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ISR PERFORMANCE REPORT

Run 1246, 26 GeV, R1, 1.3.82

Run 1250, 15 GeV, R1, 10.3.82

Measurement of betatron phase advance (2)

Summary

The betatron phase advance in the ISR was measured by observing an excited vertical betatron oscillation with beam position monitors located at different azimuthal positions. The beam was excited with a swept frequency covering 2 betatron side bands around 10.95 MHz. The relative phase of the signals from 2 different beam position monitors was measured with a network analyser HP 8505 A. The results are compared with calculations using the program AGS[1] and show an rms difference of 6°. In the second part of the experiment the phase advance was measured for different momenta (radial positions) to observe local chromatic effects. The accuracy was not quite sufficient to allow a comparison of these chromatic effects with calculations.

1. Experimental layout

1.1 Run 1246

A set-up similar to the one used in run 950[2] was used. The beam was excited with bandwidth limited noise using the kicker of the 1 MHz feedback system. The signals observed on the beam position monitors were too small to carry out a proper phase measurement even when the excitation of the beam was so strong that its lifetime was affected.

1.2 Run 1250

The set-up used in this run is shown in fig. 1. A beam on FP working line was excited with a swept frequency obtained from the HP 8505 A network analyser and fed through amplifiers to the kicker of the FFT beam observation system. The central frequency was f_c = 10.95 MHz = 34.5 f_{rev} and the betatron modes (26+Q) and (43-Q) were excited. The oscillation was observed on the beam position monitors using the difference signal of the top and bottom plates. The signal from monitor 105 was used as a reference with which the signals of the other monitors were compared.

2. Measurements (Run 1250)

First a stack of 2.18 A was made in the centre of the aperture (-6 mm to +6 mm) on an FP working line. The beam was excited vertically with a swept frequency and the phase was measured at the frequencies 10.9121 MHz and 10.9915 MHz representing the slow wave (44-Q) and the fast wave (26+Q) with Q = 8.6251. The phase was directly measured on the digital display by setting the markers at the above frequencies. Such a measurement is shown in fig. 1. The oscillation was observed on all the position monitors which gave clear signals and compared with the reference monitor 105. On a few monitors, the observed phase changed rapidly with frequency which introduced large errors. These measurements were ignored but the observed effect is not well understood, but could be due to faulty contacts in the video scanner producing reflections.

In a second experiment two small stacks at + 35 mm and at - 17 mm were made circulating simultaneously with a total current of 3.27 A. The upper stack had a central momentum $\Delta p/p = 0.0181$ and was excited at the frequencies 10.8913 MHz and 11.0088 MHz representing the modes (43-Q) and (26+Q) for Q = 8.6842. The lower stack had a central momentum of $\Delta p/p = -0.0088$ and was excited at the frequencies 10.9234 MHz and 10.9821 MHz representing the same modes as above for Q = 8.5925. The measurement was carried out the same way as before by setting a marker to each of the 4 frequencies. Only about 2/3 of the beam position monitors were measured when our MD time was used up.

3. Results

The measured phases ξ_f and ξ_s of the observed fast and slow waves of the betatron oscillation were analyzed using the formalism described in the last Performance Report[2]. Choosing the azimuthal coordinate $\Theta = 0$ for the reference monitor the signals U_f and U_s of the fast and slow wave observed with a monitor at the azimuthal position Θ[2] are

$$U_f(t,\Theta) = gI_o\, y_o \sqrt{\frac{\beta(\Theta)}{\beta(o)}}\ \cos\left[(n_1+Q_{int}+\Delta Q)\omega_o t+\phi(\Theta) - (n_1+Q_{int}+\Delta Q)\Theta\right] \qquad (1)$$

$$U_s(t,\Theta) = gI_o\, y_o \sqrt{\frac{\beta(\Theta)}{\beta(o)}}\ \cos\left[(n_1+Q_{int}-\Delta Q)\omega_o t-\phi(\Theta) - (n_1+Q_{int}-\Delta Q)\Theta\right] \qquad (2)$$

where I_o is the total current, y_o the amplitude of the oscillation at $\Theta = 0$, g is a calibration factor, $n_1 = 26.5$, $Q_{int} = 8$, $\Delta Q = Q-8.5$, $\phi(\Theta)$ is the betatron phase between $\Theta = 0$ and the observation point Θ. (Please note an error in the sign of ΔQ in the previous Performance Report[2] in the last equation on page 6 which corresponds to the above equation (2)).

