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Vertical Tune Measurements at Slow Extraction

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Subject: Vertical Tune Measurements at Slow Extraction

METHOD

In order to be able to measure vertical tune (ν_v) vs. radius during flat top, the RF was left on to 1 sec after t_o. A time interval between 650 and 880 ms. was available for tune measurements with bunched beam and the radius was controlled by a single radius shifter (RS7) during this time interval. The beam was then extracted to the C target between 1100 ms. and 1800 ms. H20 was retracted and the H20 loss monitor was defeated. Thus, although F5 losses were high, most of the beam left the machine. Measurements were made at 800 ms. by exciting coherent vertical motion at frequency f_v using the E20 tickler. Twelfth harmonic rotational frequencies (the r.f. frequency), f_r, were measured*, as well as average radii, $\hat{Y}$, using PUE's, and program ORBED.

The following functional dependencies were observed: i) ν_v vs. vertical quad strength over a limited range, ii) ν_v vs. $\hat{Y}$ for various horizontal sextupole strengths with skew quads at operating set point, iii) ν_v vs. $\hat{Y}$ with skew quads off, and iv) ν_v vs. $\hat{Y}$ with the $3/2\lambda$ H extraction bump off.

RESULTS

Vertical tunes were calculated using $\nu_v = 9-12\ f_v/f_r$. For all measurements, $f_r = 4.4534$ MHz., so ν_v was calculated from $\nu_v=9-(2.695\times10^{-6})f_v$,

*Using HP model 5345A frequency counter, sampling for an interval of 10 ms.

and $\delta\nu_v = (2.695 \times 10^{-6})\ \delta f_v$. The error δf_v is an estimate of the half width of the frequency interval over which vertical coherence is observed. This is an estimate of the tune spread present in the beam which results in a statistical uncertainty. One would expect that the resulting statistical error is significantly smaller than the tune spread.

The following tables contain the observations and the calculated vertical tunes, for fixed drive sextupole current of 357.0 amp, and horizontal quadrupole current of 129.1 amp. (See Appendix for equipment definitions.)

i) RS7A = -135 cH.†, SHORZ = -226.3 amp., |QSKEW| = 24.35 amp., HPBLW = 436.8 amp.

QVERT (amp.) (see Fig. 2)	$\hat{Y}$ (in.)	f_v (kHz.)	ν_v
-151.6	-0.254	94 ± 5	8.747 ± 0.013
-180.3	-0.256	84 ± 5	8.774 ± 0.013
-209.1	-0.252	77 ± 5	8.793 ± 0.013

ii) QVERT = -209.1 amp., |QSKEW| = 24.35 amp., HPBLW = 436.8 amp.

SHORZ (amp.) (see Fig. 1)	RS7A (cH.)	$\hat{Y}$ (in.)	f_v (kHz.)	ν_v
0	-185	-0.375	90 ± 7	8.757 ± 0.018
	-140	-0.270	85 ± 2	8.771 ± 0.005
	-110	-0.195	75 ± 2	8.798 ± 0.005
-52.6	-185	-0.366	88 ± 5	8.763 ± 0.013
	-140	-0.263	80 ± 5	8.784 ± 0.013
	-110	-0.192	77 ± 5	8.792 ± 0.013
-105.2	-185	-0.372	85 ± 5	8.770 ± 0.013
	-140	-0.259	80 ± 5	8.784 ± 0.013
	-110	-0.190	70 ± 5	8.795 ± 0.013

SHORZ (amp.) (see Fig. 1)	RS7A (cH.)	$\hat{Y}$ (in.)	f_v (kHz.)	ν_v
-226.3	-235	-0.508	92 ± 5	8.752 ± 0.013
	-185	-0.372	82 ± 5	8.779 ± 0.013
	-135	-0.255	77 ± 5	8.793 ± 0.013
	-110	-0.197	75 ± 5	8.798 ± 0.013

†AGAST command (Hamburgers)

iii) SHORZ = -226.3 amp., QSKEW = 0.0 amp., QVERT = -209.1 amp., HPBLW = 436.8 amp.

