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Bunch Tearing, Initial Observations

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Observations and Conclusion

This note describes an effort to better understand a rather peculiar and destructive beam loss phenomenon which has been observed over the past year during AGS fast beam operation. The particular signature of this phenomenon is the loss, sometimes totally, of a small fraction of the 12 AGS bunches, as observed in the extraction channel, while the remaining bunches maintain full intensity.

The studiers first managed to cause the loss to occur, and then adjusted a few machine parameters and observed whether as a result the loss condition was present or absent.

To repeat, the loss under discussion is observed during FEB operation. The beam is extracted through rather snug vertical and horizontal apertures. The characteristic observation is that some of the twelve bunches are only partly extracted while others come out at full intensity. On some cycles just a single bunch is affected, but that bunch is essentially completely lost. Apparently then this is a single bunch phenomenon. The IPM associates slightly larger transverse sizes with acceleration cycles destined to tear. The longitudinal wall monitor has yet to distinguish good from bad cycles. The extraction loss observations use a current transformer in the U-line with sufficient time resolution to separate bunches though not sufficient to see the longitudinal structure within the bunch. This "few bunch" loss will be referred to as bunch tearing.

The machine was tuned up to high intensity with a relatively clean (0.5×10^{12} loss) passage through transition. Then a procedure which has on occasion caused the tearing, namely shifting the radius by a small amount for a 200 ms interval somewhat after transition (see Figure 1), was tried. A shift of a little over a millimeter to the outside caused the effect to begin to show up. A larger shift wiped out all the bunches.

A radial shift causes a tune shift - at this momentum essentially a horizontal tune shift only (see Appendix) - and the first exercise was to investigate if that aspect of the radial shift was responsible for the presence or absence of tearing. To that end coherent tune shifts were measured, and the tune shift due to radial motion more or less duplicated by tune shifts using the high field quadrupole string. Table I gives the observations. Line 1) is the starting situation. Line 2) describes the original tear-associated radial shift from the point of view of tune shift. In line 3) the quads are powered to replace the radial shift tune shift and the radius is returned to what had been a stable position. Tearing was observed. Line 4) starts from 3) and attempts successfully to compensate for the quad horizontal tune shift with further radial tune shift. Finally, somewhat later, and from an undocumented but tearing 5) starting situation, the quads were powered in the opposite direction 6) and stability returned. The tentative conclusion from the above is that indeed horizontal tune is the relevant parameter which moves the beam from a stable cycle to a tearing cycle.

Having established ν_H as the relevant parameter, the next question addressed was whether the tune could be moved down sufficiently to again gain a stable machine. This was studied using the radius to shift the tune. A shift of radial shifter 4 (RS4) = 150 restored stability. Table II(see also Figure 2) gives the associated tune interval, this from direct coherent tune measurements.

Machine tuning at injection, capture, and early acceleration continued throughout this period and the radial shift needed to cause tearing was observed to increase. RS4 = 0 had resulted in tearing but was now stable; tearing began at ~ RS4 = +15 counts. This is not explained, it was not a change in radius or radial loop reference (the PUE's associated the same average radius with the -25 command as they had earlier). Further it was presumably not due to a change in residual tune as that would have greatly affected injection.

The case 2) of Table II was that present at highest intensity. The low tune side (large radius) was not truely stable at any setting. Some beam was extracted at 180 RS4 counts. The tunes listed are calculated from the radial position, assuming radius and tune have a fixed relation (Figure 2).

The hypothesis then was that we wanted to avoid a horizontal tune in the vicinity of 8.67 for the 200 ms time interval around 17 GeV/c, and as tuning went on that interval was getting harder to avoid on the lower side (but easier on high side?). A reasonable move was then to power the horizontal sextupoles during the interval with a polarity to reduce the magnitude of the horizontal chromaticity. This done, line 3) of Table II resulted. A stable region again existed if a positive radial shift were applied. The interpretation of this result is difficult in the spirit of avoiding tune in the vicinity of 8-2/3. However the tune evaluation requires extracting radial shift from shifter command, chromaticity and sextupole center line from measurements made at another time. The result is sensitive to these assumptions which are tabulated on the appendix.

A final study was made using this relatively stable machine, this to measure the inside radius where tearing first was observed as a function of machine intensity. The intensity was varied by varying the width of the current pulse injected from the linac. Table III is the result, the intensity was first reduced and then increased again, the results repeated nicely. If the edge is a measure of the region of tearing, the effect first gets stronger as intensity is reduced, and then weakens a bit. A very curious observation.

