PERFORMANCE OF THE ESRF LATTICE IN THE PRESENCE OF ERRORS

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Abstract

The sensitivity of the lattice to errors is one of the challenging problems confronting the new generation of synchrotron light sources designed for high brilliance like the ESRF under construction in Grenoble.

In the ESRF, the dominant sources of errors come from the strong sextupoles needed for chromaticity correction and from the amplification of quadrupole or sextupole misalignments. The effects of these errors on machine performance have been investigated in terms of distortions of the linear optics, closed orbit deviations, reduction of the dynamic aperture and coupling between the horizontal and vertical planes. Closed orbit correction has more severe requirements than for other accelerators. The strategy of correction will be described and its impact on some crucial parameters of the machine presented.

Introduction

The ESRF optics design has been optimized to provide a large dynamic aperture as far as the ideal machine is concerned [1]. Magnet field imperfections as well as misalignment of the magnetic elements will affect machine performance. In this paper, we investigate the effects arising from these perturbations and specify the tolerances to be set for the different kinds of magnets. Since the closed orbit errors are the most important source of optics distortions, an effective closed orbit correction capability is crucial to achieve design goals. The performance of the lattice after correction is evaluated.

Magnet multipole errors

Field errors are unavoidable during magnet design and construction. Systematic multipole components arise from the fact that the magnet poles have finite dimensions and random multipoles come from magnet construction imperfections. These imperfections lead to a change in tune dependence on amplitude, possible excitation of resonances and reduction of the dynamic aperture.

In order to determine the harmful components, the influence of individual multipole components in the dipole and quadrupole magnets has been investigated separately and their effects measured by computing the reduction of dynamic aperture [2]. The tolerances set for the different magnets are listed in Table 1. They are expressed in terms of field error at a given radius. For the dipole, an octupole component allowed by the dissymmetry of the magnet has been considered, in addition to the natural systematic sextupole and decapole components. As the quadrupoles are split in the median plane for the emerging radiation, systematic octupole components are present in magnets, in addition to the standard dodecapole component.

Table1. Magnet tolerances

Dipole $\Delta Bl/Bl$ at 25 mm

	sextupole	octupole	decapole	dodecapole
systematic	$5\ 10^{-3}$	$7\ 10^{-4}$	$2\ 10^{-3}$	
random	$5\ 10^{-4}$	$7\ 10^{-4}$	$5\ 10^{-4}$	

Quadrupole $\Delta Gl/Gl$ at 32 mm

	sextupole	octupole	decapole	dodecapole
systematic		$5\ 10^{-3}$		$5\ 10^{-3}$
random	$1.2\ 10^{-3}$	$1.5\ 10^{-3}$	$1.8\ 10^{-3}$	$2.3\ 10^{-3}$

Fig. 1 shows the effect on the dynamic aperture of all systematic and random multipoles in the quadrupole. The larger effect occurs in the horizontal plane.

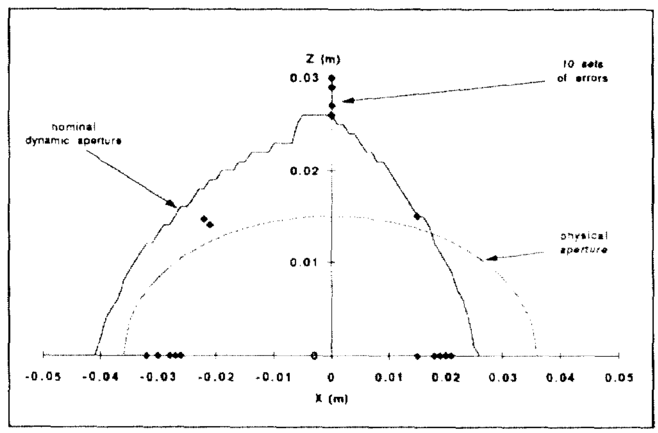

Fig. 1. Dynamic aperture in the presence of multipole errors

Focusing errors

Focusing errors are responsible for tune changes and excitation of quadrupolar random resonances. The excitation of these resonances creates stop-bands limiting the region allowed in the tune diagram and induces a modulation of β-functions. As a consequence of this modulation, the harmonic correcting sextupole strengths are no longer matched to correct the driving terms of the third-integer resonances and the net result is a reduction of dynamic aperture.

