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MULTIPOLE RANDOM ERRORS IN DAΦNE MAIN RINGS

M. R. Masullo and F. Sannibale

In circular particle accelerators it is very important to minimize field errors in the magnets. These errors, that can be both systematic and random, can lead to a reduction of the dynamic aperture. In particular, systematic multipolar components arise from pole shaping, which usually differs from the ideal one, while random components come from mechanical tolerances and magnet assembly.

In this note we deal with the effects of random field errors on the dynamic aperture of the DAΦNE main rings. Being very difficult to correlate these errors to their mechanical origins, we use experimental data from other machines in operation or construction (PEP, AGS, ALS) to estimate the magnitude of random components in our simulations.

In the first part of this note we briefly describe the mechanical tolerances which are the source of random errors. In the second part we estimate the magnitude of the errors to be used in the tracking code. Finally we compare the dynamic apertures obtained with and without random components.

1 - Mechanical tolerances

1.1 *Dipole magnets*

The most important mechanical errors in bending magnets are [1]

Parallelism error. It is the projection of the 3-D twist error on the transverse plane. The twist error indicates a torsion of the magnet body in the longitudinal direction. It is typically 0.25 mrad. For example if we have a pole width of 20 cm then the tolerance in the pole faces parallelism will be 50 μm (total).

Flatness error. It is given by the tolerance in the pole face flatness. Its typical value is 10 μm (total) in solid and 20 μm (total) in laminated body magnets. In the laminated case this error also includes the differences between the sheets.

Finish error. It indicates the tolerance in the pole face finish. For typical magnets it is about 2 μm.

The parallelism error mainly causes a quadrupolar term in the magnetic field, which does not affect the dynamic aperture, at least if the total betatron tunes are restored by using the other quads in the lattice, and if the variations in the phase advances between sextupoles are not significant.

The finish error is one order of magnitude smaller than the others. Furthermore the surface variations which cause this error have a so fine structure that the iron can locally saturate and thus the field "mediates" the irregularities. For these reasons the effects of the finish error can be neglected.

It follows from these considerations that the multipolar contributions in dipole magnets come mainly from flatness errors.

1.2 *Quadrupole magnets*

The most important mechanical errors in quadrupole magnets are [1]

Symmetry error. Comes from the tolerance in the pole mutual position. It is typically 80 μm (total) in both solid and laminated quadrupoles.

Pole profile error. It indicates how much the actual pole shape is different from the ideal shape. It reaches typically 50 μm (total) in solid and 30 μm (total) in laminated quadrupoles.

Finish error. It is the tolerance in the pole faces finish. For typical quadrupoles it is about 2 μm.

The symmetry and the pole profile errors are the main sources of multipolar terms in quadrupole magnets, as described in [2].

The finish error can be neglected as in the case of the dipole magnets.

2 - Magnitude of multipole random errors for computer simulations

In order to study the sensitivity of dynamic aperture to random errors we used the tracking code PATRICIA [3]. The non linear contributions to the magnetic field must be given to the code in the form of separate terms in the field expansion.

The values for each component and for each magnetic element in the lattice are extracted from gaussian distributions, whose standard deviations have been derived from the above mentioned experimental data properly scaled to our magnets. In order to be conservative we used for the extrapolation the most pessimistic case.

Several extractions for different PATRICIA runs have been performed to obtain a statistically significant estimate of the random errors effects.

It is worth pointing out that random errors may excite multipolar components which change along a single magnetic element in the beam direction. To take this effect into account one should divide the magnets in several parts, assigning to each one different sets of errors for each multipolar component. However, for sake of simplicity, we neglected in our simulations the longitudinal variation of random multipoles, which means taking an average of the non linear terms over each magnet in the lattice.

2.1 *Dipole magnets*

The vertical component B of the magnetic field in dipoles in the horizontal midplane can be written as a power expansion:

$$B = B_0 \rho \sum_{n=0}^{l} \frac{k_n}{n!} x^n \tag{1}$$

with

$$k_0 = \frac{1}{\rho}$$

where B_0 is the nominal dipole field value, ρ is the curvature radius of the central trajectory, n indicates the 2(n+1)-pole term and x the radial position with respect to the central trajectory. The k_n coefficients are the strength of the multipolar components in the form of the input data required by the tracking program.

From the experimental data we find that the harmful multipolar components in dipoles are 6-pole, 8-pole and 10-pole . As mentioned before, we neglected the 4-pole term assuming that the tune shift will be corrected with the lattice quads.