Changing the chromaticity with the sextpoles was meant to give an almost redundant confirmation that it is the horizontal tune which causes the bunch tearing. However, the elaboration of the experiment result has been confusing for the interpretation of the effect. If the polarity of the sextupole power supply were reversed, line 3b of Table II would result, which would fit the tune hypothesis. The shift of the upper edge of the unstable region from +15 counts to −30 counts with sextupoles is also only consistent with a negative change of chromaticity since the beam radius at this time was positive relative to the sextupole centerline and hence a decreasing chromaticity would reduce the beam tune pushing it into the unstable region, which then would be compensated for the required inward radial shift. However there is no reason to believe the sextupole polarity was reversed.

There is a strong suggestion in these observations that bringing the beam near the horizontal 8 2/3 stopband will initiate bunch tearing and that there are regions of stability on either side. Moreover, observing the beam size as a function of time on the IPM shows that the beam first starts growing in the horizontal plane and later in the vertical plane. The final event is the vertical scraping of the beam tails on the extraction apertures. Why all this, at least in its mildest manifestation, affects only individual bunches is not clear. During this first systematic study of the phenomena we may very well not have had consistent control over all the relevant parameters and we are not yet able to fully characterize the events. Needless to say, much work awaits us when we again have a high intensity machine to study.

TABLE I

	Radial Shift "4" command	Horizontal Quad current (amps)	State	$\Delta\nu_{hori}$	$\Delta\nu_{vert}$
1)	-25	0	stable	(8.73)	(8.75)
2)	0	0	tear	-.015	-.002
3)	-25	-25	tear	-.036	+.018
4)	-70	-25	stable	-.036 +.027 = -.009	+.016
5)	α	0	tear	X	-
6)	α	+25	stable	X +.036	-

TABLE II

Horizontal Tune Interval Associated with Tearing

1) Original machine

+150 cnts $\geq$ RS4 $\geq$ −25 cnts

$8.61 \pm .013 \leq \nu_H \leq 8.73 \pm .013$ (measured)

$\Delta\nu_H = .12 \pm .026$ $\overline{\nu_H} = 8.67 \pm .013$

2) Tuned machine

(+180 cnts) $\geq$ RS4 $\geq$ +15 cnts

unstable point

(8.61) $\leq \nu_H \leq 8.706$ (calculated)

3) Tuned + sextupoles

90 cnts $\geq$ RS4 $\geq$ −30 cnts

Δ R = .55 cm

a) $\Delta\xi = +0.8$: $8.68 \leq \nu_H \leq 8.73$ (calculated)

$\Delta\nu_H = .05$ $\overline{\nu_H} = 8.705$

b) $\Delta\xi = -0.8$: $8.63 \leq \nu_H \leq 8.72$ (calculated)

$\Delta\nu_H = .09$ $\overline{\nu_H} = 8.67$

TABLE III

Intensity	Radial Shifter 4 Stable	Radial Shifter 4 Tearing	Threshold $(\nu_{\#})_{cal}$
16×10^{12}	+ 10	- 12	8.70
8×10^{12}	- 22	- 20	8.72
4×10^{12}	- 10	- 6	8.71
8×10^{12}	- 22	- 18	8.72
16×10^{12}	+ 12	+ 14	8.70

Appendix

The measurements were made at:

415 ms from T_0

365 ms from injection "peaker"

33,000 Guass counts ≃ 17 GeV/c

r ≡ average of the horizontal PUE system (zero = beam coordinate axis)

RS4 ≡ radial shifter level 4, set to control the radius at above time

$\Delta r/\Delta(RS4) \simeq 0.46$ cm/100 counts

Horizontal chormaticity (ξ_H) @ 17 GeV/c - 2.45*

Vertical chromaticity (ξ_V) @ 17 GeV/c - 0.3

Effect of the 8 horizontal sextupoles:

$$\Delta\xi_H = 0.135\ I/P\ \left[\frac{GeV/c}{Amp}\right]$$

$$\Delta\xi_V = -\ 0.064\ I/P\ \left[\frac{GeV/c}{Amp}\right]$$

$$\frac{\Delta\nu}{\Delta r} = (0.05)\ (\xi)\ cm^{-1}$$

High field quads: $\begin{pmatrix}\Delta\nu_H \\ \Delta\nu_V\end{pmatrix} = (0.0218)\left(\frac{P_{inj}}{P}\right)\begin{pmatrix}2 & -1 \\ -1 & 2\end{pmatrix}^{**}\begin{pmatrix}I_H \\ I_V\end{pmatrix}_{amps}$

Sextupole center = - 0.4 cm (PUE system)

*AGS Study Note #182.
**The signs in this matrix are not necessarily time independent.