Various sources of focusing errors have been considered. Field index in the dipoles, rotation of the faces of the dipole, azimuthal mispositioning of the quadrupoles have negligible effect. The dominating contributions are due to random errors of the integral of gradient in quadrupoles (field errors due to pole positioning and length errors) and horizontal mispositioning of sextupoles. The comparison of the influence of these errors on the dynamic aperture is shown in Fig. 2. The deterioration applies mainly in the horizontal plane and yields dynamic apertures smaller than the physical aperture. To keep distortions within reasonable limits, the following tolerances have been set:

$$< \Delta Gl/Gl > \; = 1.\ 10^{-3}$$
$$< \delta x_{sext} > \; = 0.1 \text{ mm}$$

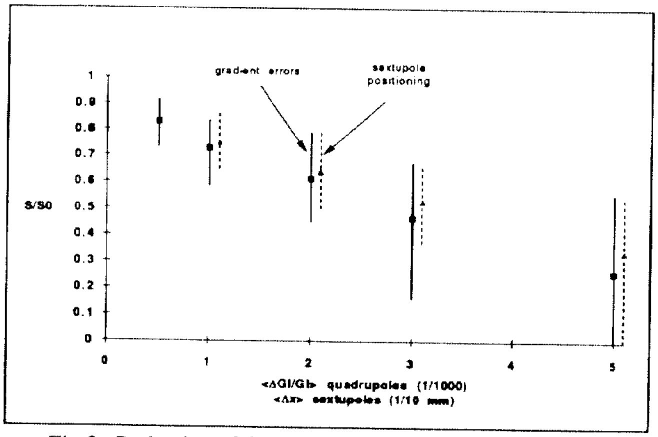

Fig.2. Reduction of dynamic aperture due to focusing errors

Closed orbit distortions and correction

Closed orbit errors are mainly produced by individual errors of the field integral in bending magnets, vertical mispositioning and tilt of dipoles, misalignment of quadrupoles. Closed orbit distortions have been simulated for each source of errors by generating an ensemble of machines with different sets of random errors selected from Gaussian distributions. The amplification factors, defined as the ratio of the rms closed orbit at the observation point to the rms amplitude of the defect are given in Table 2, together with the resulting tolerances. Due to the strong focusing required to obtain a low emittance, the mispositioning of quadrupoles is the dominant contribution to the closed orbit. The resulting tolerances correspond to the state-of-the-art survey techniques. On the other hand, the figures quoted for the dipoles are quite standard when compared to operating accelerators.

Table 2

	source of error	amplification	tolerance
dipole	$\Delta Bl/Bl$	1.1	$5\ 10^{-4}$
	azimuthal positioning	3.4	1 mm
	vertical positioning	0.5	1 mm
	tilt	12.7	0.2 mrad
quadrupole	horizontal positioning	132	0.1 mm
	vertical positioning	84	0.1 mm

The correction scheme [3] uses 96 horizontal correctors and 64 vertical correctors whilst the orbit is sampled at 224 beam position monitors around the circumference. The correctors are incorporated in the sextupoles that are equipped with backleg coils to generate the required dipolar fields.

Due to the very large amplification factors, the orbit distortions during the initial turn-on process could be very large, leading to amplitudes larger than the beam stay-clear aperture or, possibly, to unstable machines. Therefore the first turn transmission has been carefully studied by transporting the incoming beam step by step, using alignment procedures similar to those used in a transfer line. Each corrector strength is computed so as to minimize the orbit deviations on the next position monitors. Once the beam is transmitted through one turn, the correction procedure consists in applying a set of bumps which are chosen such that any combination of correctors can be represented by a unique set of bumps, which leads to faster convergence and smaller residual orbit distortions. The "most effective corrector" method is applied once in spite of its low convergence, to correct possible errors in closing the first turn.

The gain in the convergence speed due to the first turn steering is quite significant. On an average, only five iterations are necessary to obtain residual closed orbits less than 0.1 mm in both planes. The above correction procedure has been applied to 100 different machines. The results for the horizontal orbit are shown in Fig. 3.

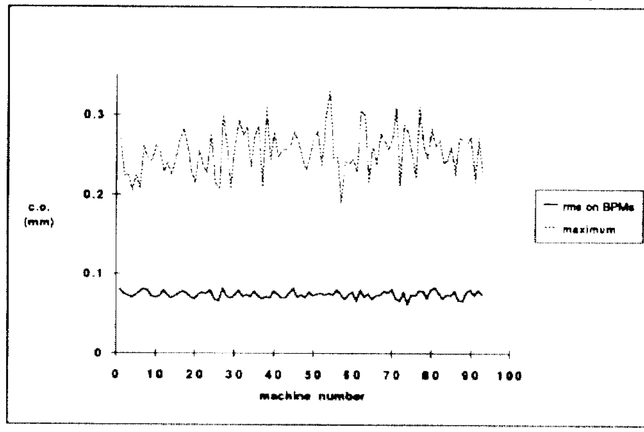

Fig. 3. Closed orbit after correction

Machine performance after closed orbit correction

Uncorrected closed orbits will affect the performance of the storage ring by inducing reduction of the dynamic aperture, mismatching of the dispersion function, modulation of the β-functions, coupling between horizontal and vertical planes. It could be expected that, after closed orbit correction, most of the nominal characteristics of the machine could be restored. Fig. 4 shows the dynamic aperture of 10 different machines after closed orbit correction. The average reduction is 15 %.

