BNL-104111-2014-TECH

AGS.SN235;BNL-104111-2014-IR

Orbits at Various Tunes

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October 1987

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U.S. Department of Energy

USDOE Office of Science (SC)

Number 235

AGS Studies Report

Date(s) 10/1/87 - 10/3/87 Time(s) Various

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Subject Orbits at Various Tunes

Introduction

In a preceeding study, we moved nine magnets to cancel the ninth harmonic measured in the horizontal orbit. The method used does not properly eliminate the true ninth harmonic from the orbit because the orbit as measured by the PUE system includes not only the real orbit but also distortions caused by gain and offset errors in the PUEs. The gains can be checked by comparing measured and expected difference orbits, but the offsets are impossible to measure directly with the beam and are derived instead from various mechanical and electrical measurements on the hardware.

The harmonic components of the PUE offsets can be determined, however, for harmonics near the tune, from the orbit measurements at different tunes. Then the true harmonics of the orbit can be determined and corrected. We present here the data and a preliminary analysis.

Data

The orbits were taken near 20 GeV/c while the tunes were varied with the high field quads (or, in some cases, radial shifts) and measured with the tune meter. The orbits were saved in files RT01.PUE through RT42.PUE in area [25,26].

Nine magnets were moved to change the ninth harmonic, as described in a preceeding sutdies report, between data sets RT27 and RT28.

Variation With Tune

The PUE orbit is analyzed into components such that

$$x = \sum (A_n \cos n\,\theta + B_n \sin n\,\theta).$$

Each coefficient has contributions from two sources:

$$A_n = A_n^{\circ} + A_n^{1},$$

where A_n° is due to PUE offset error, and A_n^{1} is from the true beam orbit position. (Note that gain errors must be taken care of before this analysis.) Following Guignard (CERN 77-10, p. 9), the beam orbit is related to the magnet deviations by

$$x = \sqrt{\beta} \sum_{n=0}^{\infty} \frac{Q^2}{Q^2-n^2} \left(a_n \cos \frac{n\mu}{Q} + b_n \sin \frac{n\mu}{Q}\right)$$

where

$$a_n = \frac{1}{2\pi Q} \int_{o}^{2\pi Q} d\mu \; \beta^{3/2}(\mu) \frac{\Delta B(\mu)}{B\rho} \cos \frac{n\mu}{Q}$$

$$b_n = \text{(same with sin)}$$

The a_n's and b_n's are functions of the magnet displacements, and will be assumed not be change with tune, although there will clearly be some change due to the change in $\mu(s)$ and β. Thus, the measured components should depend on tune as

$$A_n = A_n^{\circ} + a_n \frac{Q^2}{Q^2-n^2}$$

$$B_n = B_n^{\circ} + b_n \frac{Q^2}{Q^2-n^2} \; .$$

Thus, each component plotted against $Q^2/(Q^2-n^2)$ should give a straight line, whose slope depends on magnet errors and intercept on PUE offset errors. Figures 1-12 show several such plots for orbits where the tune ranges from just above 8.5 to just below 9. The plots show harmonics where this approach appears promising, and also harmonics farther from the tune range, where trying to extract meaningful coefficients is nonsensical.

The straight lines on the plots are fits to A + ax, with equal weight to all data points. The coefficients are shown in Table I. The standard deviations on the coefficients are those given by the least-squares analysis, with the error in the measurement estimated (separately for each fit) as

$$\sigma^2 = \frac{1}{N-2} \sum_{\text{data}} \left(A_n^{\text{meas}} - A_n^\circ - a_n \frac{Q^2}{Q^2-n^2}\right)^2$$

where N is the number of measurements. (The standard deviations shown in the legends of the figures are wrong, due to a miscounting of the data points.)

The effect of moving the magnets to change the horizontal ninth harmonic shows up nicely in Figures 3 and 4. The intercepts were unchanged, as they should be, and the slopes changed by:

cos: 0.0065 - (0.0072) = -0.0137

sin: 0.0136 - 0.0048 = -0.0088

At the tune of 8.73, this corresponds to changes in the components of:

cos: -0.22 cm

sin: -0.14

Conclusions

It is apparent that the true ninth harmonic driving term can be extracted from these data, and thus corrected better than we have done so far. The eighth and tenth also look quite clean, but the signal for the other harmonics, especially below eight, is rapidly disappearing into the noise.

mvh

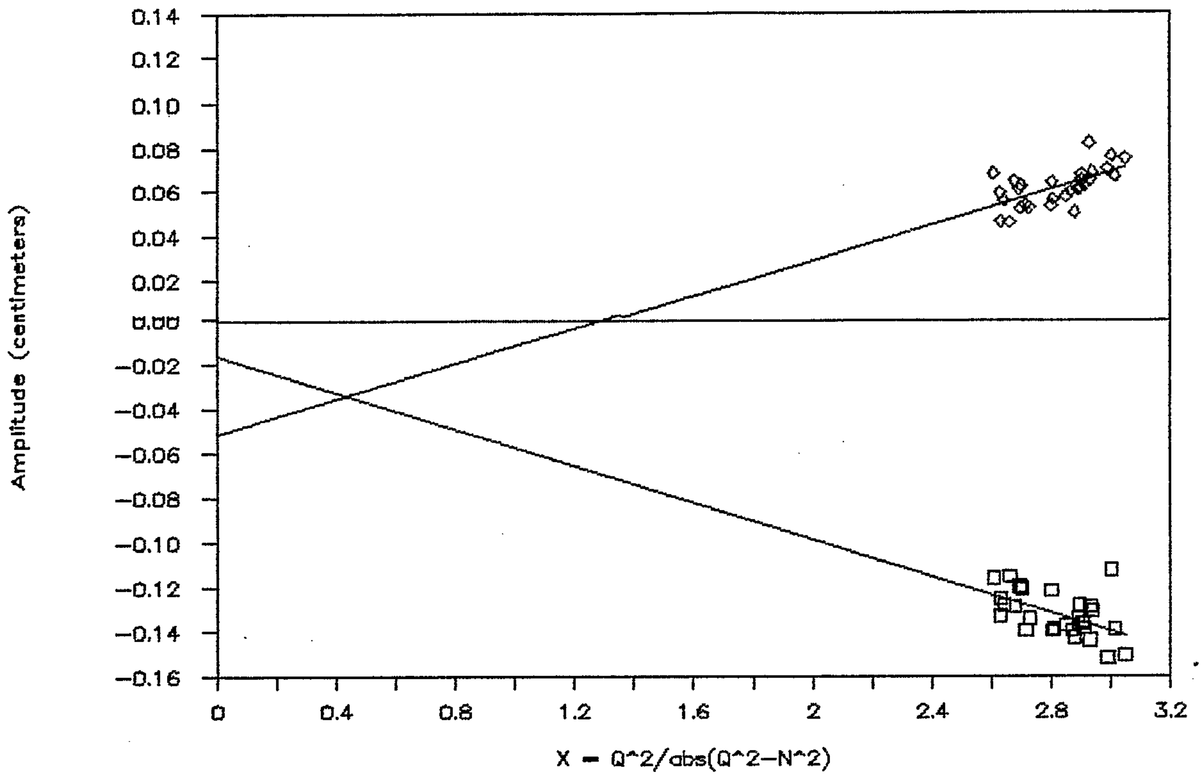
Table 1. Coefficients of fits of harmonic components to