We recall here the strengths k_n from AGS and ALS data, normalized to the fundamental term k_0 :

AGS [4]:

k_2/k_0	(6-pole)	1.78×10^{-2}	m^{-2}
k_3/k_0	(8-pole)	8.40×10^{-1}	m^{-3}
k_4/k_0	(10-pole)	2.40×10^{1}	m^{-4}

Advanced Light Source (ALS) [5]:

k_2/k_0	(6-pole)	5.66×10^{-1}	m^{-2}
k_3/k_0	(8-pole)	8.50×10^{1}	m^{-3}
k_4/k_0	(10-pole)	5.67×10^{2}	m^{-4}

AGS data are derived from magnetic measurements, while the values for ALS are estimates based on dipole field measurements at PEP (SLAC), SPS (CERN) and SRS (Daresbury) for tracking purposes. In the Conceptual Design Report of ALS [5] is remarked that these extrapolated values are conservative.

In order to scale the AGS values to our dipoles we have taken into account the different required field uniformity ($1.5x10^{-4}$ AGS, $5x10^{-4}$ DAΦNE) and gaps (8 cm AGS, 5 cm DAΦNE). The results is an increase by a factor 5.3 (3.3x1.6) of the AGS values as an estimate for DAΦNE. Since the scaled values are still smaller than the ALS ones, we have chosen the latter as standard deviations for our random extractions, without further scalings, being their dipoles quite similar to ours and their estimates conservative, as mentioned before.

2.2 *Quadrupole magnets*

For normal quadrupoles magnets the magnetic field on the horizontal midplane (y=0) is:

$$B = B_0 \rho \sum_{n=1}^{l} \frac{k_n}{n!} x^n \tag{2}$$

For these magnets the experimental measurements show that the harmful multipolar components are 6-pole, 8-pole, 10-pole, 12-pole and 20-pole.

Again we recall the measured strengths k_n normalized to the fundamental term k_1 extracted from the experimental data.

AGS data [4]:

k_2/k_1	(6-pole)	2.0×10^{-3}	m^{-1}
k_3/k_1	(8-pole)	6.0×10^{-2}	m^{-2}
k_4/k_1	(10-pole)	2.4	m^{-3}
k_5/k_1	(12-pole)	4.8×10^{2}	m^{-4}

PEP insertion quads [5]:

k_2/k_1	(6-pole)	5.0×10^{-4}	m^{-1}
k_3/k_1	(8-pole)	8.0×10^{-2}	m^{-2}
k_5/k_1	(12-pole)	1.2×10^{2}	m^{-4}
k_9/k_1	(20-pole)	3.2×10^{9}	m^{-8}

We have considered also the experimental data from the ALS quadrupoles [6]. They include systematic errors that are not specified, and since the 12-pole and 20-pole components are dominated by systematics we have not taken them into account:

k_2/k_1	(6-pole)	3.0×10^{-2}	m^{-1}
k_3/k_1	(8-pole)	5.33	m^{-2}
k_4/k_1	(10-pole)	124	m^{-3}

The PEP insertion quads [5] and the AGS ones [4] have been built with very small tolerances, while we ask for larger tolerances in our quads. Using the <u>standard</u> PEP quad specifications, as done by ALS people, we find multipole components 30 times larger than the insertion ones [5]. These values are in good agreement with the ALS experimental data scaled to our pole radius . We therefore took for the 10-pole term (which is absent in the PEP table) the scaled value of ALS.

We summarize finally the multipole components used in our tracking simulations:

k_2/k_1 (6-pole)	1.5×10^{-2}	m^{-1}
k_3/k_1 (8-pole)	2.4	m^{-2}
k_4/k_1 (10-pole)	6.0×10^{1}	m^{-3}
k_5/k_1 (12-pole)	3.6×10^{3}	m^{-4}
k_9/k_1 (20-pole)	9.6×10^{10}	m^{-8}

3- Preliminary tracking results

Preliminary results of tracking simulations shown in this section have been obtained inserting the random multipolar components in the DAΦNE lattice DAΦ-9 (working point Qx =5.12, Qy =5.17).

We have studied the sensitivity of the dynamic aperture to random errors, by running the computer code PATRICIA at the nominal energy and at relative energy deviations $\Delta p/p$ of ±1 %. The low-beta quadrupoles, which will be realized with permanent magnets, have not been taken into account, and the solenoidal fields for the experiment have not been included as well.