RS7A (cH.) (see Fig. 1)	Y (in.)	f_v (kHz.)	ν_v
-185	-0.370	83 ± 0.5	8.776 ± 0.001
-145	-0.274	78 ± 1	8.790 ± 0.003
-110	-0.192	75 ± 3	8.798 ± 0.008

iv) SHORZ = -226.3 amp., |QSKEW| = 24.35 amp., QVERT = -209.1 amp., HPBLW = 0.0 amp.

RS7A (cH.) (see Fig. 1)	Y (in.)	f_v (kHz.)	ν_v
-185	-0.384	83 ± 4	8.776 ± 0.011
-145	-0.281	80 ± 4	8.784 ± 0.011
-110	-0.207	75 ± 4	8.798 ± 0.011

Note from the above that the tune spread is noticably narrower with QSKEW off. From a somewhat simplistic point of view this seems odd, if one assumes that the normal setting for the skew quadrupoles decouple horizontal and vertical motion. A more tightly coupled horizontal and vertical motion (a zero command) would seem to imply a more smeared out excitation distribution.

It is of interest to compute the average machine extraction radius from f_r and an assumed extraction momentum of 29.0 Gev/c, using $R = 6\beta c/(\pi f_r)$.* One obtains R = 5059.1 in. The radius of the survey "pedestal stations" is 5057.4 in.[1] Assuming that these average radii should agree, and assuming the discrepancy is due to a systematic error in f_r, one finds that ν_v is changed by less than 0.001.

Comparing case ii) with iv) we note no change in ν_v within the error of measurement, consistent with the predictions of the BEAM program when the PBLW's are turned off. Similarly, when comparing case iii) with ii) no change ν_v is noted when skew quads are switched off.

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[1] Buchanan, M., and Reading, C.S., "Standard Survey Data," Aug 20, 1957.

*Here, β = particle velocity, c = velocity of light, and the assumption was made that the beam orbit was a perfect circle of radius R.

COMPARISON OF RESULTS WITH THOSE OF BEAM PROGRAM

The accompanying graph summarizes this comparison. Two[2] assumptions have been made in the BEAM program, concerning the main magnet multipole moments, i) field option 2 quadrupole moments with x3 sextupole increase (f.o.2 x 3 m.m.s.m.), and ii) multipole moments taken from a plot of Blewett measurements made by H. Weisberg (29 GeV/c Blewett m.m.m.m.).[3] In each case, BEAM was run with the no. 13 compensating†† sextupoles on and off. Latest available current calibrations were used,††† except for orbit bumps.

Examination of the graph clearly shows that the 29.0 GeV/c main magnet quadrupole strengths result in calculated vertical tunes in agreement with measured vertical tunes. However, the corresponding horizontal tune, ν_H, at $\hat{Y}_P$ = -0.42" equals 8-2/3, which means at the least that extraction should have been occurring during the tune measurements, which it did not. Putting the situation in another way: the value of $\hat{Y}_{PUE}$ associated with ν_H = 8-2/3 for the choice of 29 Gev/c multipoles lies at too small a radius in the machine. The field option 2 (x3 sextupole) main magnet multipole moment calculation does not suffer from this difficulty; however in this latter case, the calculated vertical tunes do not agree with those measured. See Figure 4.

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[2]Barge and Glenn, AGS Division Tech. Note No. 167, p. 5.

[3]ibid., p. 5, reference no. 8.

††Since February 1983 SEB has been with the drive sextupole set C13, F13, I13, L13. The remaining no. 13 sextupoles (in series) consist the compensating set (SHORZ).