y = int. + slope * abs[Q*Q / (Q*Q - N*N)]

			COSINE (cm)				SINE (cm)			
Harmonic	Data	#	int.	s.d.	slope	s.d.	int.	s.d.	slope	s.d.
5	H 13-42	29	0.3427	0.1025	-0.2865	0.0688	-0.1913	0.1485	0.1086	0.0996
6	H 13-42	29	0.1022	0.0745	-0.0460	0.0392	-0.0340	0.0552	0.0178	0.0290
7	H 13-42	29	-0.0168	0.0354	-0.0410	0.0126	-0.0518	0.0275	0.0399	0.0098
8	H 13-42	29	0.0222	0.0209	0.0239	0.0032	0.1420	0.0144	-0.0305	0.0022
9	H 13-27	15	0.0979	0.0095	0.0065	0.0005	-0.0439	0.0101	0.0136	0.0005
9	H 28-42	14	0.0958	0.0101	-0.0072	0.0004	-0.0215	0.0067	0.0048	0.0003
10	H 13-42	29	0.0110	0.0169	0.0286	0.0052	0.0284	0.0147	-0.0261	0.0046
11	H 13-42	29	-0.0624	0.0176	0.0424	0.0103	-0.0272	0.0199	-0.0076	0.0117
12	H 13-42	29	-0.0429	0.0419	0.0296	0.0373	0.0717	0.0357	0.0298	0.0317
13	H 13-42	29	0.0469	0.0205	0.0374	0.0250	-0.0511	0.0465	-0.0027	0.0566
14	H 13-42	29	0.0700	0.0360	-0.0958	0.0566	0.0154	0.0395	0.0321	0.0622
5	V 13-42	29	-0.1179	0.1097	0.1164	0.0740	-0.1221	0.1457	0.0767	0.0982
6	V 13-42	29	0.0283	0.0557	-0.0014	0.0296	0.0656	0.0899	-0.0230	0.0477
7	V 13-42	29	-0.0319	0.0339	0.0268	0.0122	-0.0369	0.0258	0.0200	0.0093
8	V 13-42	29	0.0202	0.0093	0.0133	0.0015	-0.0187	0.0074	0.0005	0.0012
9	V 13-27	15	-0.0552	0.0032	0.0004	0.0001	0.0013	0.0021	0.0013	0.0001
9	V 28-42	14	-0.0457	0.0049	0.0003	0.0001	0.0163	0.0030	0.0015	0.0001
10	V 13-42	29	0.0286	0.0129	0.0007	0.0038	-0.0181	0.0082	0.0098	0.0024
11	V 13-42	29	-0.0699	0.0202	0.0038	0.0115	-0.0374	0.0136	0.0015	0.0077
12	V 13-42	29	-0.0590	0.0164	0.0196	0.0143	0.0326	0.0226	0.0680	0.0197
13	V 13-42	29	-0.0645	0.0222	0.0703	0.0266	0.0121	0.0261	0.0402	0.0312
14	V 13-42	29	0.0100	0.0360	-0.0031	0.0558	-0.0376	0.0338	0.0890	0.0523

7th HARMONIC VS TUNE FACTOR (HORIZONTAL)

