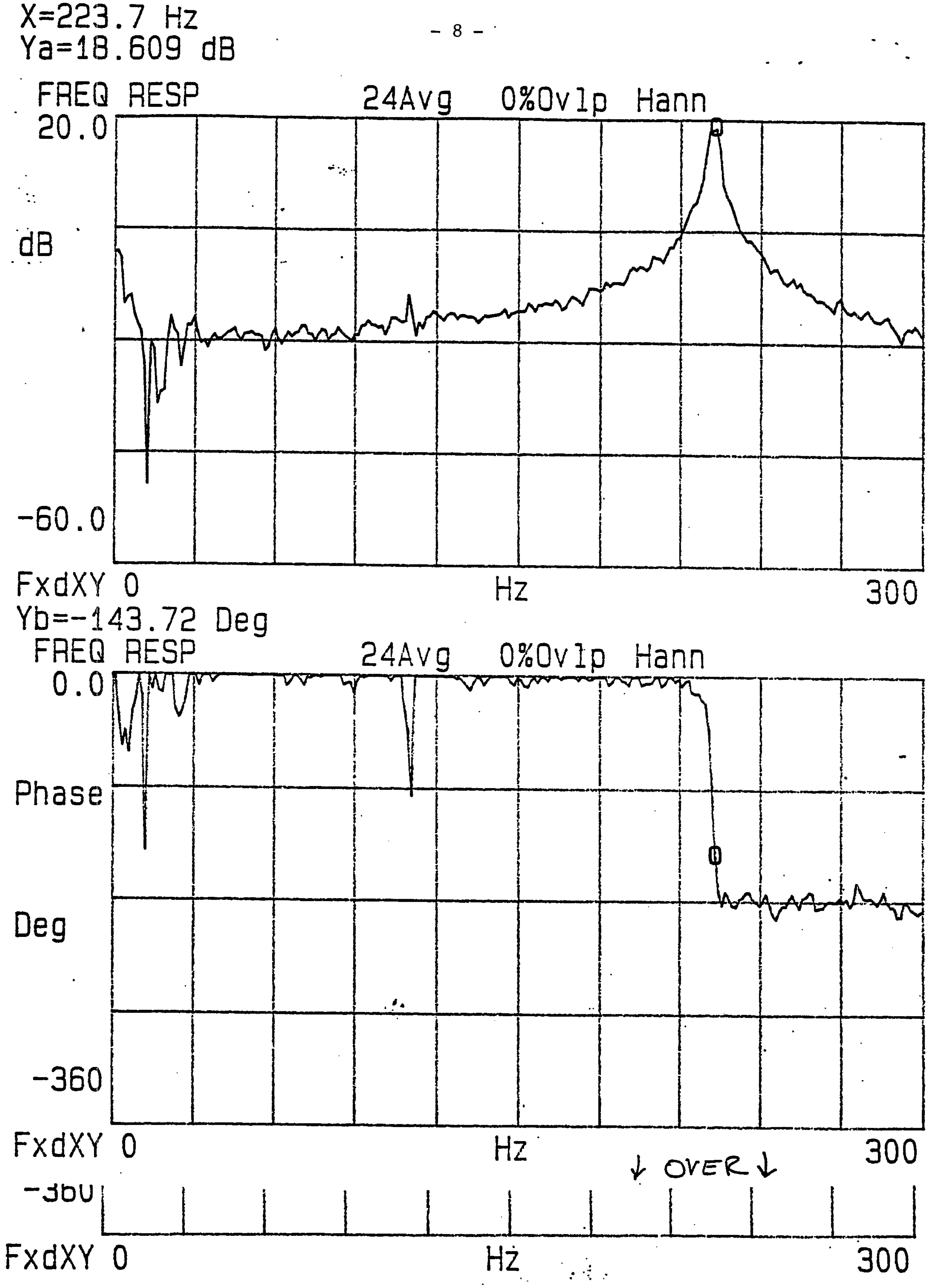
X=223.7 Hz
Ya=18.609 dB
FREQ RESP
24Avg 0%Ovlp Hann
20.0
dB
-60.0
FxdXY 0
Hz
300
Yb=-143.72 Deg
FREQ RESP
24Avg 0%Ovlp Hann
0.0
Phase
Deg
-360
FxdXY 0
Hz
300
↓ OVER ↓
-360
FxdXY 0
Hz
300

