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COMPARISON OF MEASURED ACCEPTANCES OF PETRA WITH RESULTS FROM BEAM TRACKING

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ABSTRACT

The acceptance of PETRA has been measured using one optics and 4 different distributions of sextupole excitation with up to 6 independently powered sextupole families. The selected sextupole arrangements correct the chromaticity up to third order and/or compensate the energy dependence of the betas to first order in the interaction points.
Beam tracking, not including energy oscillations and machine imperfections has been used to calculate the acceptances as a function of energy for the 4 sextupole arrangements.
All the measured acceptances agree with the tracking results around the nominal energy within a factor of 2.

INTRODUCTION

The acceptance of a storage ring like PETRA is limited by resonances which are mainly caused by the distributed sextupole magnets needed for chromaticity correction. The 152 sextupoles in PETRA are arranged in six separatly powered families. The families S1 and S2 with 64 and 56 sextupole magnets are predominently used to compensate the horizontal and vertical linear chromaticities. The 4 sextupoles in each PETRA octant which are closest to the four low beta insertions are powered separately and form the families S3, S4, S5, S6 with 8 magnets each. These families have been used either to support families S1 and S2 or to compensate nonlinear chromaticity terms and/or the energy dependence of the beta functions at the interaction points (1) (2).

The machine acceptance of PETRA was measured for the M50 injection optics (β_{xo} = 4.6 m, β_{zo} = .5 m) using four different sextupole power distributions. The sextupole arrangement M50.2.1 has all sextupole magnets grouped into 2 families whereas the arrangement M50.2.2 uses only the families S1 and S2. In both cases the sextupoles are powered such as to correct the linear chromaticity in both planes. The 6-family sextupole arrangement M50.6.1 compensates the linear chromaticity terms, the vertical quadratic term, and in addition the energy dependence of the beta functions to first order in the interaction points. In the modified 6-family arrangement M50.6.4 the chromaticity is corrected in both planes up to third order.

The optics and sextupole distributions used were simulated by beam tracking to determine the theoretical acceptances as a function of energy. The aim of the investigation was to find out if beam tracking gives a reliable prediction of the machine acceptance for sextupole corrected optics.

THE MEASUREMENTS

After a standard orbit correction the machine acceptances were measured using kickers to excite betatron oscillations in one plane at a time with amplitudes large enough to cause a small reduction in life time. Machine scrapers at two stations in the ring were then used to determine the aperture at which a further life time decrease could be observed. From this aperture and the known beta functions at the scraper positions the acceptances can be calculated.

The experimental acceptances as defined by this procedure were measured for each of the selected sextupole arrangements (3). The results are shown in Tab. 1 together with the sextupole strengths. Also shown are the beam emittances for the M15 luminosity optics at 19 GeV for 6.5 standard deviations, and the mechanical acceptances which are limited vertically by the vacuum chamber height and horizontally by the good field region of the weak bending magnets.

Tab. 1: Distributions of sextupole excitation for M50 optics and measured acceptances

Sextupole family	Number of sextupoles	Sextupole strengths (m^{-2}) for arrangements			
		M50.2.1	M50.2.2	M50.6.1	M50.6.4
S1	64	.36	.43	.45	.33
S2	56	-.25	-.32	-.26	-.21
S3	8	= S1	0	.61	.89
S4	8	= S2	0	-.30	-.83
S5	8	= S1	0	-.57	.17
S6	8	= S2	0	-.21	-.09
measured acceptances in mm mrad		$a_x = 30$	13	16	37
		$a_z = 7$	10	5	9

Tunes: $Q_x = 25.18$ $Q_z = 23.27$, $Q_s = .077$

Mechanical acceptances: $a_x = 37$ (mm mrad)
$a_z = 17$ "

Beam emittances for M15 optics $\varepsilon_x = 8$ "
at 19 GeV for 6.5 st.dev. and $\varepsilon_z = 1.6$ "
$\varepsilon_z = .2\,\varepsilon_x$

For the M50.2.2 sextupole arrangement with measured acceptances below the mechanical limits it was shown that the remaining rms orbit distortions of $x = 2$ mm and $z = 1.4$ mm had no influence on the small horizontal acceptance. Using orthogonal correction coils the horizontally excited beam could be distorted horizontally to amplitudes of ± 15 mm in the arcs until a further life time decrease was observed. The sum of orbit distortion amplitude and beam size yielded ± 65 mm in the weak bending magnets and is close to the ± 60 mm good field region of these magnets.