DATA SETS RT13 – RT42

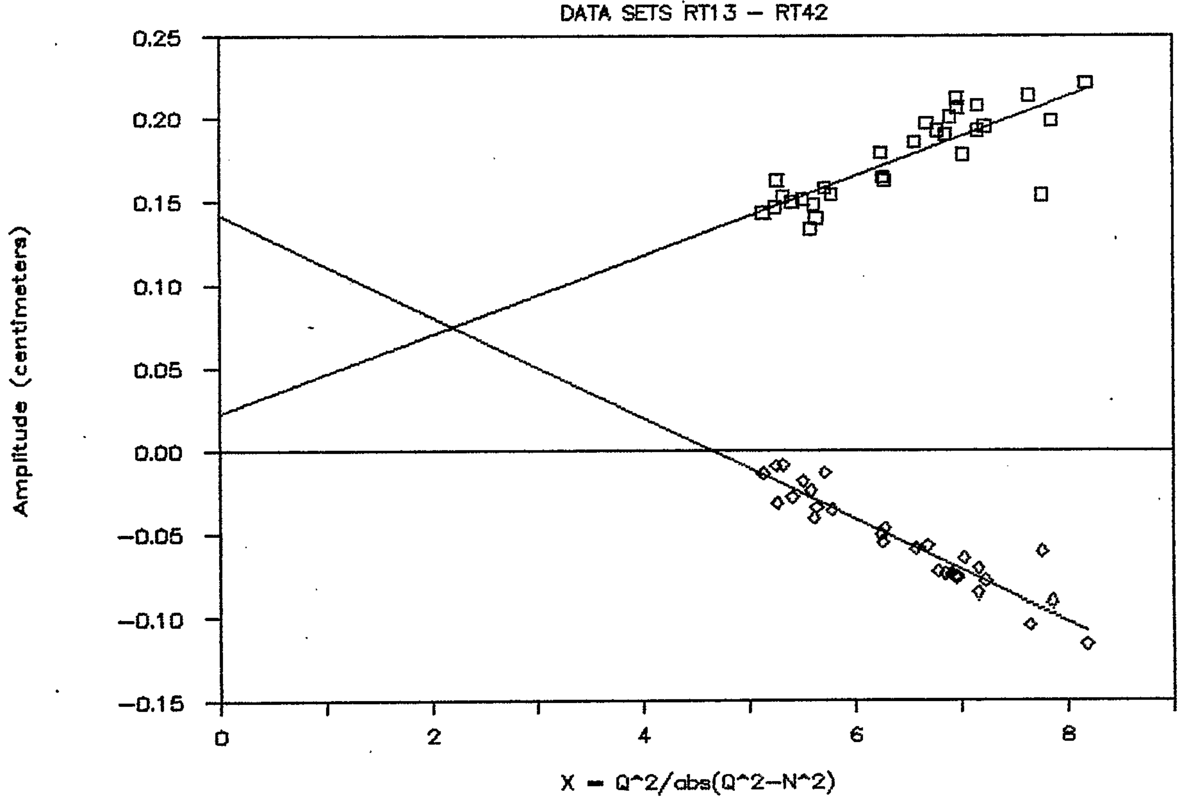


□ COS: –0.0168 (0.0296) –0.0410 (0.0105) * X
◇ SIN: –0.0518 (0.0230) +0.0399 (0.0081) * X

FIGURE 1

8th HARMONIC VS TUNE FACTOR (HORIZONTAL)