Figure 3

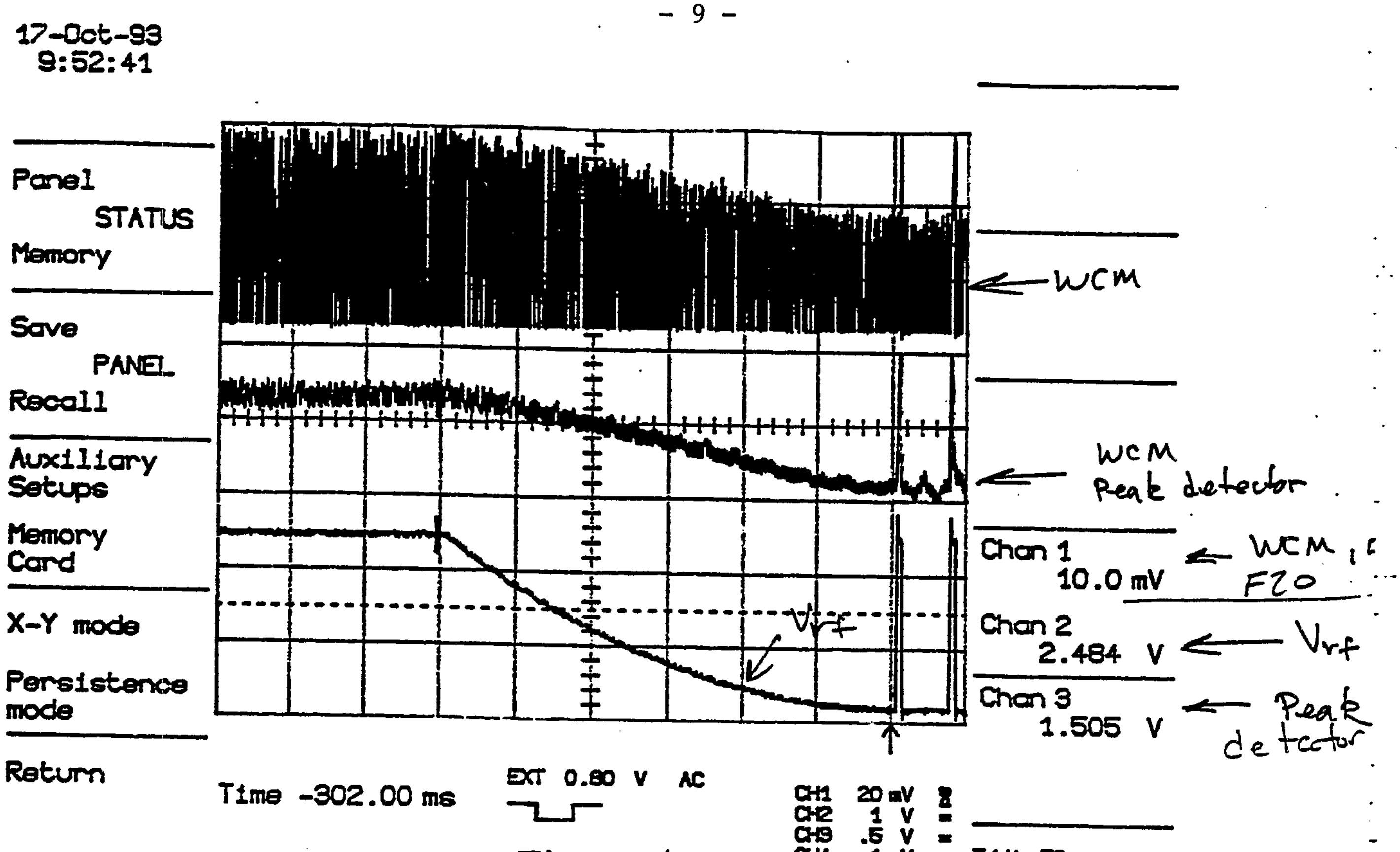

Figure 4

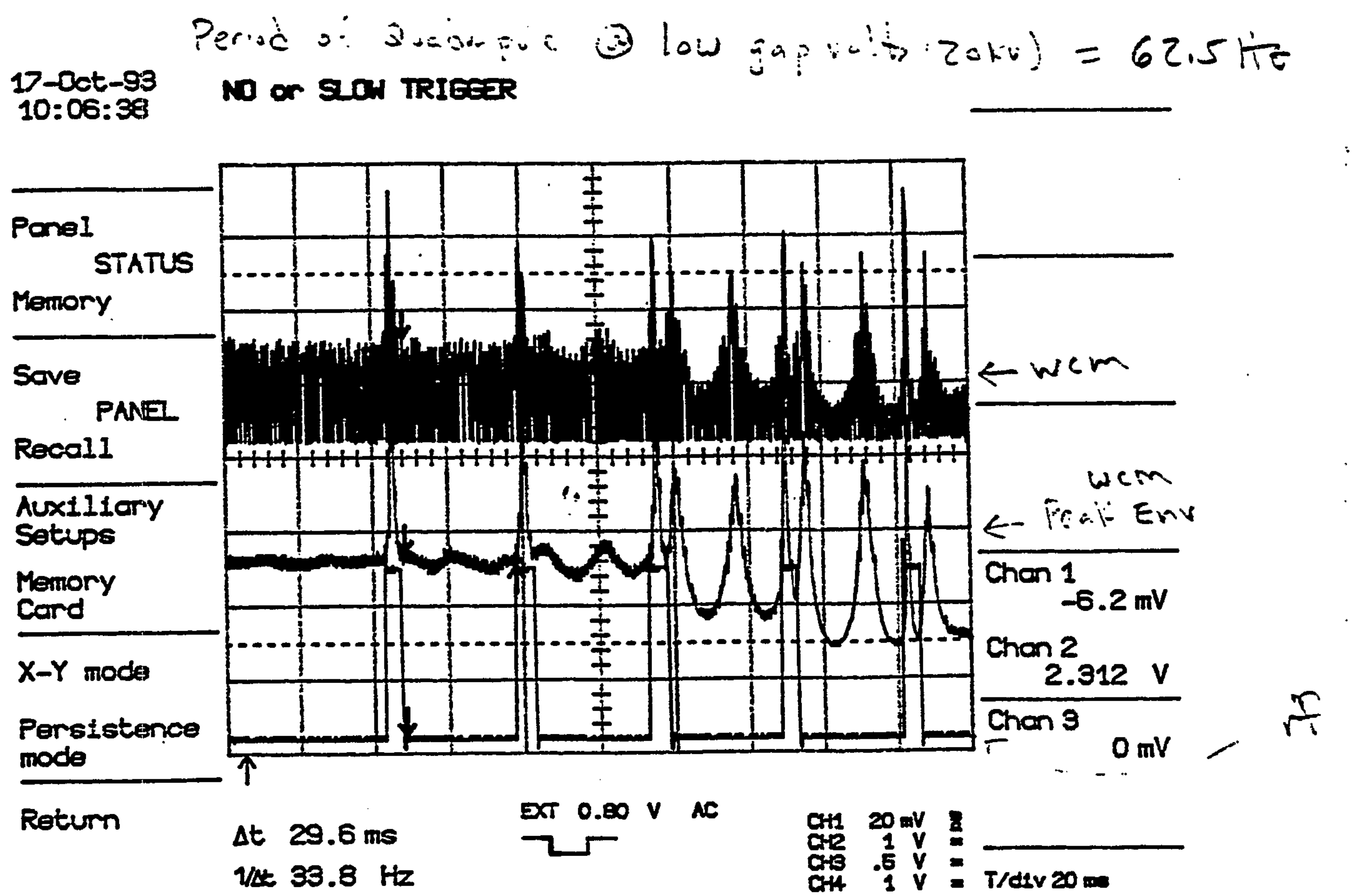

Figure 5

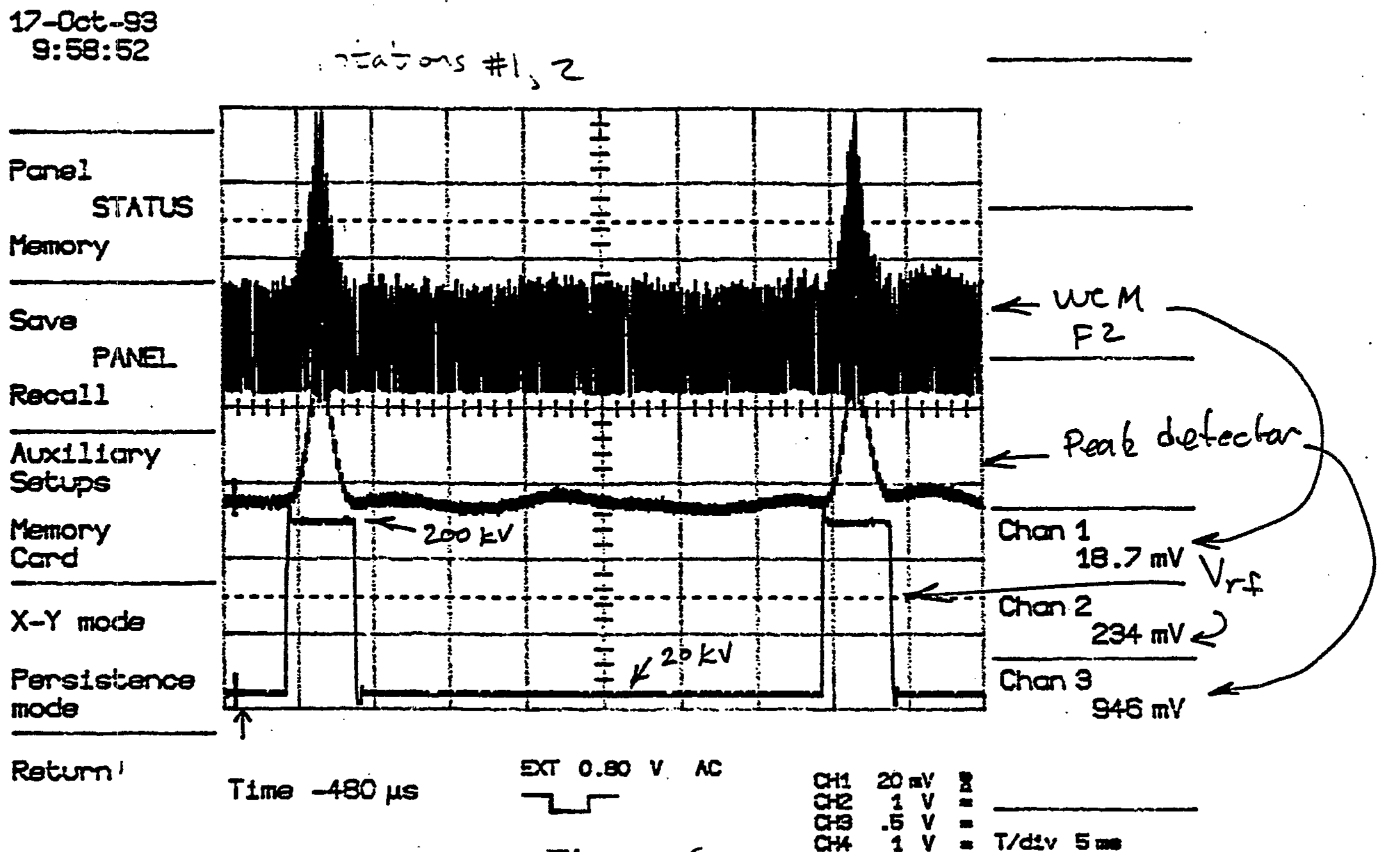

Figure 6

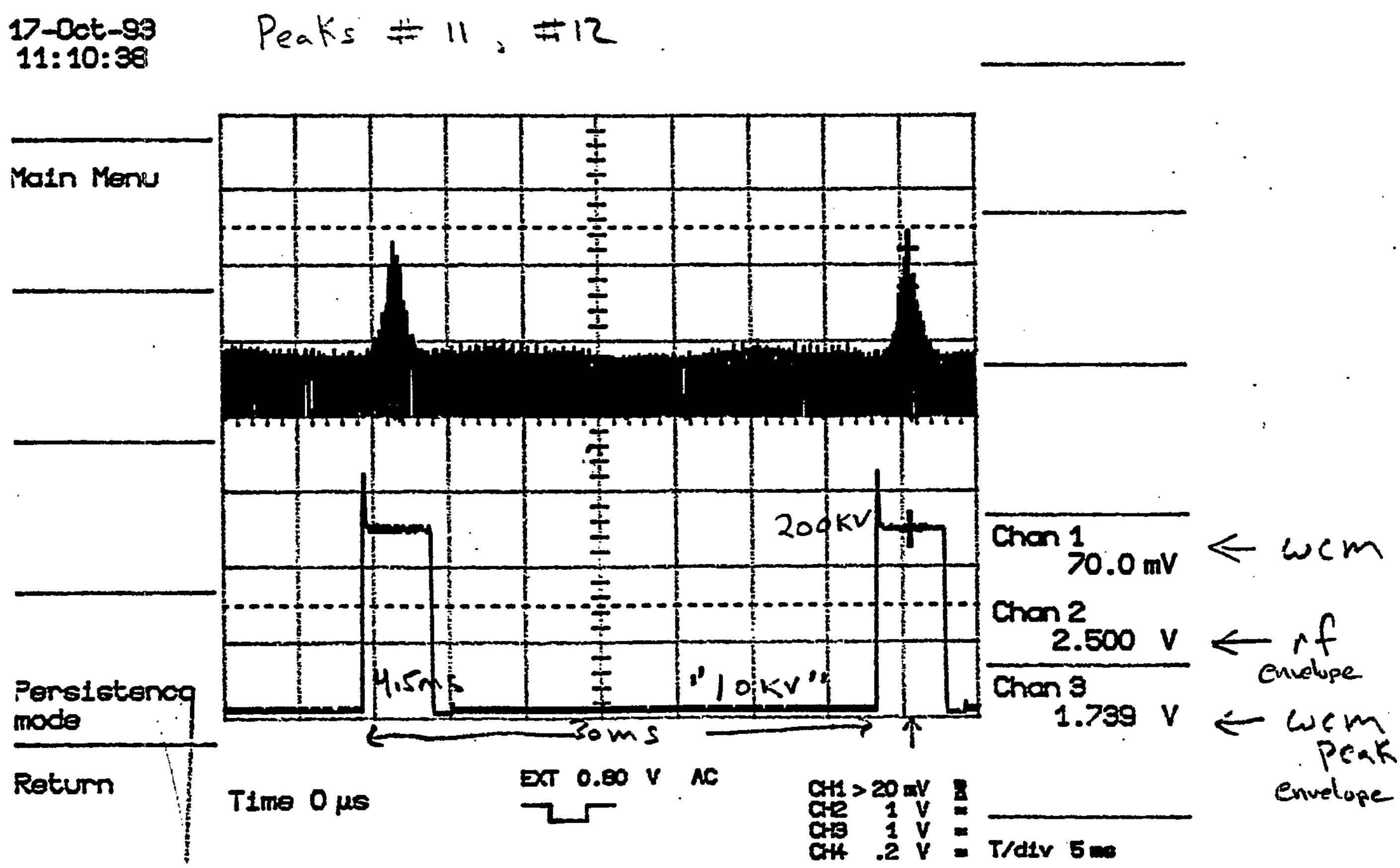

Figure 7