†††Readbacks from SEB devices, at the time of this study, were unusable. Instead AGAST commands were compared with shunt calibrations made over an extended period of time. Maximum variations of 5% were observed in the ratios cH/ampere for extraction quadrupoles and sextupoles. It seems reasonable to assume that the ratios cH/ampere are subject to errors of less than 5%. The resulting strengths used in beam were: horizontal quads (2753.7 g.), vertical quads (-4460.7 g.), no. 13 horizontal compensating sextupoles were displaced radially inward by 0.191 inch to correspond with locations as indicated by standard survey data (reference 1). F and H bump strengths as in reference 2.

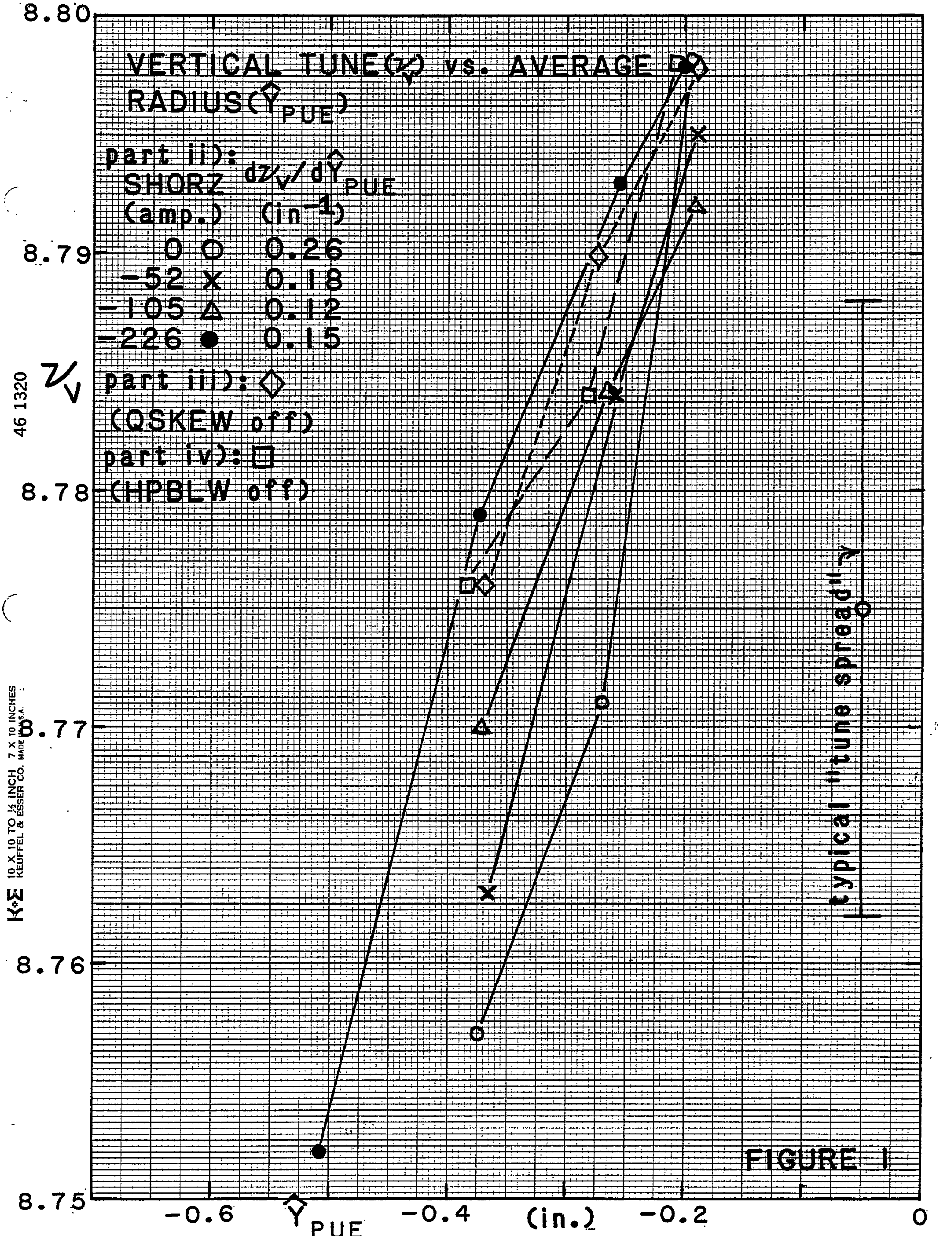
From part i), one obtains $\delta\nu_V/\delta I_{Q_V} = -8(\pm 4) \times 10^{-4}$ amp^{-1} (from an eyeball straight line fit of the 3 data points - see Fig. 2), whereas the BEAM program predicts that $\delta\nu_V/\delta I_{Q_V} = -11 \times 10^{-4}$ amp^{-1}. This quantity, according to BEAM, shows very little dependence on I_{Q_V}, radius, or on the two choices of main magnet multipole moments assumed. For part ii), for fixed radii of -110, -140, -185 (units of cH), one might try to extract $\delta\nu_V/\delta I_{S_H}$. For the errors assumed, any value of the quantity is permitted which lies in the range -2×10^{-4} and 0.5×10^{-4} amp^{-1}.