Fig. 1

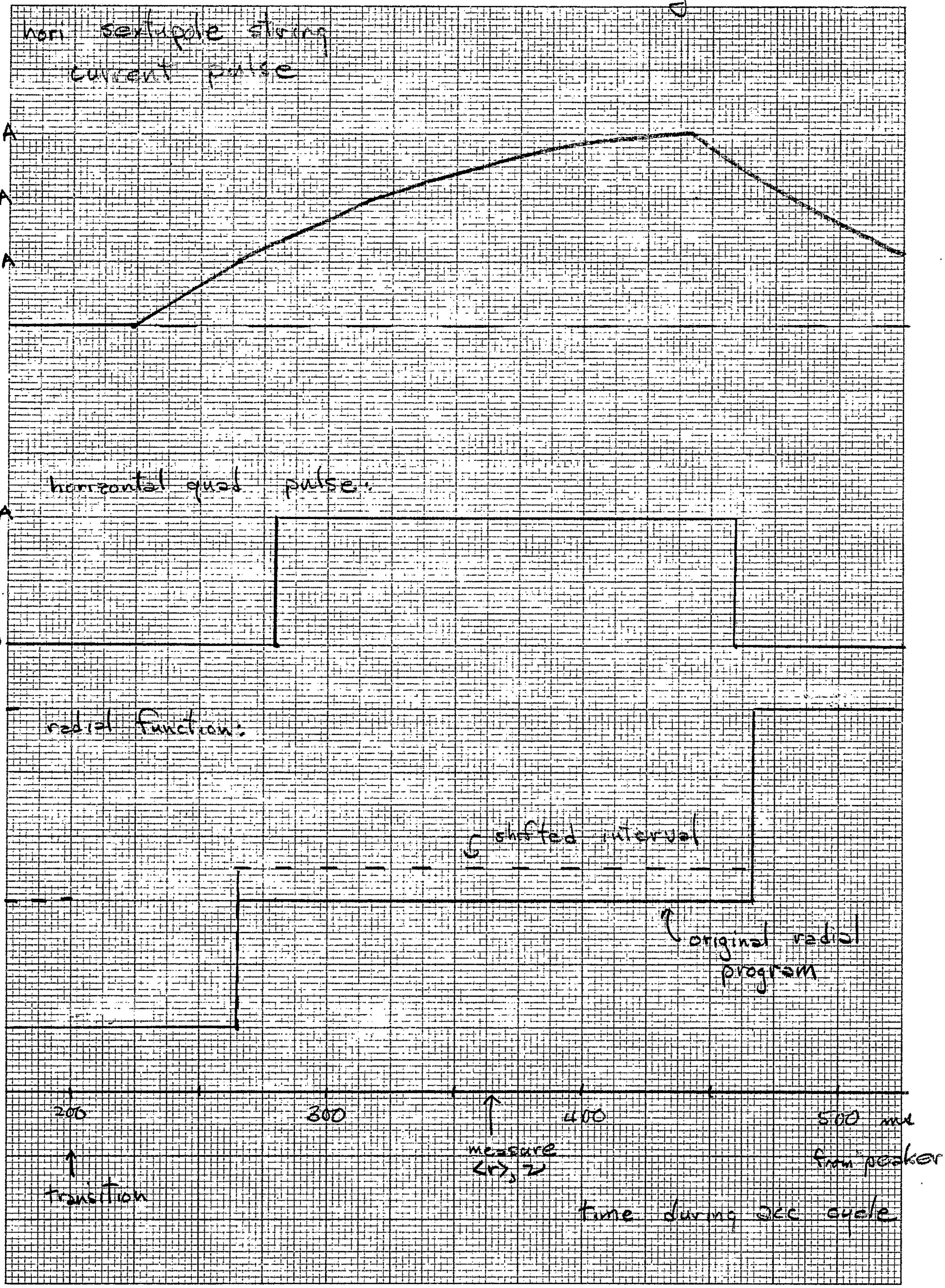
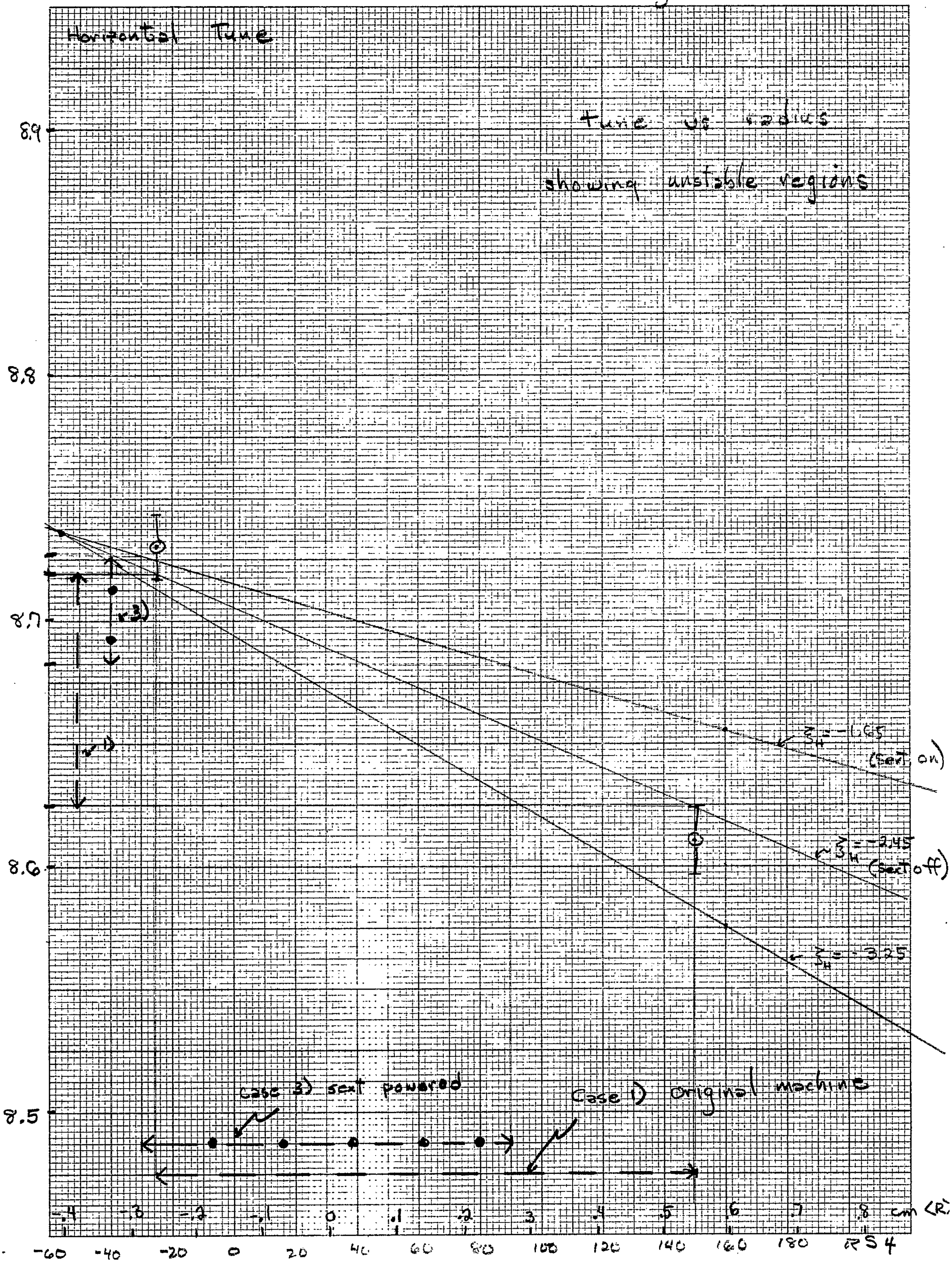

hori sextupole string current pulse
150A
100A
50A
horizontal quad pulse.
25A
0
149
radial function:
shifted interval
-25
original radial program
-105
200
300
400
500 ms from peaker
transition
measure <r>, z
time during acc cycle

Fig. 2



Horizontal Tune
tune vs radius
showing unstable regions
8.9
8.8
8.7
8.6
8.5
3)
1)
$\xi_H = -1.65$
(Sext on)
$\xi_H = -2.45$
(Sext off)
$\xi_H = -3.25$
case 3) sext powered
Case 1) original machine
-.4
-.3
-.2
-.1
0
.1
.2
.3
.4
.5
.6
.7
.8
cm (R)
-60
-40
-20
0
20
40
60
80
100
120
140
160
180
RS 4