DATA SETS RT13 – RT42



□ COS: 0.0222 (0.0177) +0.0239 (0.0027) * X
◇ SIN: 0.1420 (0.0122) –0.0305 (0.0018) * X

FIGURE 2

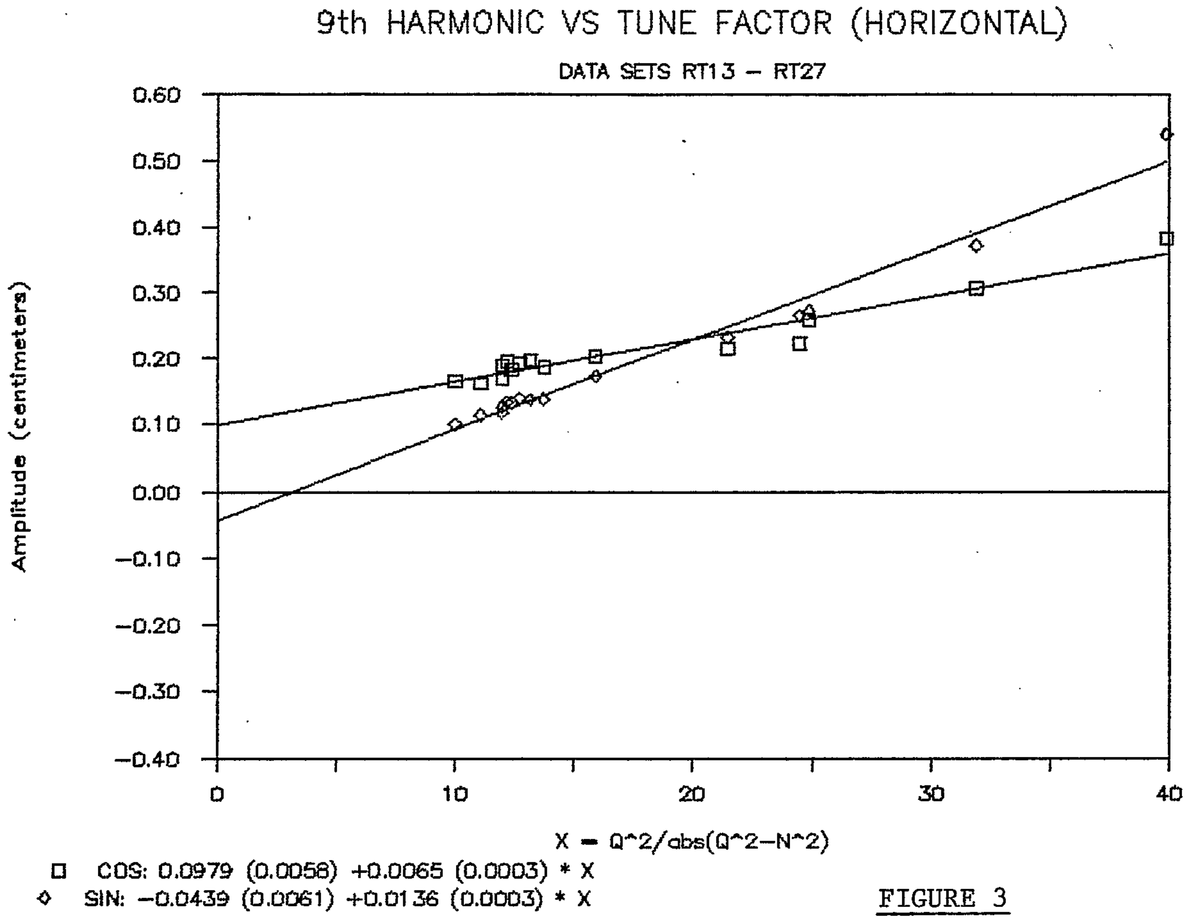


FIGURE 3

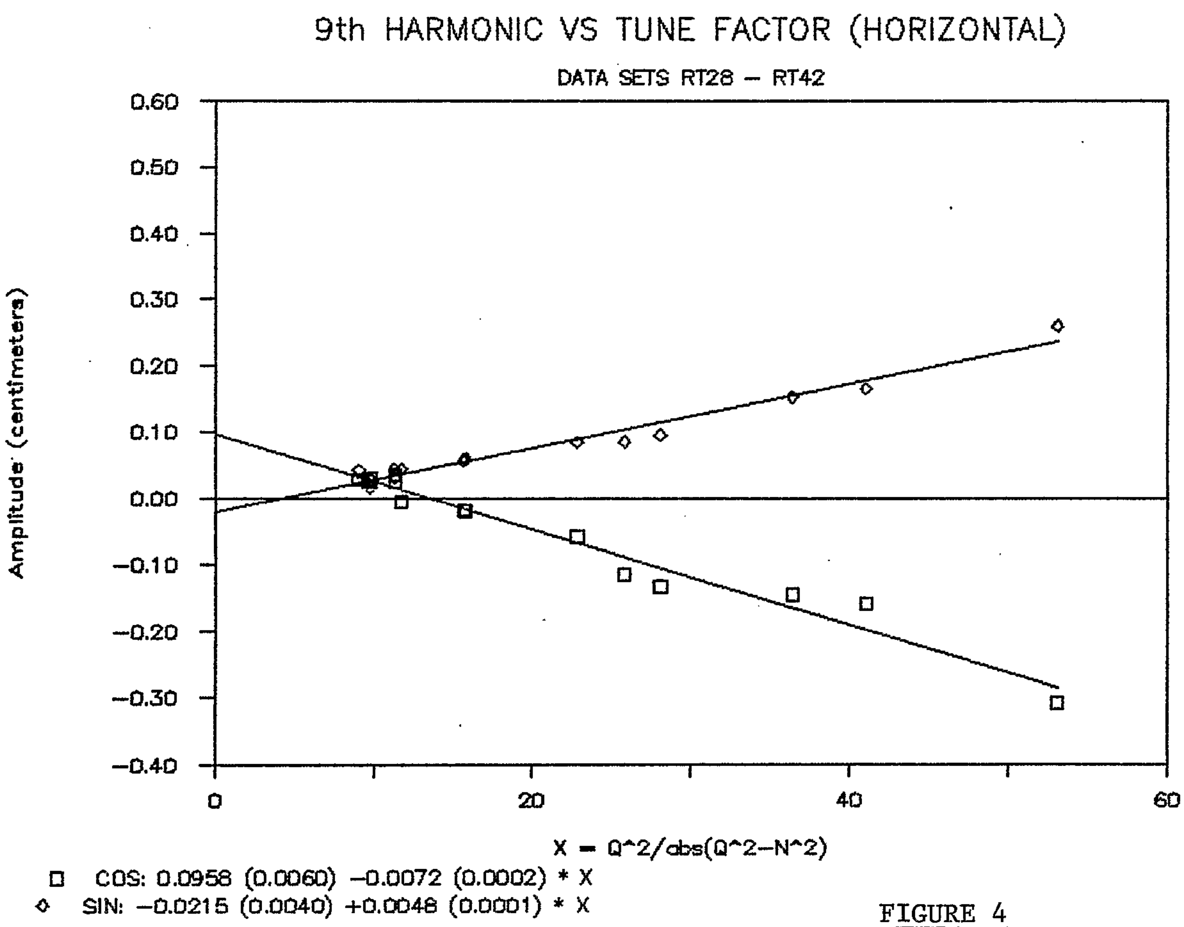
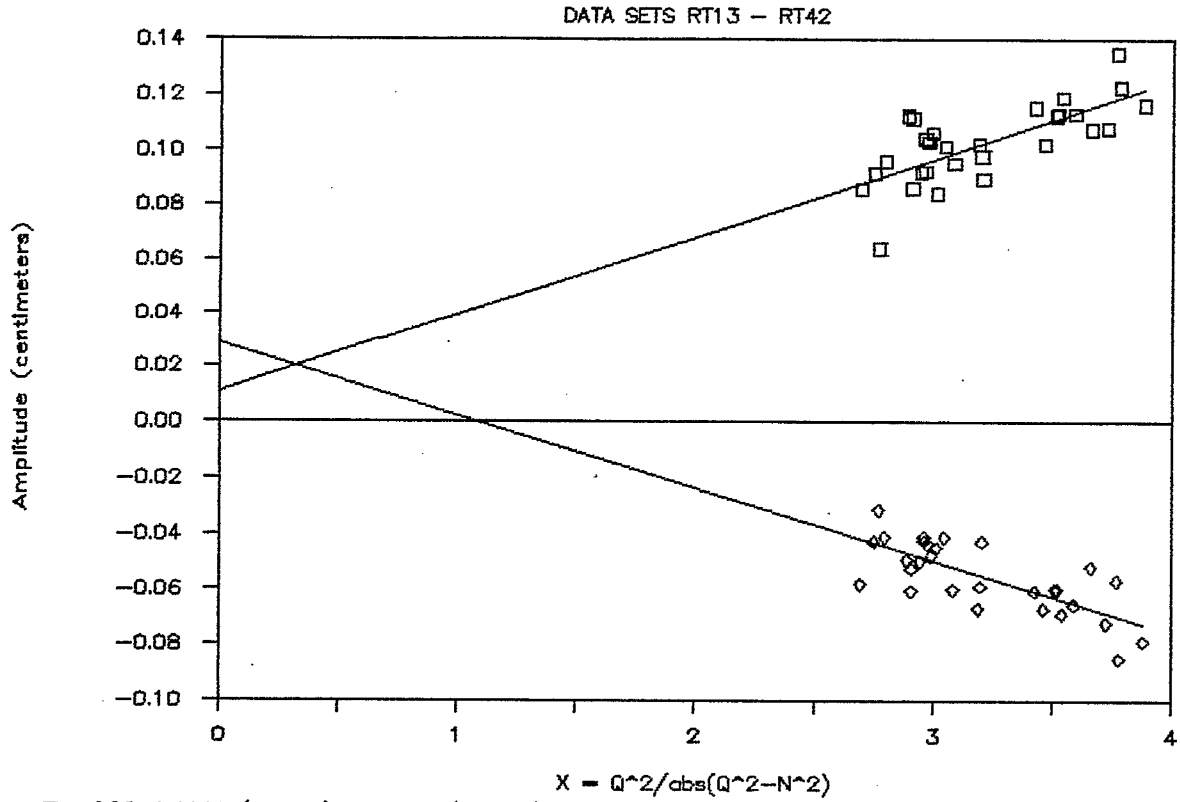


FIGURE 4

10th HARMONIC VS TUNE FACTOR (HORIZONTAL)