Narrow bunch of 12th rotation

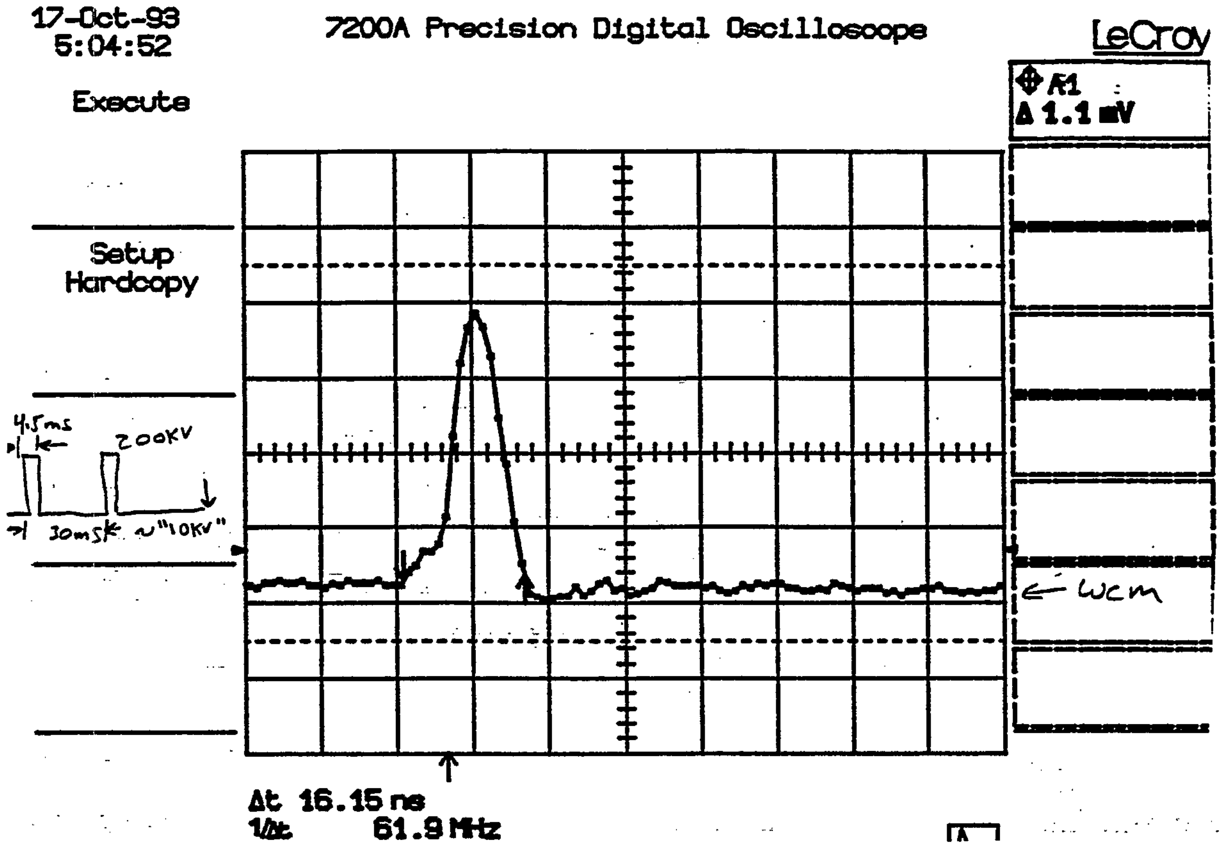

Figure 8

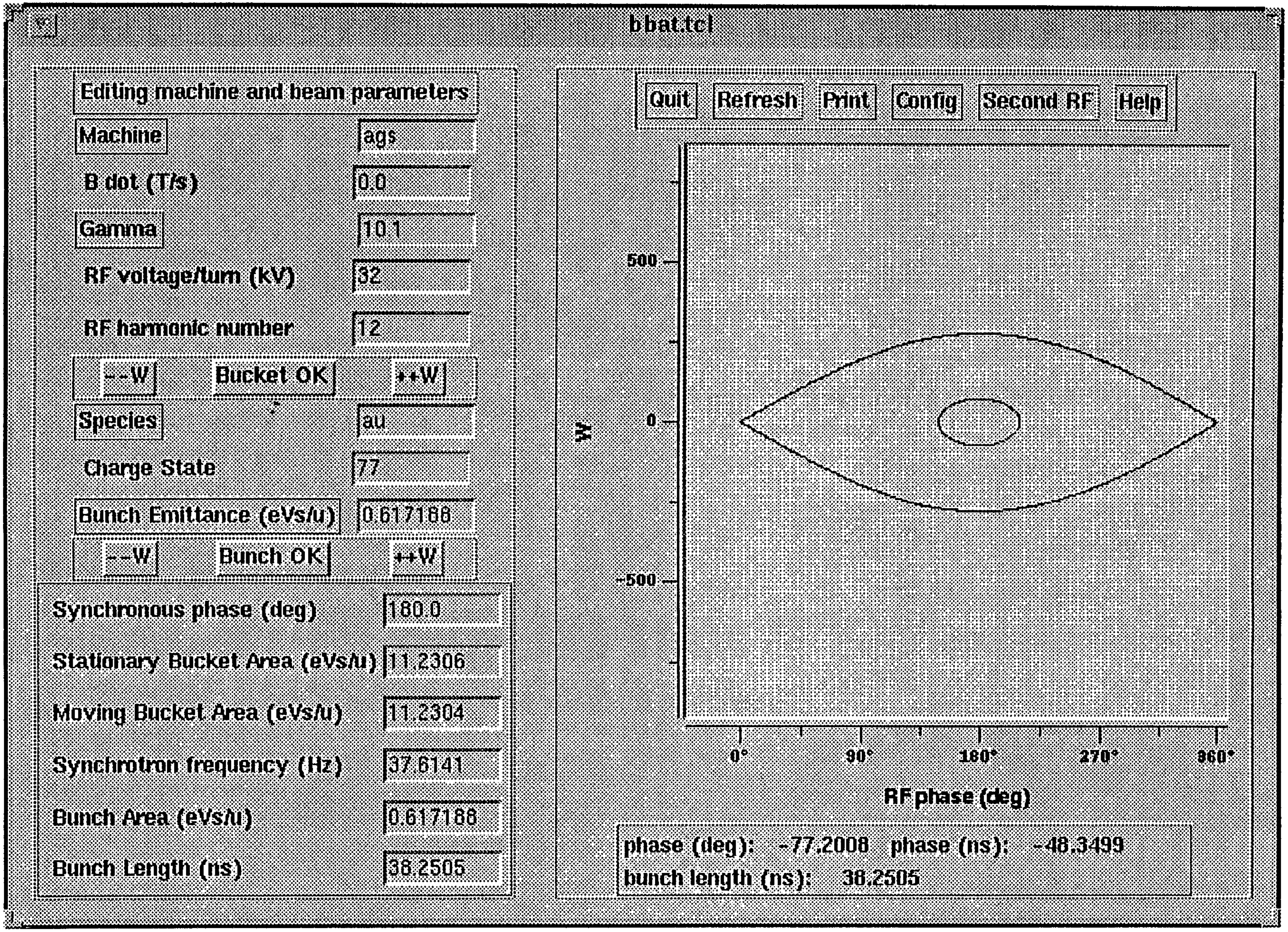
bbat.tcl
Editing machine and beam parameters
Machine
ags
B dot (T/s)
0.0
Gamma
10.1
RF voltage/turn (kV)
32
RF harmonic number
12
--W
Bucket OK
++W
Species
au
Charge State
77
Bunch Emittance (eVs/u)
0.617188
--W
Bunch OK
++W
Synchronous phase (deg)
180.0
Stationary Bucket Area (eVs/u)
11.2306
Moving Bucket Area (eVs/u)
11.2304
Synchrotron frequency (Hz)
37.6141
Bunch Area (eVs/u)
0.617188
Bunch Length (ns)
38.2505
Quit
Refresh
Print
Config
Second RF
Help
W
500
0
-500
0°
90°
180°
270°
360°
RF phase (deg)
phase (deg): -77.2008 phase (ns): -48.3499
bunch length (ns): 38.2505