Again, examining the results of part ii), one might argue that some sort of mistake, say, was made in the measurement of ν_V vs. $\hat{Y}_{PUE}$ vs. for SHORZ set at -226 amp. For the other 3 values of SHORZ examined, a very smooth trend is observed in the function $d\nu_V/d\hat{Y}_{PUE}$ vs I_{S_H}. See Figure 3. One is somewhat encouraged to take this view, if one believes that the statistical error in the measurements is smaller than the tune spread. However, if one believes the results of BEAM (again consult Fig. 3) one is inclined to the notion that the statistical error is comparable with the tune spread, and that no mistake was made for the measurements associated with SHORZ set at -226 amp.

APPENDIX - Pertinent Equipment Definitions

AGAST label	Function
HPBLW	current control on $3/2\lambda$ power backleg extraction bump for H20 electrostatic septum, with windings on main magnets G18, G19, H12, H13, I6, I7, I20, J1.
QSKEW	current control for skew quadrupoles at A5, D5, G5, J5.
QVERT	current control for quadrupoles at st. scn. no. 3 (a vertical β_{max}) in each superperiod.
RS7A	radius shift amplitude control.
SHORZ	current control for compensating sextupoles located at the no. 13 straight sections (a horizontal β_{max}) in superperiods A,B,D,E,G,H,J,K.

Distribution: A.D. S&P staff.


VERTICAL TUNE(ν_V) vs. AVERAGE PUE RADIUS($\hat{Y}_{PUE}$)
part ii): SHORZ (amp.) $d\nu_V/d\hat{Y}_{PUE}$ (in^{-1})
0 ○ 0.26
−52 × 0.18
−105 △ 0.12
−226 ● 0.15
part iii): ◇ (QSKEW off)
part iv): □ (HPBLW off)
ν_V
8.80
8.79
8.78
8.77
8.76
8.75
−0.6
−0.4
−0.2
0
$\hat{Y}_{PUE}$ (in.)
typical "tune spread" ν
FIGURE 1
46 1320
K+E 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