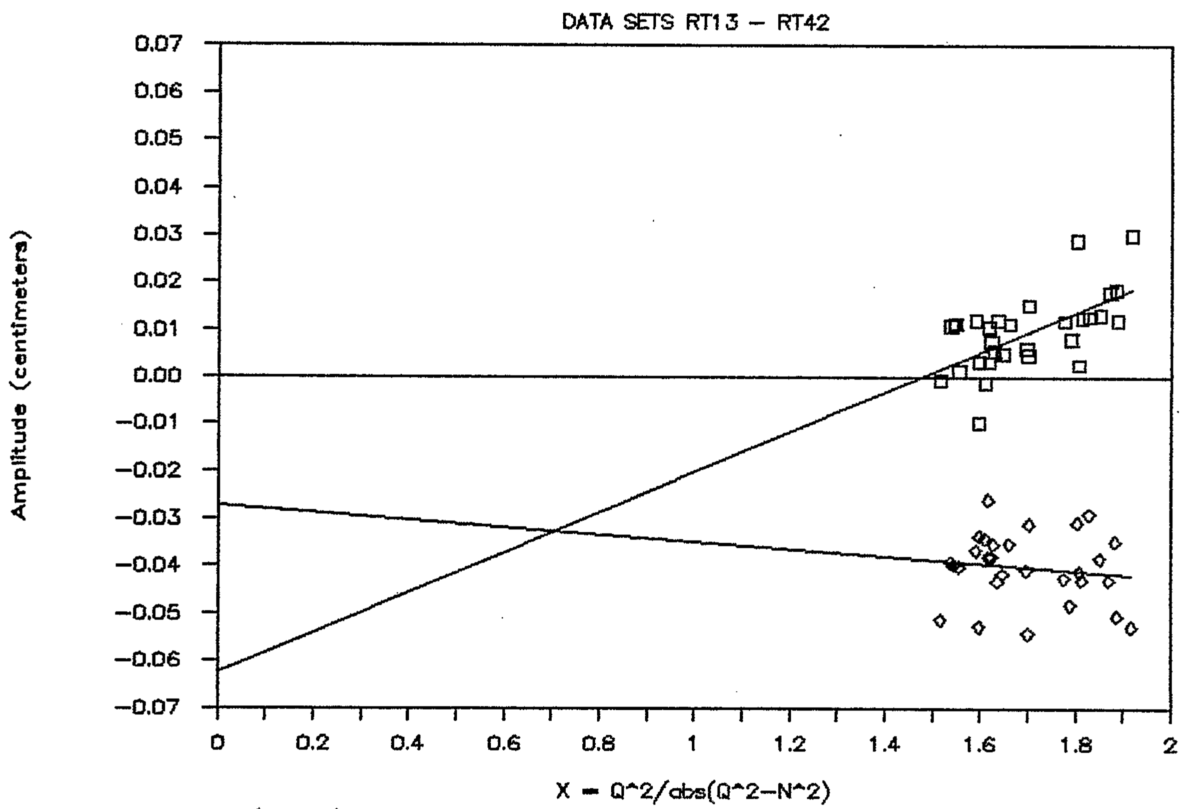


□ COS: 0.0110 (0.0142) +0.0286 (0.0043) * X

◇ SIN: 0.0284 (0.0124) –0.0261 (0.0038) * X

FIGURE 5

11th HARMONIC VS TUNE FACTOR (HORIZONTAL)