Figure 9

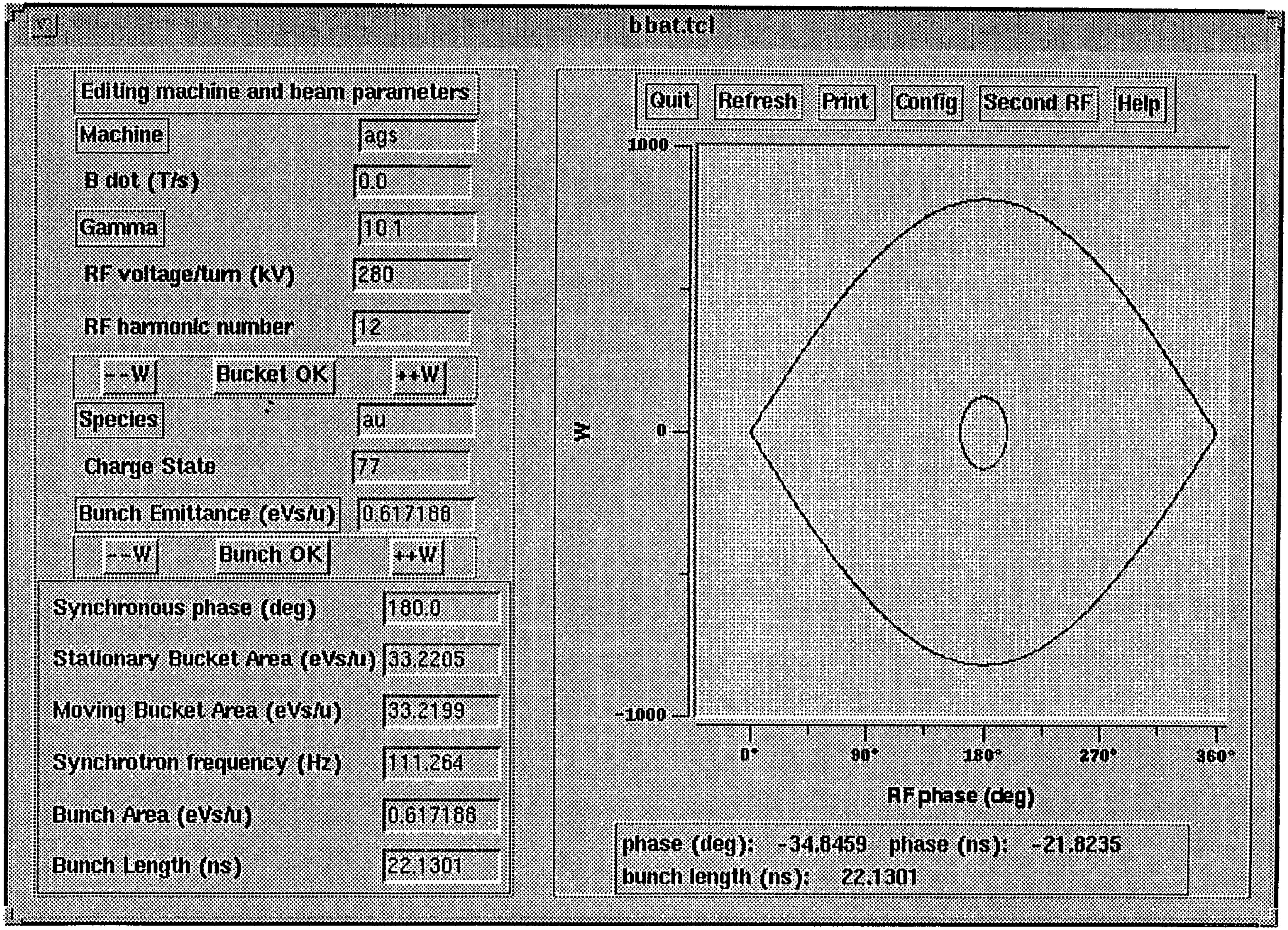
bbat.tcl
Editing machine and beam parameters
Machine
ags
B dot (T/s)
0.0
Gamma
10.1
RF voltage/turn (kV)
280
RF harmonic number
12
--W
Bucket OK
++W
Species
au
Charge State
77
Bunch Emittance (eVs/u)
0.617188
--W
Bunch OK
++W
Synchronous phase (deg)
180.0
Stationary Bucket Area (eVs/u)
33.2205
Moving Bucket Area (eVs/u)
33.2199
Synchrotron frequency (Hz)
111.264
Bunch Area (eVs/u)
0.617188
Bunch Length (ns)
22.1301
Quit
Refresh
Print
Config
Second RF
Help
1000
0
-1000
W
0°
90°
180°
270°
360°
RF phase (deg)
phase (deg): -34.8459 phase (ns): -21.8235
bunch length (ns): 22.1301