Since the cable to the different monitors have about the same length we get for the betatron phase

$$\phi(\Theta) = \tfrac{1}{2}(\xi_f - \xi_s + \Theta\Delta Q)$$

where $_f$ and $_s$ are the observed phases of the singals U_f and U_s.

The results are shown in Table 1. The measured betatron phase PHI-MEAS, the corresponding phase calculated with AGS PHI-AGS and the difference DIFF between the two is listed in degrees. The rms value of the difference is 5.8°. In the last two columns the 'smooth' phase advance Θ.THETA is subtracted from the actual measured and calculated phase. The resulting quantity is also plotted in fig. 2 and shows clearly the 4 superperiods of the ISR.

It should be noted that the ISR has often several focussing elements between the monitors where the oscillation is observed. The phase advance between the measured points is therefore not very smooth and it would not make sense just to draw a curve through the points shown in fig. 2.

In the second part of the experiment the betatron phase advance was measured for 2 stacks having a momentum deviation $\Delta p/p = + 0.0181$ and $\Delta p/p = - 0.0088$ compared to the first stack. The results are shown in Table 2. The last two columns show the measured and calculated derivative Phi=$d\phi(\Theta)/(dp/p)$ of the phase advance with respect to the relative momentum. This quantity has been defined and used by B.W. Montague in LEP Note 165 where it is called $\Delta\phi$. Unfortunately, the total chromaticity in the experiment was $Q' = dQ/(dp/p) = 3.4$ which is different from the theoretical one $Q' = 2.1$ used in the calculation. Since we don't know where and how the extra chromaticity was produced, we cannot easily compare the experimental results with calculations. Furthermore, the expected difference in phase advances for the different momenta used is only about 6° which is of the order of the measurement accuracy. However, in a machine where chromatic errors are not corrected locally where they occur, (dispersion free low-beta insertions) these effects are larger and the above measurement could give valuable information.

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References

1. E. Keil, Y. Marti, B.W. Montague, A. Sudboe, CERN 75-13 (1975).

2. J. Borer, A. Hofmann, ISR Performance Report, run 960, Feb. 1982.

3. B.W. Montague, CERN LEP Note 165, July 1979.

N	MONITOR	PATHL(M)	THETA(DEG)	MEAS.PHASE	AGS-PHASE	DIFFERENCE	(PHASE-Q.THETA)-MEAS.	(PHASE-Q.THETA)-AGS
1	105	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	865	23.296	8.897	76.613	76.723	-.111	-.122	-.011
3	857	36.615	13.984	104.749	103.558	1.191	-15.861	-17.051
5	841	63.254	24.157	233.521	242.298	-8.777	25.163	33.941
6	833	76.574	29.244	270.657	267.131	3.526	18.424	14.900
7	821	96.551	36.873	345.111	339.505	5.606	27.076	21.472
8	813	109.870	41.960	416.248	415.879	.368	54.338	53.972
9	805	123.190	47.047	445.884	442.609	3.275	40.100	36.828
10	761	146.485	55.944	517.496	517.892	-.396	34.977	35.377
11	745	174.509	66.646	603.835	604.238	-.404	29.006	29.414
12	733	186.442	71.204	634.905	630.511	4.394	20.770	16.380
13	721	207.636	79.298	690.417	690.710	-.293	6.471	6.769
14	717	221.915	84.751	736.099	742.486	-6.387	5.115	11.507
15	705	235.659	90.000	782.255	776.758	5.498	6.000	.508
16	665	258.955	98.897	849.868	852.419	-2.551	-3.122	-.566
17	657	272.274	103.984	883.004	879.062	3.942	-13.861	-17.796
18	649	285.594	109.070	955.140	957.193	-2.053	14.401	16.460
19	641	298.914	114.157	1019.777	1018.267	1.509	35.163	33.660
20	633	312.233	119.244	1038.413	1042.693	-4.281	9.924	14.212
21	621	332.210	126.873	1114.867	1115.957	-1.090	20.576	21.674
22	613	345.529	131.960	1192.503	1191.985	.518	54.338	53.828
23	605	358.849	137.047	1219.139	1218.222	.917	37.100	36.191
24	561	382.145	145.944	1298.252	1294.315	3.937	39.477	35.549
25	545	410.168	156.646	1386.090	1380.168	5.922	35.006	29.093
27	521	443.295	169.298	1466.172	1466.982	-.810	5.971	6.791
29	505	471.318	180.000	1555.011	1552.849	2.162	2.500	.349
30	465	494.614	188.897	1624.123	1628.287	-4.164	-5.122	-.947
31	457	507.934	193.984	1655.760	1655.507	.253	-17.361	-17.602
33	441	534.573	204.157	1797.532	1793.891	3.641	36.663	33.034
34	433	547.892	209.244	1819.668	1818.785	.883	14.924	14.054
35	421	567.869	216.873	1891.122	1892.477	-1.355	20.576	21.944
36	413	581.189	221.960	1970.258	1967.540	2.718	55.838	53.133
37	405	594.508	227.047	1998.395	1994.213	4.182	40.100	35.932
39	345	645.828	246.646	2159.846	2156.616	3.230	32.506	29.291
41	321	678.954	259.298	2264.928	2243.736	21.192	28.471	7.295
43	305	706.978	270.000	2329.766	2329.304	.462	1.000	.554
44	265	730.273	278.897	2413.379	2404.994	8.384	7.878	-.490
45	257	743.593	283.984	2425.015	2432.261	-7.246	-24.361	-17.098
46	249	756.912	289.070	2495.651	2509.729	-14.078	2.401	16.496
48	233	783.552	299.244	2606.423	2595.524	10.899	25.424	14.543
49	221	803.528	306.873	2661.878	2669.000	-7.123	15.076	22.217
51	205	830.167	317.047	2760.650	2770.942	-10.292	26.100	36.410
52	161	853.463	325.944	2848.763	2847.391	1.371	37.477	36.125
54	133	901.061	344.122	2960.536	2958.988	1.548	-7.536	-9.064
55	121	914.613	349.298	3020.683	3020.202	.481	7.971	7.511