□ COS: –0.0624 (0.0147) +0.0424 (0.0086) * X

◇ SIN: –0.0272 (0.0166) –0.0076 (0.0097) * X

FIGURE 6

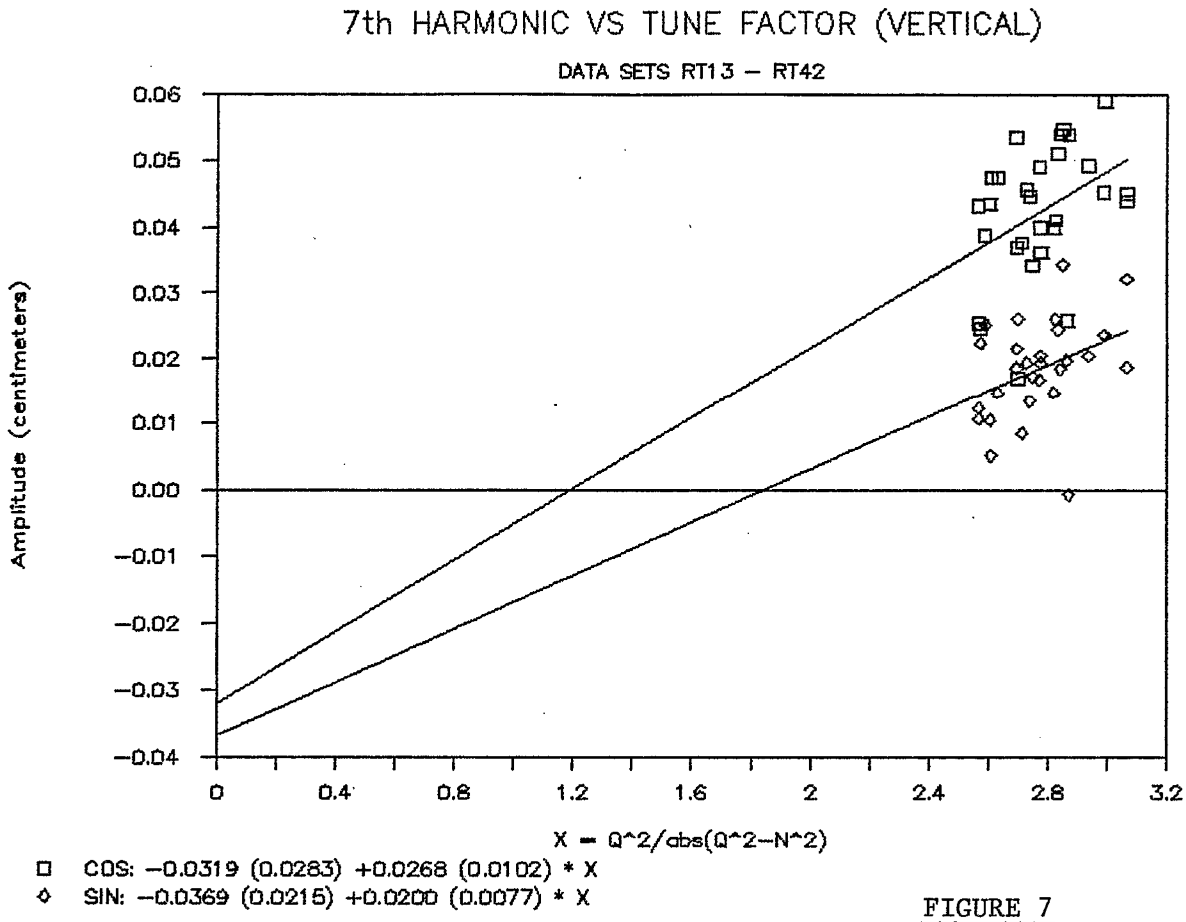