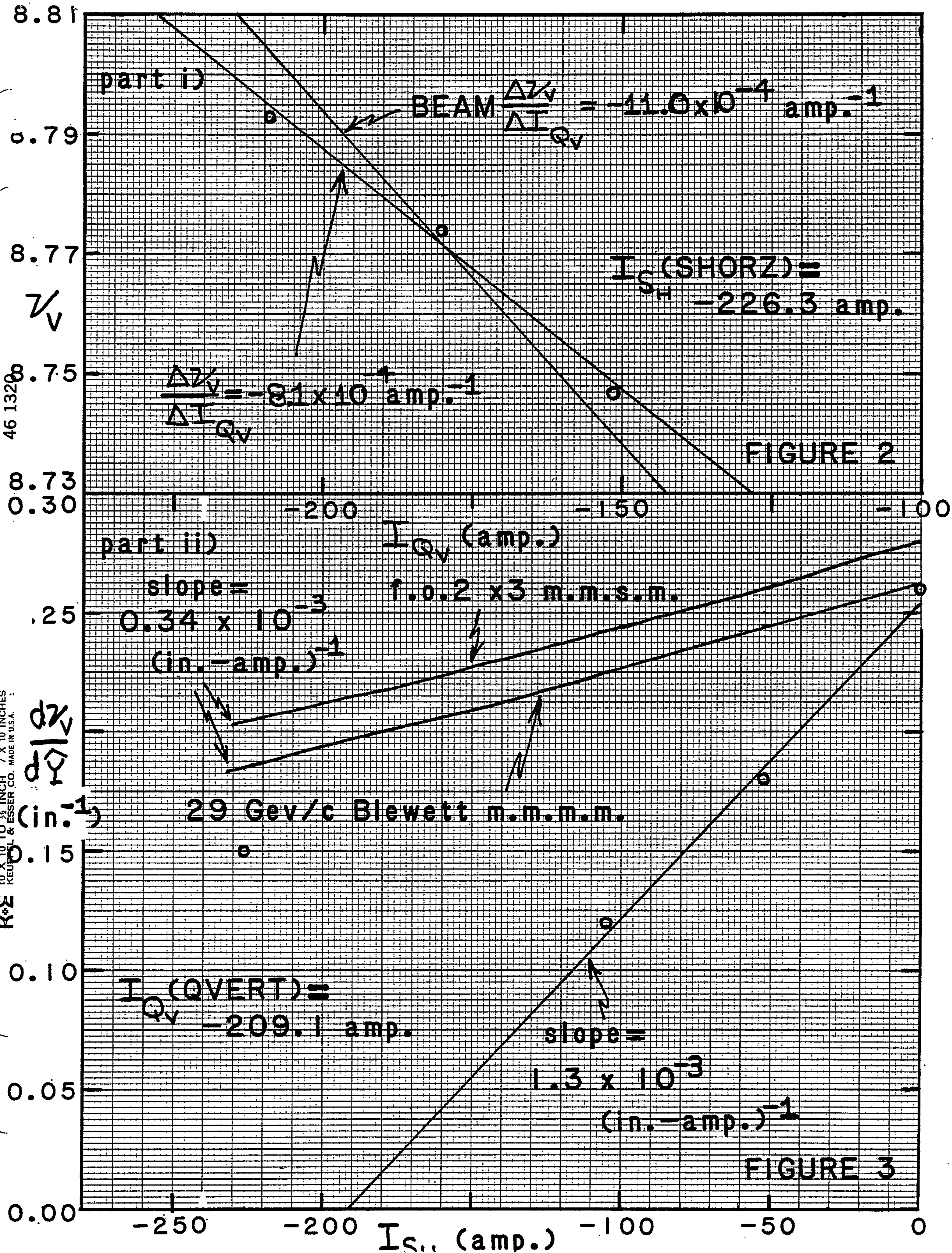
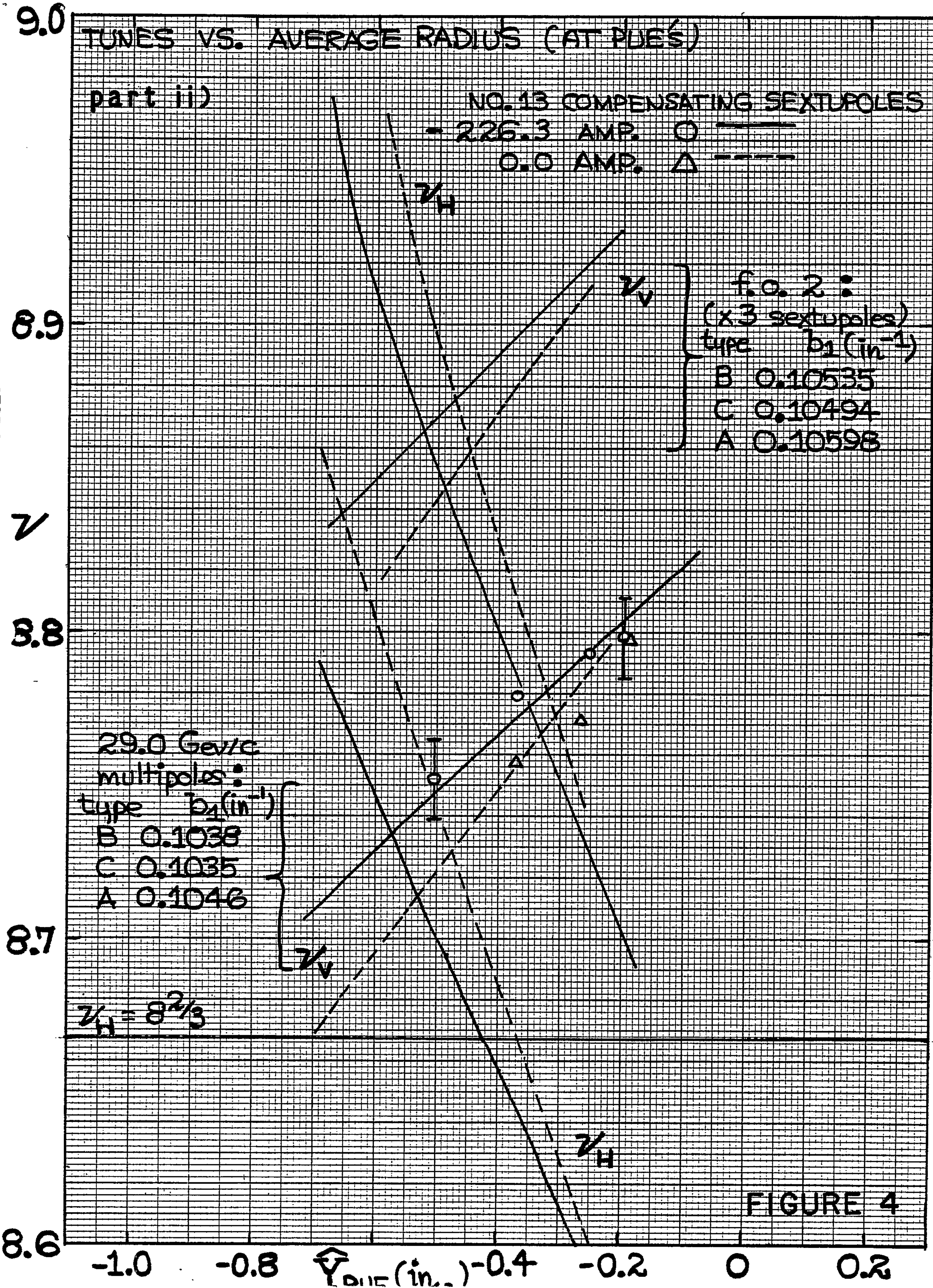


FIGURE 2

FIGURE 3



TUNES VS. AVERAGE RADIUS (AT PUE'S)
part ii)
NO. 13 COMPENSATING SEXTUPOLES
-226.3 AMP. ○
0.0 AMP. △
f.o. 2:
(x3 sextupoles)
type b1(in-1)
B 0.10535
C 0.10494
A 0.10598
29.0 Gev/c
multipoles:
type b1(in-1)
B 0.1038
C 0.1035
A 0.1046
ν_H
ν_V
$\nu_H = 8^2/3$
ν
9.0
8.9
8.8
8.7
8.6
-1.0
-0.8
-0.4
-0.2
0
0.2
$\hat{Y}_{PUE}$ (in.)
FIGURE 4