RMS PHASE DIFFERENCE = 5.80

Table 1 : Measured (MEAS.PHASE) and calculated (AGS-PHASE) betatron phase advances at different beam position monitor with monitor 105 used as reference.

MON.	PHI-ME	PHI-AG	DIFF	PHI-ME	PHI-AG	DIFF	PHI-ME	PHI-AG	DIFF	PHI' MEAS.	PHI' AGS
	DP/P = .0181			DP/P = 0.0000			DP/P = -.0088				
105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
613	1203.8	1192.6	11.3	1192.5	1192.0	.5	1185.2	1191.8	-6.6	681.5	28.1
605	1230.2	1220.1	10.2	1219.1	1218.2	.9	1211.2	1217.3	-6.1	694.6	103.7
561	1312.4	1295.2	17.2	1298.3	1294.3	4.0	1291.0	1293.9	-2.9	792.8	47.5
545	1395.4	1381.1	14.3	1386.1	1380.1	5.9	1371.5	1379.8	-8.4	831.2	45.9
521	1482.2	1473.8	8.4	1466.2	1467.0	-.8	1461.7	1463.5	-1.9	781.1	362.0
505	1566.2	1559.5	6.7	1555.0	1552.8	2.2	1548.2	1549.7	-1.6	661.4	363.3
465	1639.3	1634.3	4.9	1624.1	1628.3	-4.1	1615.5	1625.3	-9.8	878.5	336.2
457	1671.7	1662.5	9.2	1655.8	1655.5	.3	1651.4	1652.0	-.5	773.3	390.8
441	1810.6	1799.1	11.5	1797.5	1793.9	3.7	1788.4	1791.4	-3.0	810.6	286.3
433	1835.0	1824.8	10.2	1819.7	1818.8	.9	1810.9	1815.8	-4.9	891.8	335.9
421	1905.9	1897.4	8.5	1891.1	1892.5	-1.3	1879.6	1890.1	-10.6	956.8	271.7
413	1985.4	1972.0	13.4	1970.3	1967.5	2.7	1958.0	1965.4	-7.4	989.9	243.7
405	2012.3	1999.7	12.6	1998.4	1994.2	4.2	1999.5	1991.5	8.0	520.3	305.5
345	2163.9	2160.8	3.1	2159.8	2156.6	3.3	2147.8	2154.6	-6.8	543.5	232.3
321	2279.8	2253.6	26.2	2264.9	2243.7	21.2	2259.0	2238.9	20.1	779.4	545.4
305	2347.7	2339.3	8.5	2329.8	2329.3	.5	2317.5	2324.5	-7.0	1105.2	550.2
265	2433.9	2414.1	19.7	2413.4	2405.0	8.4	2408.3	2400.6	7.7	977.8	504.4
257	2441.3	2442.3	-1.0	2425.0	2432.2	-7.2	2406.8	2427.3	-20.6	1226.8	556.6
249	2517.2	2518.7	-1.5	2495.7	2509.7	-14.1	2481.7	2505.4	-23.6	1301.1	497.5
233	2631.1	2604.6	26.5	2606.4	2595.5	10.9	2597.7	2591.1	6.6	1261.2	501.9
221	2697.0	2677.2	19.8	2661.9	2669.0	-7.1	2647.9	2665.0	-17.1	1843.9	454.7
205	2784.9	2779.5	5.4	2760.6	2770.9	-10.3	2752.8	2766.8	-14.0	1214.3	472.6
161	2873.0	2854.8	18.3	2848.8	2847.4	1.4	2835.1	2843.8	-8.7	1398.5	406.8
133	2982.9	2967.9	15.0	2960.5	2959.0	1.6	2949.8	2954.7	-4.9	1229.7	490.4
121	3048.3	3033.4	15.0	3020.7	3020.2	.5	3010.8	3013.7	-2.9	1415.0	729.4