BEAM TRACKING

For the above optics and sextupole arrangements the LIMATRA beam tracking program (4) was used to predict the acceptances in both planes as a function of energy. For each energy 32 simulated particles with initial conditions on a 4 dimensional phase ellipsoid were tracked through up to 50 turns using emittance coupling values of K = 0, .05 and 5.0. Synchrotron oscillations and machine imperfections were not included. The tracking program used the mechanical acceptances as an amplitude cutoff.

The predicted horizontal (a_x) and vertical (a_z) acceptances are shown as a function of energy in Fig. 1 and 2. The a_x-values are derived from the maximum stable horizontal amplitudes of the tracked particles for zero emittance coupling. With the exception of a few points at a vertical resonance causing vertical overflow, the tracking forK = .05 gives identical results for all sextupole arrangements. For the large emittance coupling factor K = 5 the overflow occurs pedominantly in the vertical plane. In these cases the maximum stable vertical amplitude is used to calculate the vertical acceptance.

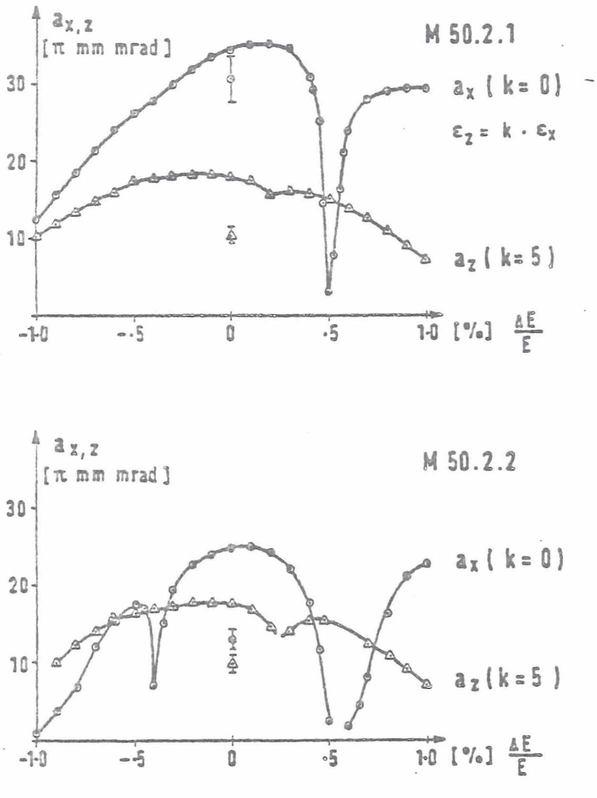


Fig. 1 ACCEPTANCE vs. ENERGYDEVIATION

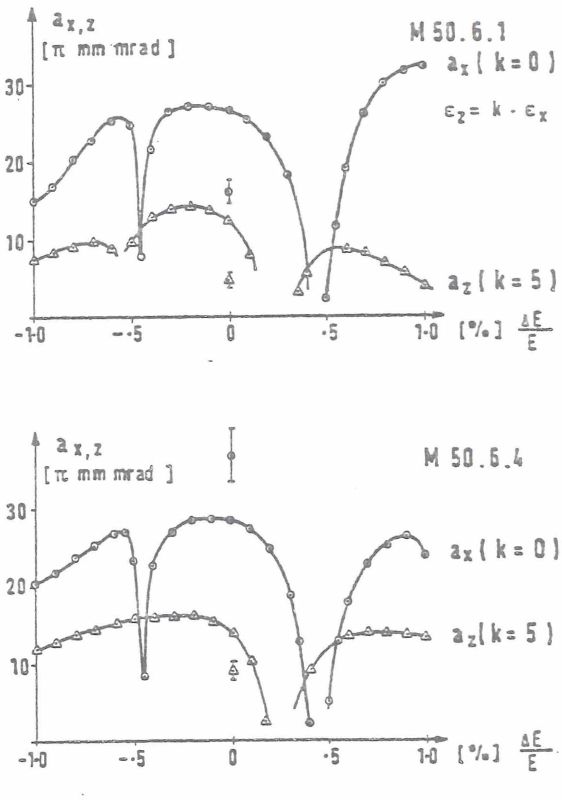


Fig. 2 ACCEPTANCE vs. ENERGYDEVIATION

The points with error bars in Fig. 1 and 2 indicate the experimental acceptances which are assumed to be known within ± 10 %. The data were taken at 6 geV where the natural energy width of the beam yields: $6.5\,\sigma_E/E = .24$ %

DISCUSSION OF THE TRACKING RESULTS

As can be seen from Fig. 1 and 2 all the predicted acceptance vs. energy curves show dips and/or holes for certain energy values. The sextupole arrangement M50.2.1 with the smallest sextupole strengths shows the weakest structures. Increasing the sextupole strengths by using either fewer and thus stronger excited sextupole magnets or exciting certain families stronger as in the case of the 6-family arrangements causes the structures to appear amplified. The dips have become holes and new dips appear.

All these structures can be attributed to intrinsic resonances into which the tracked particles are moved by the nonlinear tune shift. This is demonstrated for the 6-family sextupole arrangement M50.6.4. The phase plots for this distribution using 5 % emittance coupling relate holes, dips and resonances as shown in Fig. 3:

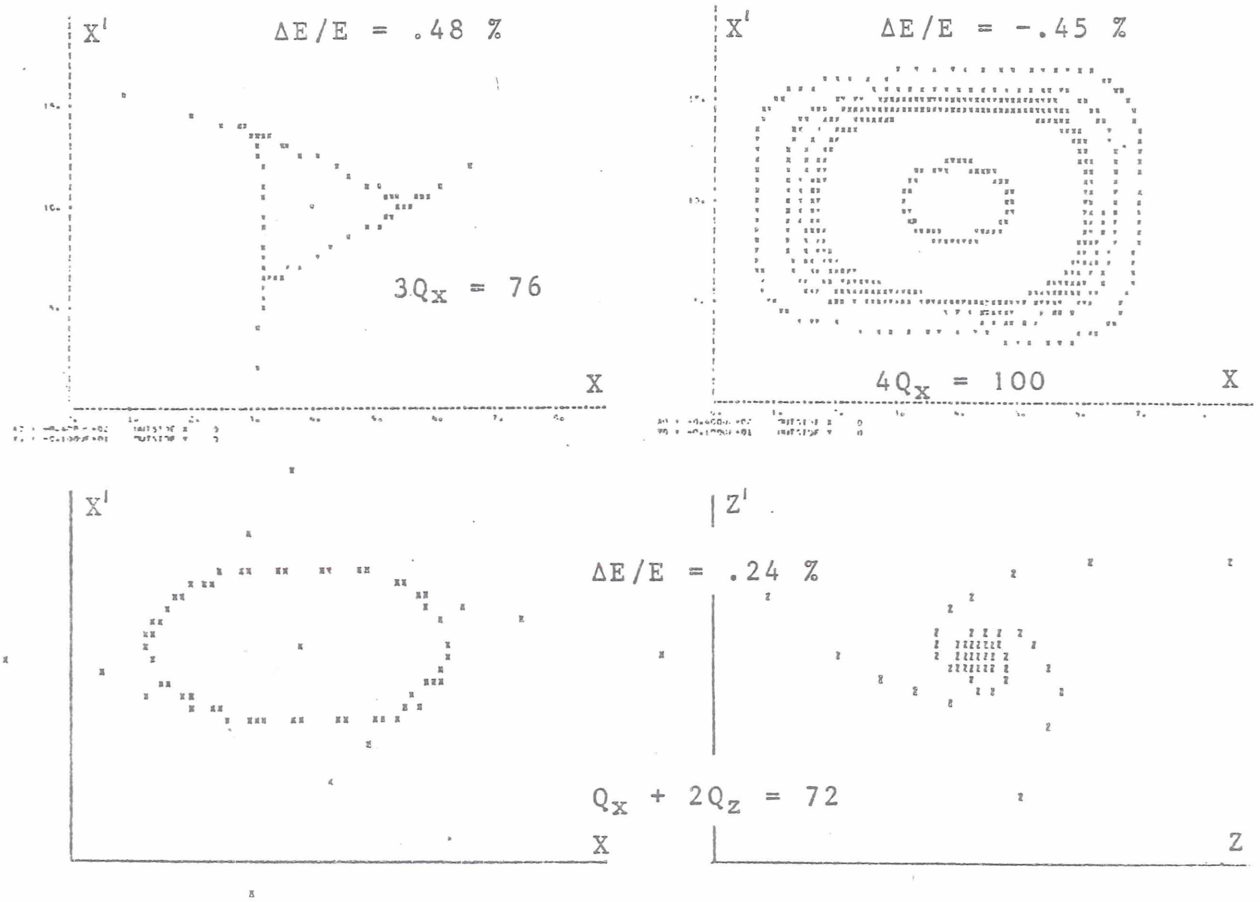
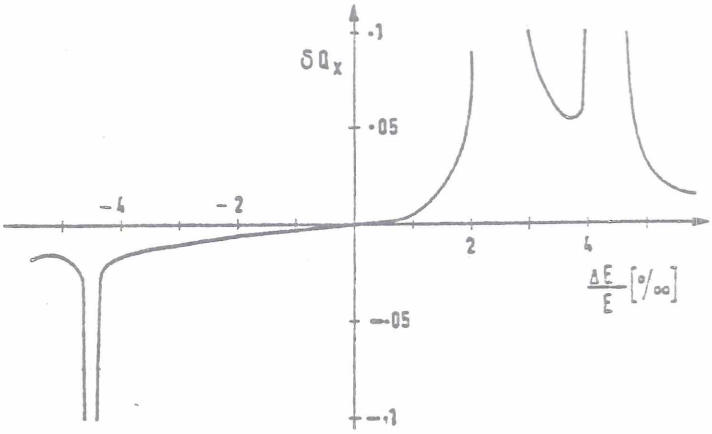


Fig. 3: Phase plots for M50.6.4 arrangement (K = .05)

The nonlinear tune shift which is caused by the betatron amplitude and the energy dependence of the sextupole corrected optics is shown in Fig.4, quadratically normalized to 10 mm amplitude. As compared to this effect the energy dependence of the tunes due to nonlinear chromaticity terms is negligible.

Fig. 4: Nonlinear horizontal tune shift vs. energy deviation quadratically normalized to 10 mm betatron amplitude



COMPARISON OF EXPERIMENTAL AND TRACKING RESULTS

Although synchrotron oscillations and machine imperfections were not taken into account, all the experimental results agree with the tracking calculations around the nominal energy within a factor of 2. With one exception all the measured values are somewhat lower than the calculated values.

Synchrotron oscillations (1 oscillation per 13 turns) are expected to weaken the effect of the resonances since, in tracking, the particle loss occurs in a time comparable to the synchrotron oscillation period. At the $3Q_x$-resonance for instance the tracked particles in the above example reach the cutoff after 7, 19, 43 turns for initial betatron amplitudes of 20, 10 and 5 mm respectively. Off the resonances the averaging effect of synchrotron oscillations is expected to be less important.

CONCLUSION

The agreement of experimental and tracking results is good. For all investigated sextupole arrangements the nonlinear tune shift is large enough to drive off-momentum particles with large amplitudes into structure resonances in the neighbourhood of the working point. These resonances appear at approximately the same energy values for all sextupole distributions and show the weakest influence on the predicted acceptance for the arrangement with the smallest sextupole strengths.

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