Figure 1 shows the dynamic aperture at the interaction point with and without the random errors for particles on energy and with $\Delta p/p$ of ±1%. The dashed area includes the results obtained with different sets of randomly extracted errors.

As result of this preliminary tracking we can conclude that the dynamic aperture seems to be not so sensitive to random non linear errors, but still some other runs, using many different sets of random errors, are to be performed in order to have more reliable results.

Furthermore future work has to be done to reach a better understanding of the dependence of random errors on mechanical tolerances and on the analysis of the experimental measurements performed on other machines.

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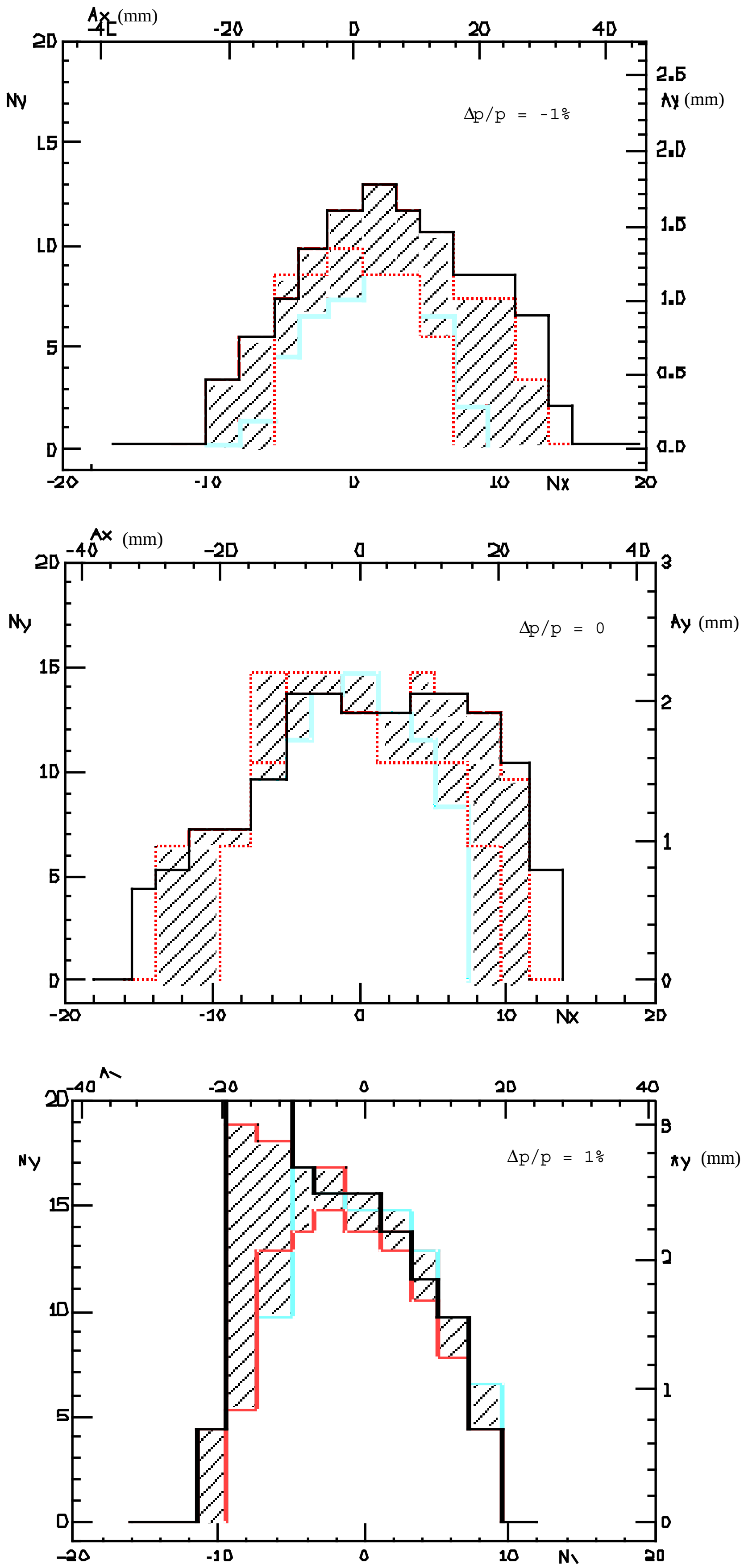

Figure 1. Dynamic apertures with a) Δp/p=-1%, b) Δp/p=0, c) Δp/p=1%. Solid line: without errors, dashed and dotted lines: with errors.