Table 2: Measured (PHI-ME) and calculated (PHI-AG) betatron phase advances for different relative momenta dp/p and derrivatives PHI' of the phase advance with respect to dp/p.

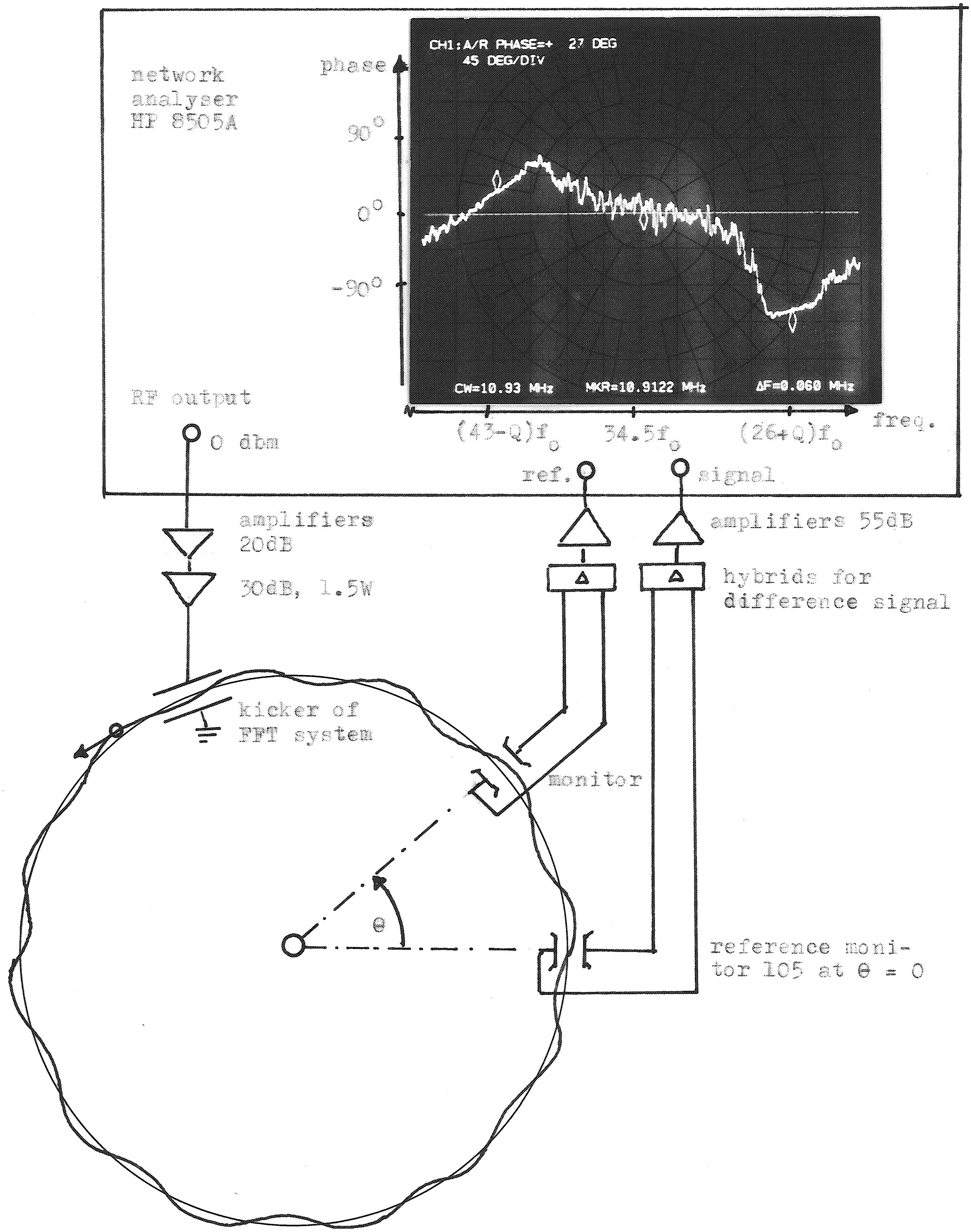

Fig. 1. Experimental layout for the measurement of the betatron phase $\Phi(\theta)$.