FIGURE 7

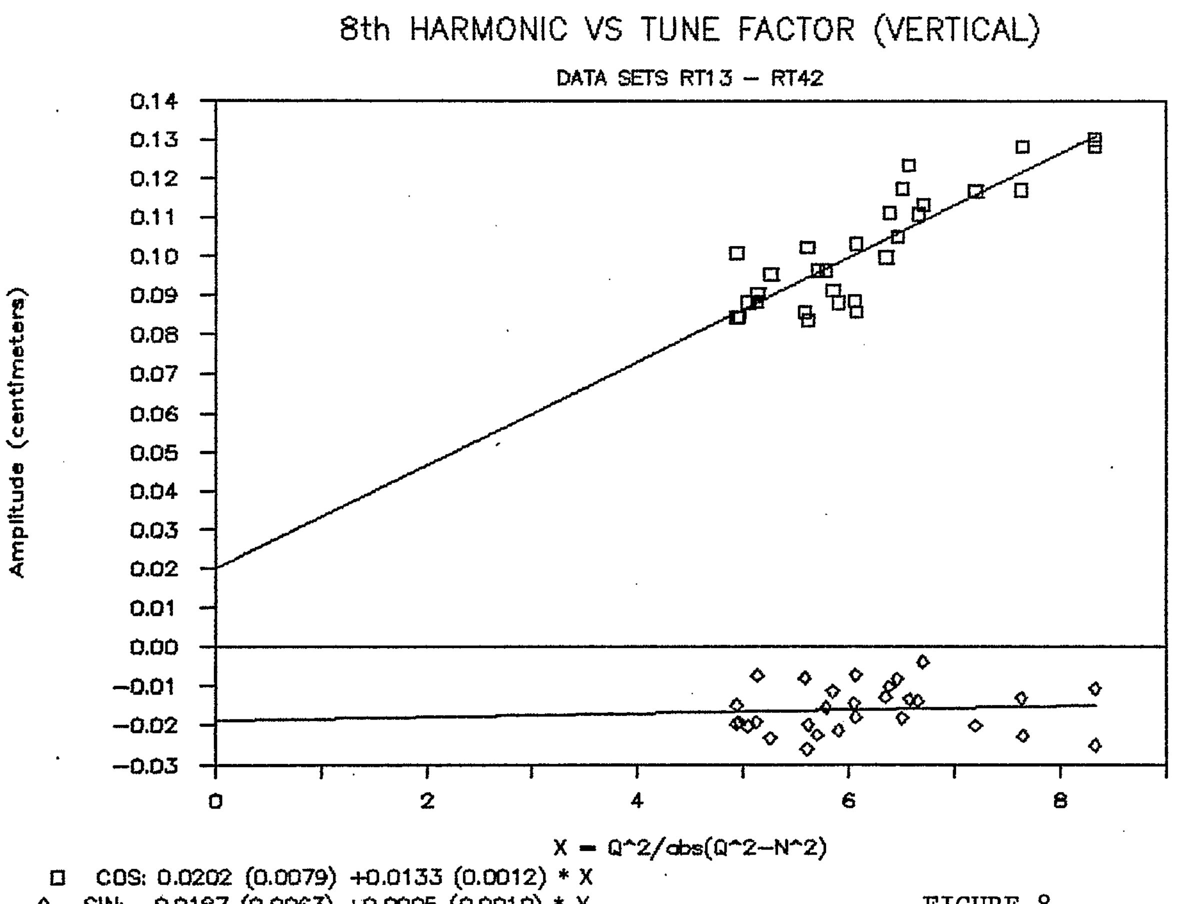
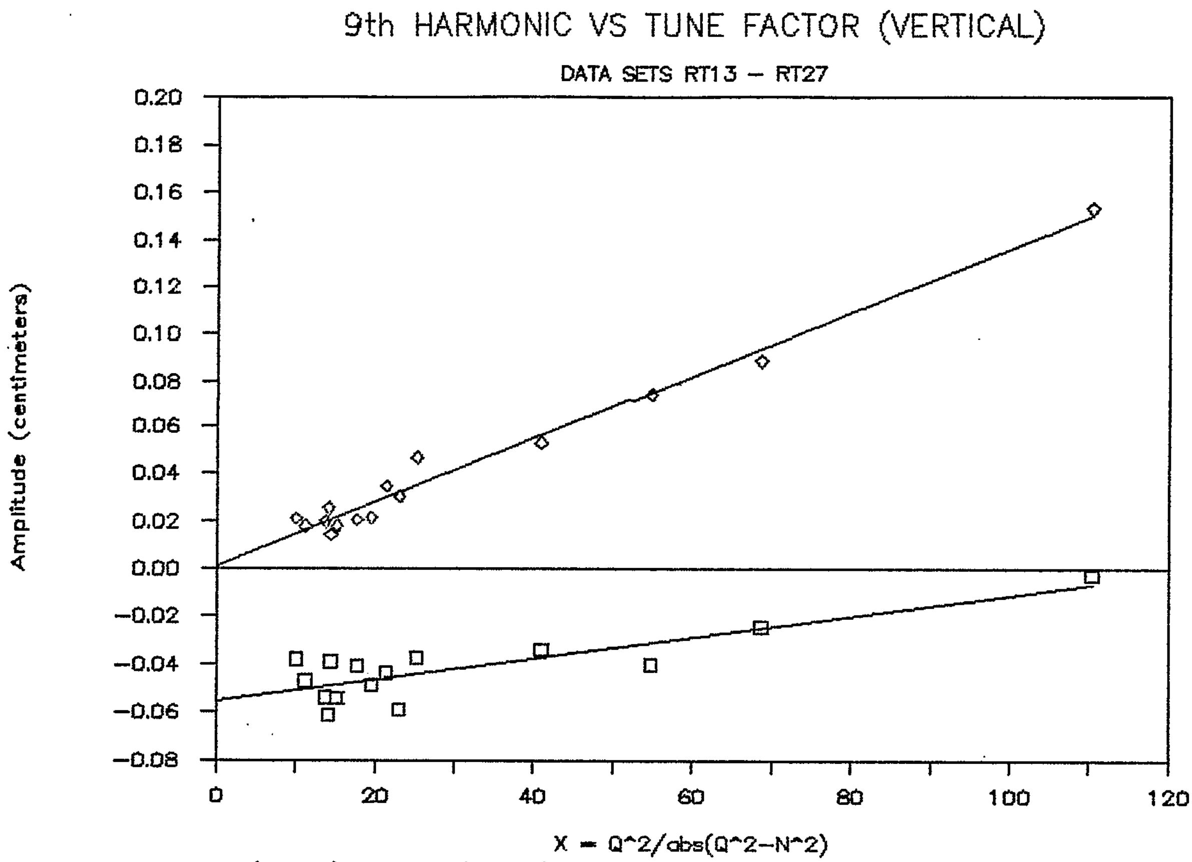
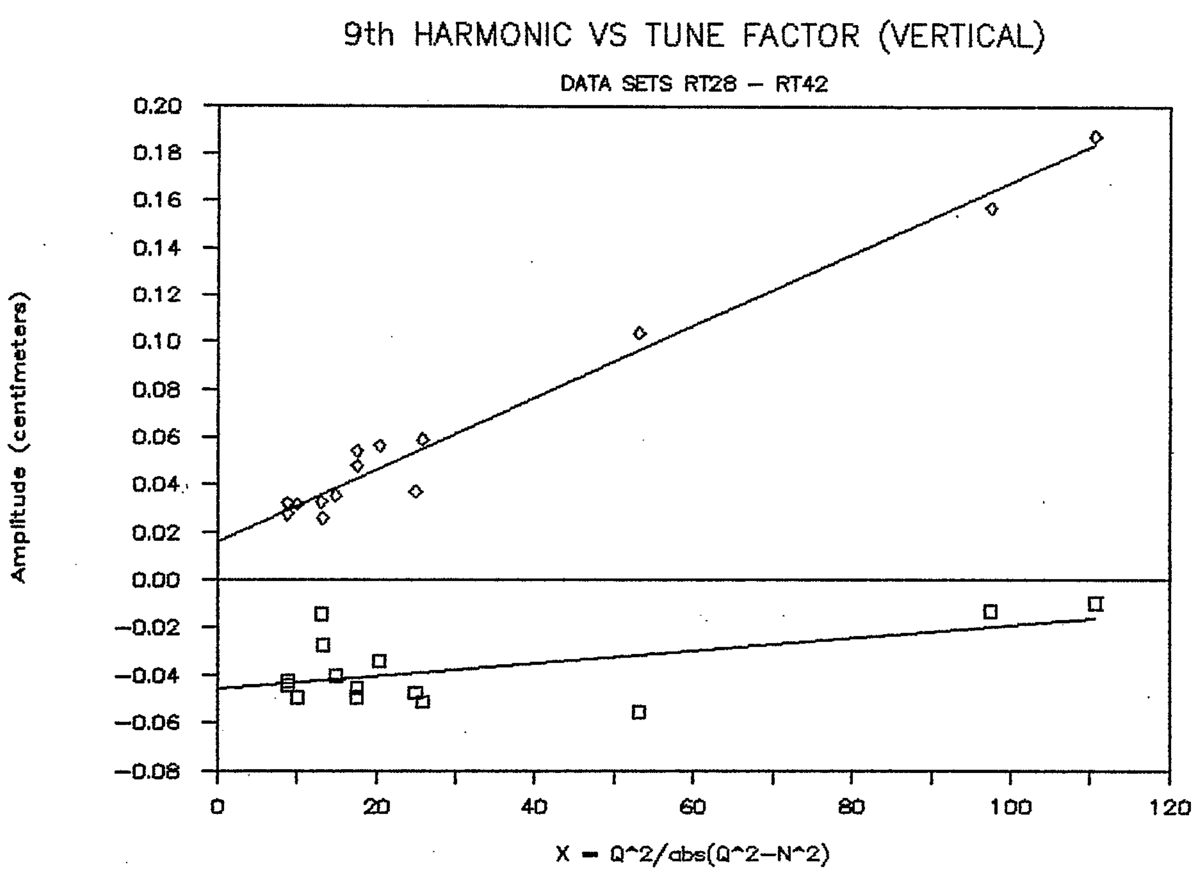