Figure 10

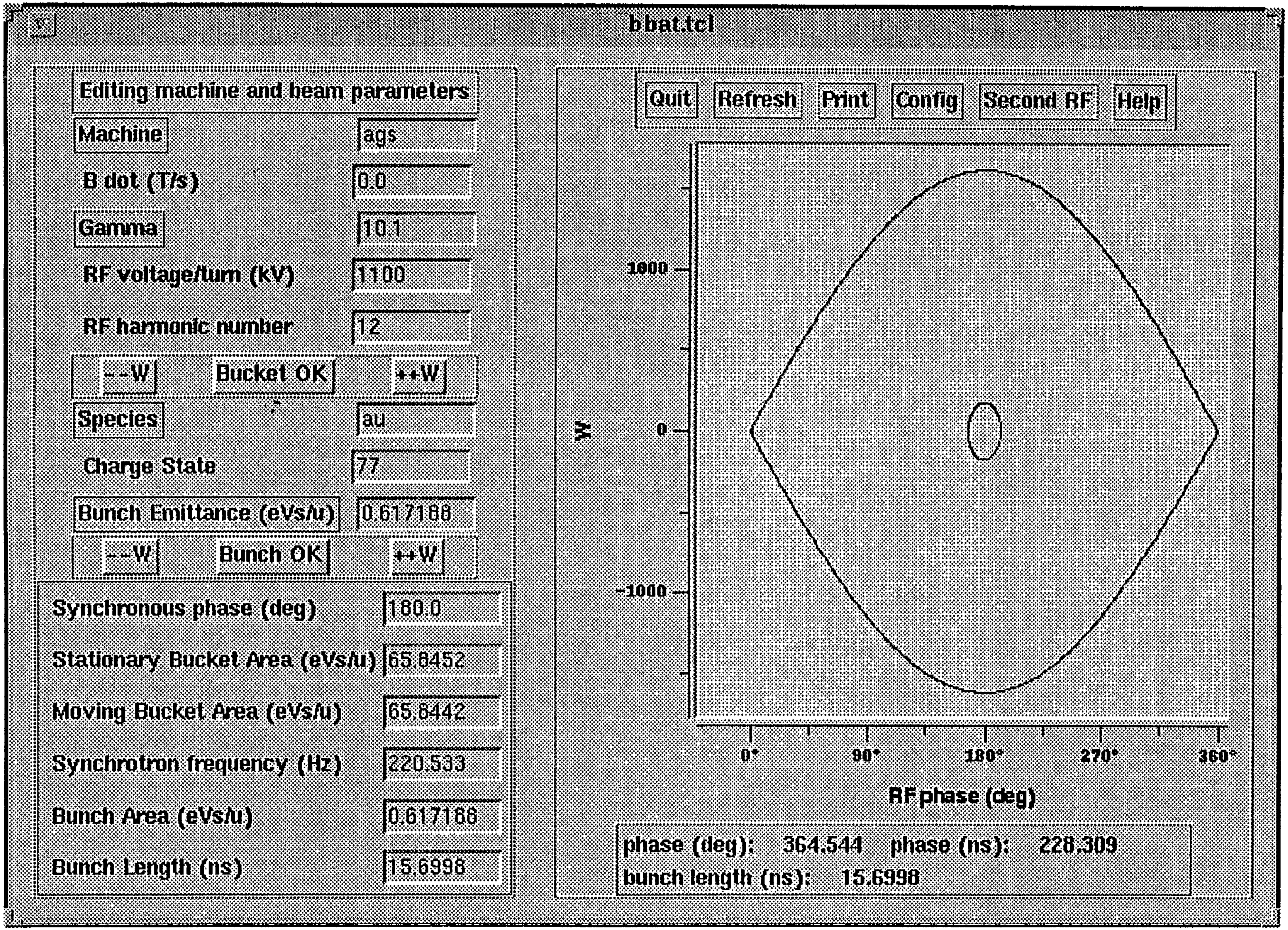
bbat.tcl
Editing machine and beam parameters
Machine
ags
B dot (T/s)
0.0
Gamma
10.1
RF voltage/turn (kV)
1100
RF harmonic number
12
--W
Bucket OK
++W
Species
au
Charge State
77
Bunch Emittance (eVs/u)
0.617188
--W
Bunch OK
++W
Synchronous phase (deg)
180.0
Stationary Bucket Area (eVs/u)
65.8452
Moving Bucket Area (eVs/u)
65.8442
Synchrotron frequency (Hz)
220.533
Bunch Area (eVs/u)
0.617188
Bunch Length (ns)
15.6998
Quit
Refresh
Print
Config
Second RF
Help
W
1000
0
-1000
0°
90°
180°
270°
360°
RF phase (deg)
phase (deg): 364.544 phase (ns): 228.309
bunch length (ns): 15.6998