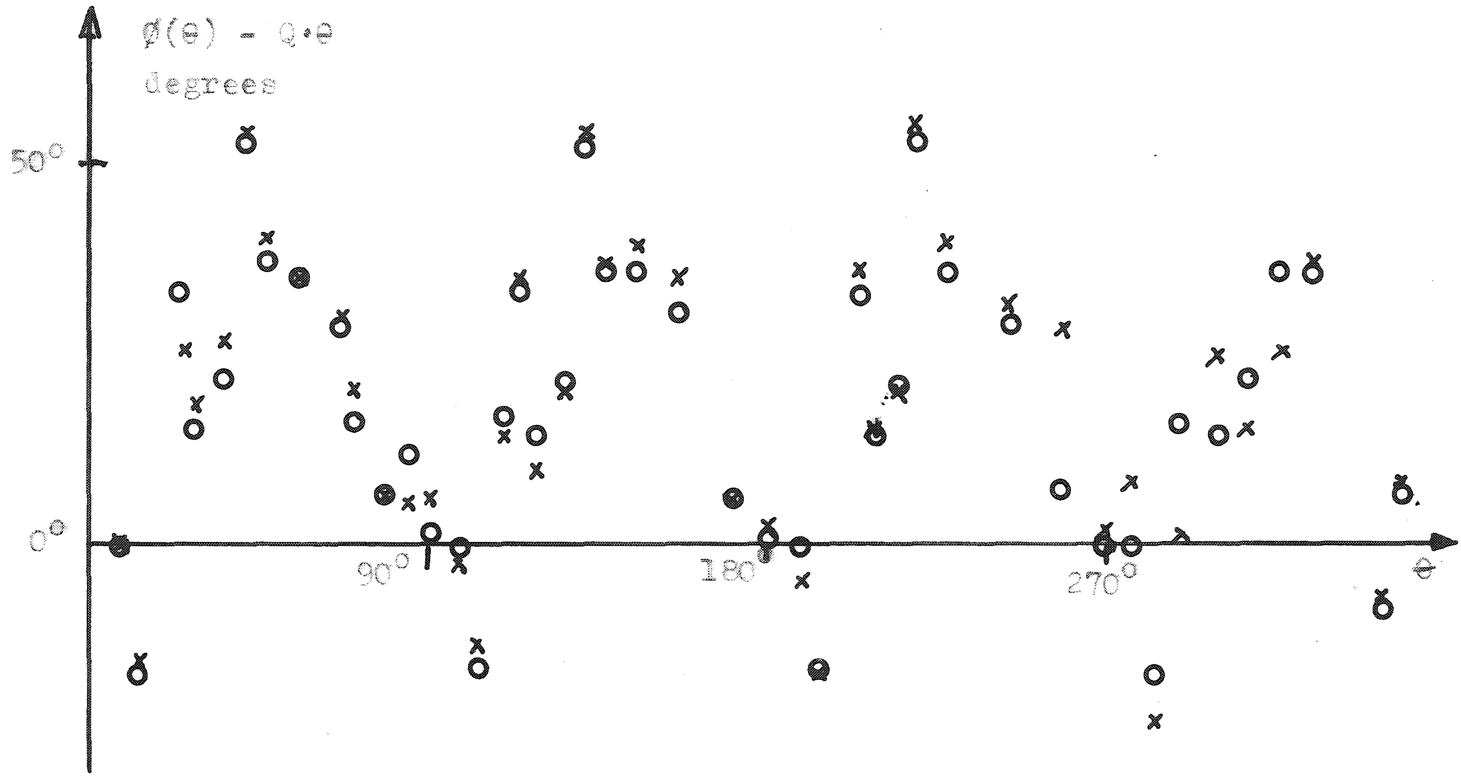

Fig. 2. Betatron phase Ø(θ) minus average phase advance Q θ, circles indicate AGS calculations, crosses are measurements