FIGURE 8



□ COS: –0.0552 (0.0021) +0.0004 (0.0000) * X
◇ SIN: 0.0013 (0.0014) +0.0013 (0.0000) * X

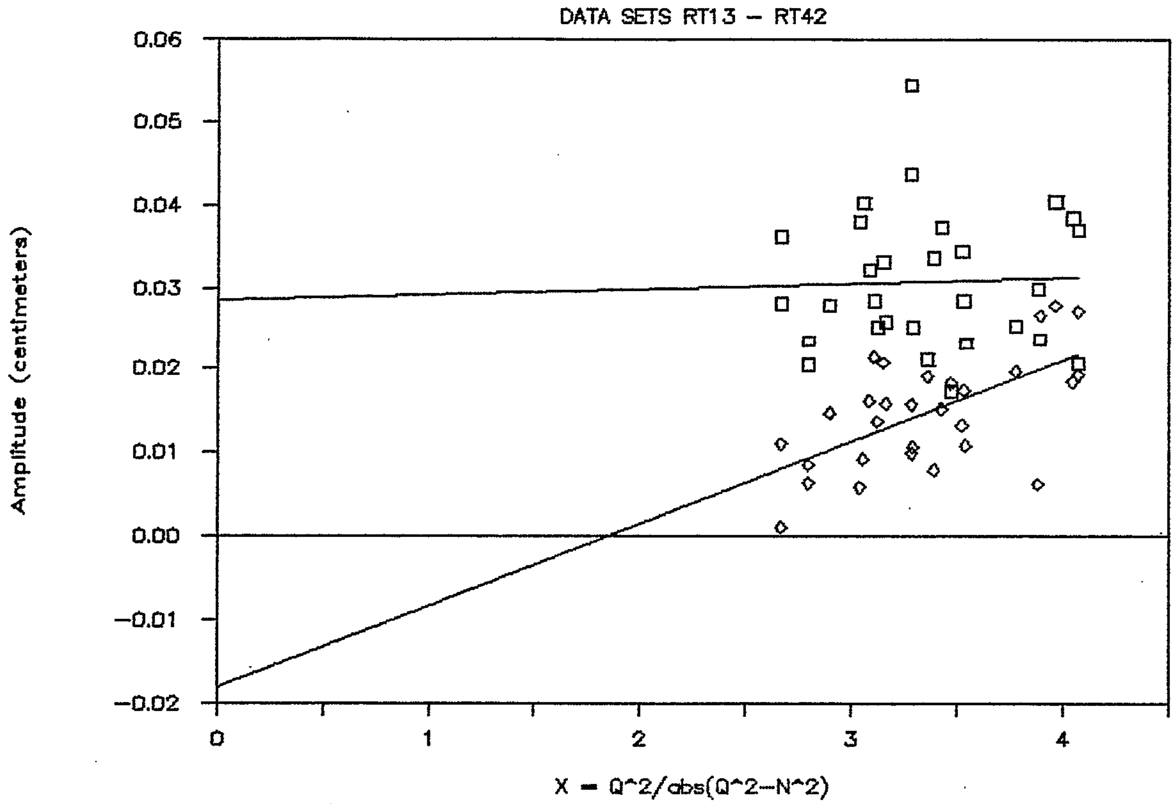
FIGURE 9



□ COS: –0.0457 (0.0031) +0.0003 (0.0001) * X
◇ SIN: 0.0163 (0.0019) +0.0015 (0.0000) * X

FIGURE 10

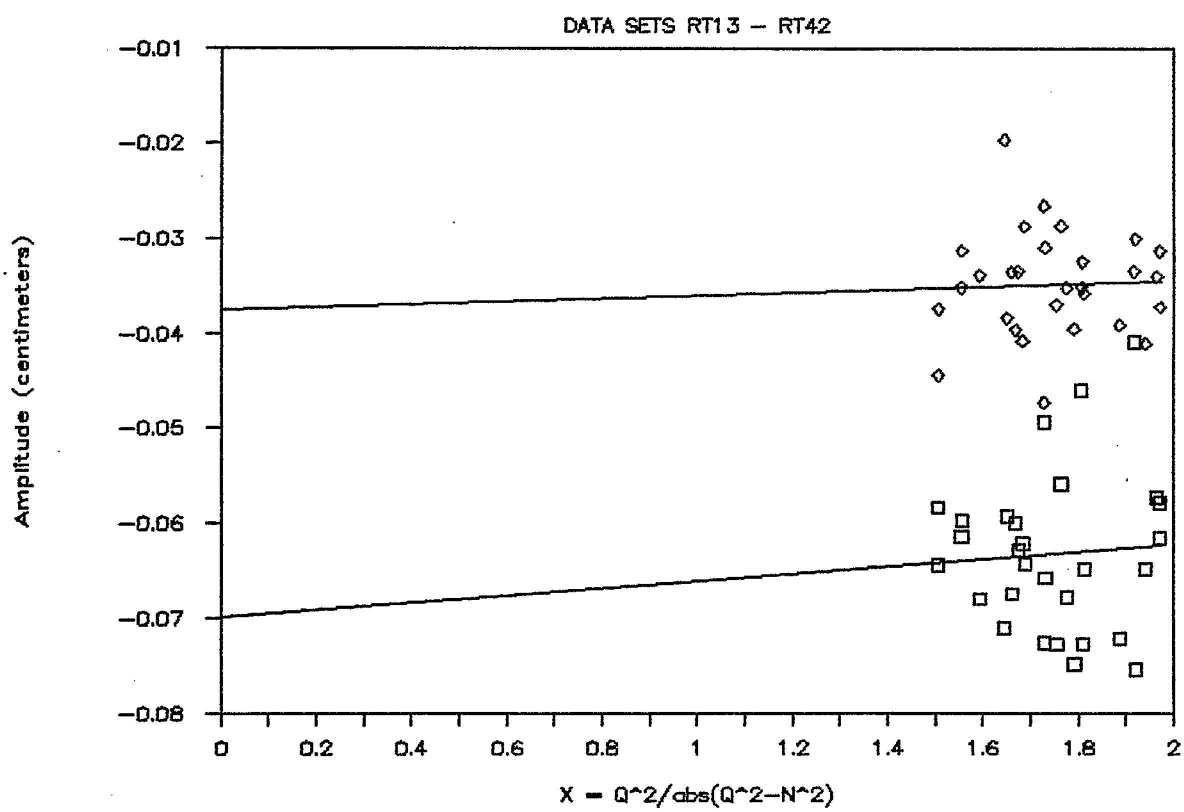
10th HARMONIC VS TUNE FACTOR (VERTICAL)



□ COS: 0.0286 (0.0109) +0.0007 (0.0032) * X
◇ SIN: –0.0181 (0.0069) +0.0098 (0.0020) * X

FIGURE 11

11th HARMONIC VS TUNE FACTOR (VERTICAL)



□ COS: –0.0699 (0.0169) +0.0038 (0.0096) * X
◇ SIN: –0.0374 (0.0114) +0.0015 (0.0064) * X

FIGURE 12