Figure 11

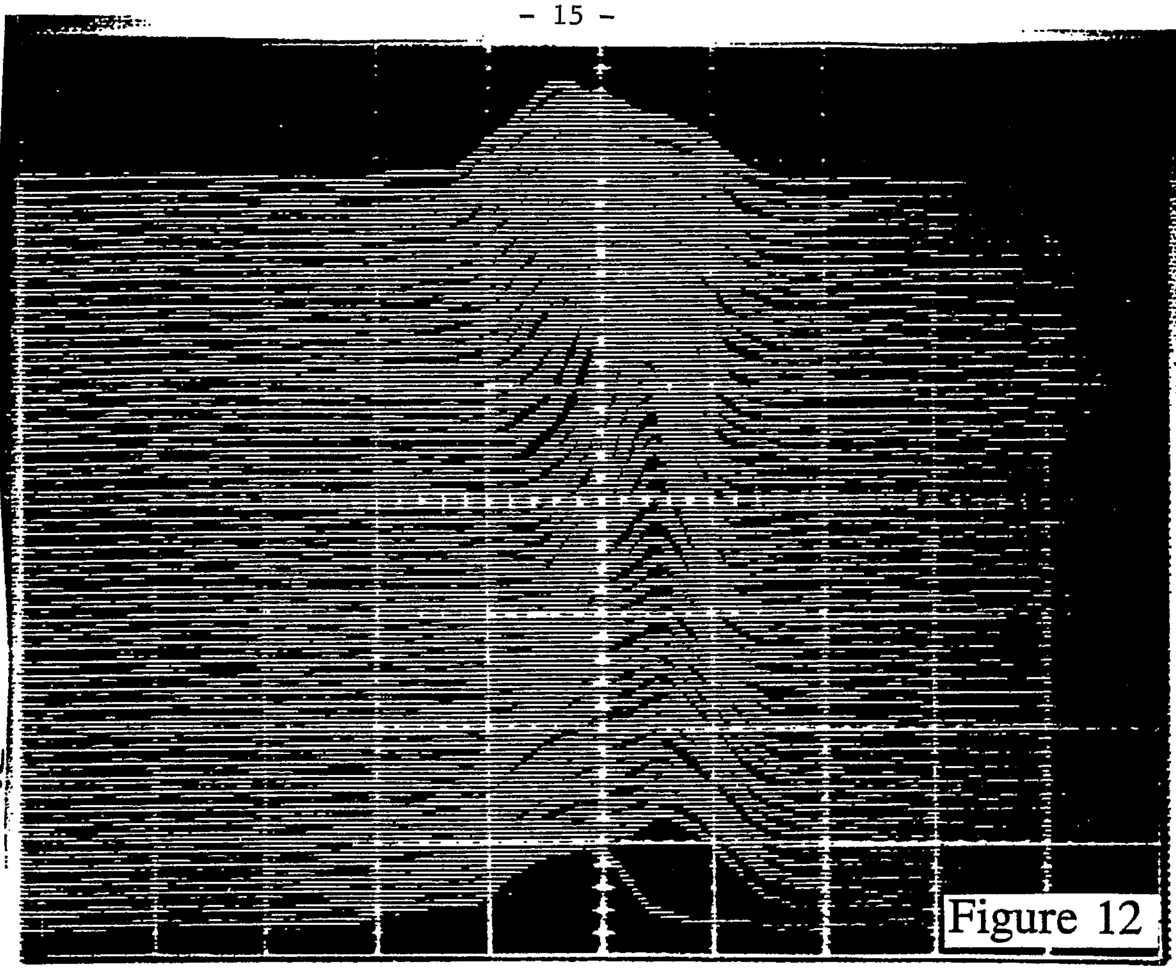

Figure 12

1st Compression " " 10 ns/div, 32 turns/trace 12th Compression

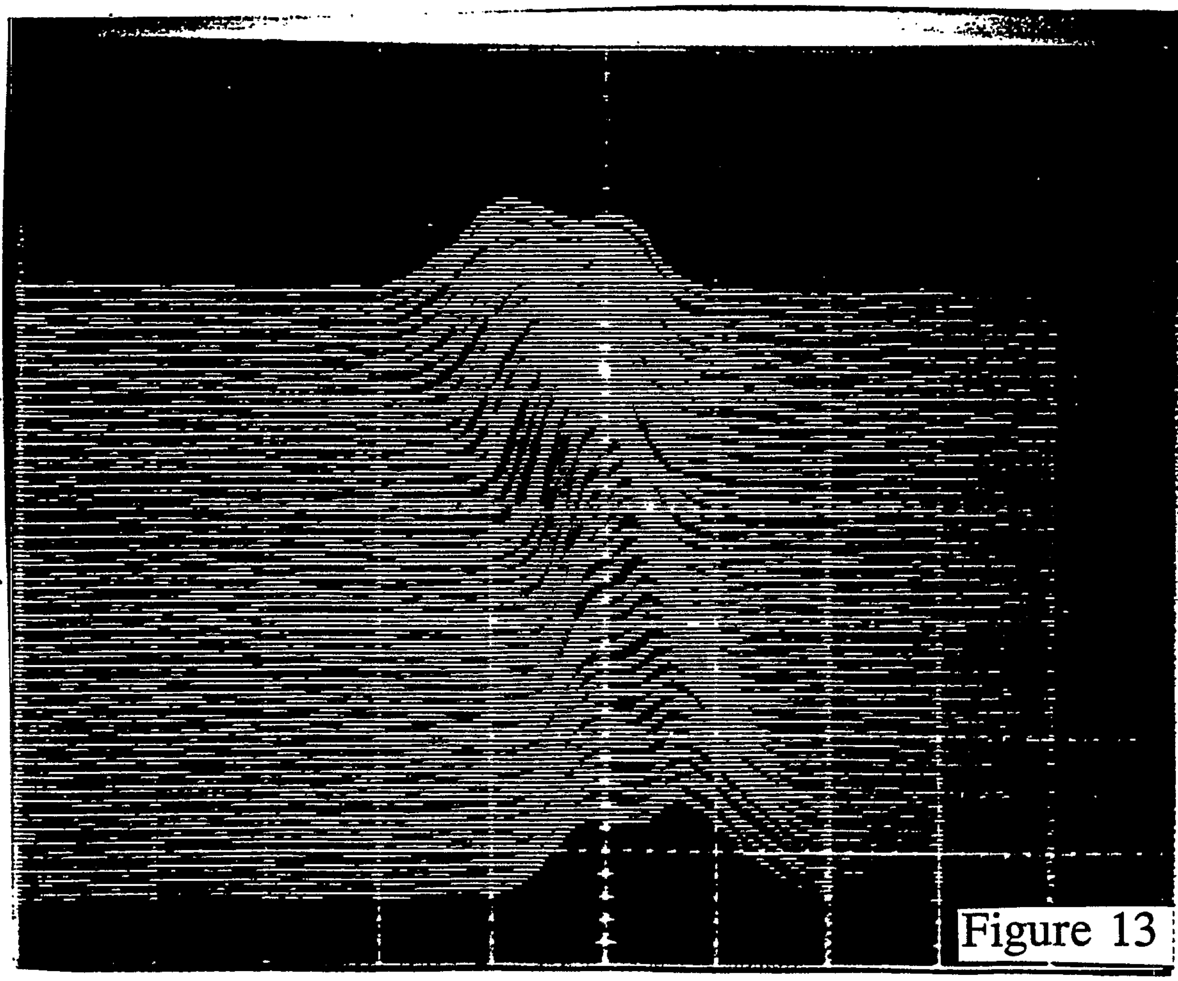

Figure 13