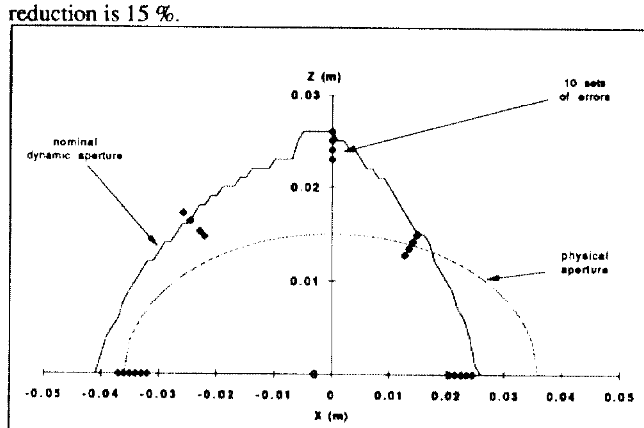

Fig. 4. Dynamic aperture after closed orbit correction

After correction, a very high modulation of the β-functions was obtained in both planes. It appeared that the skew quadrupole term arising from the residual vertical closed orbit in sextupoles induced a strong coupling because the working point was sitting on the coupling resonance $\upsilon_x - \upsilon_z = 25$. Moving the tune away from this resonance leads to a small modulation as shown in Fig. 5.

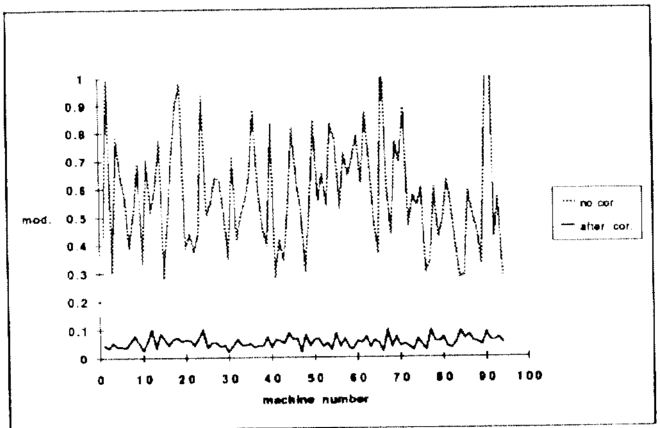

Fig. 5. Residual modulation of β-functions

One of the most significant benefits of the closed orbit correction is to reduce the distortion of the horizontal dispersion to a low level and to minimize the consequences on chromaticity correction, beam sizes at the insertion device locations, equilibrium emittances in the presence of insertion devices. This is illustrated in Fig. 6 where the rms value of the dispersion in high-β straight sections of 100 sample machines is plotted.

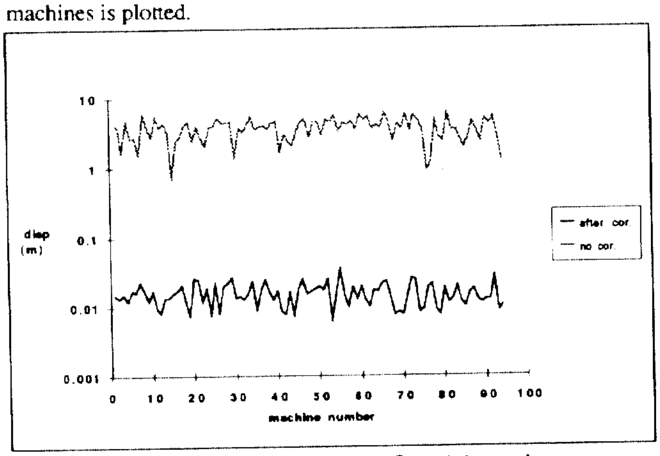

Fig. 6. Rms dispersion in high-β straight sections

Design specifications, in terms of brilliance, assume that a 10 % coupling is achievable. This corresponds to emittances of the order of 6.3 10^{-9} m.rad in the horizontal plane and 6.3 10^{-10} m.rad in the vertical plane. It is therefore essential to control the residual coupling for proper beam performance. Fig. 7 shows the residual coupling factor $\kappa = \varepsilon_z/\varepsilon_x$ (ε_x and ε_z are the effective horizontal and vertical emittances) for 100 randomly generated sets of errors after closed orbit correction and adjustment of coupling by skew quadrupoles.

Large variations in coupling values may appear if the errors combine in an unfavourable way. However coupling less than 10 % can be expected provided the closed orbit is corrected at best. The deterioration of performance induced by an imperfect closed orbit correction has been simulated by decreasing the number of iterations used in the standard correction procedure. The evolution of horizontal beam sizes in high-β straight sections is shown in Fig. 8. The figures of merit are not the coupling factors (which remain within a range of a few %) but the increase of beam sizes and their modulation from one straight section to another which are due to both the modulation of β-functions and the change in emittances. Enlargement of the order of 40 % in both planes are obtained with closed orbit distortions less than 0.4 mm [4].

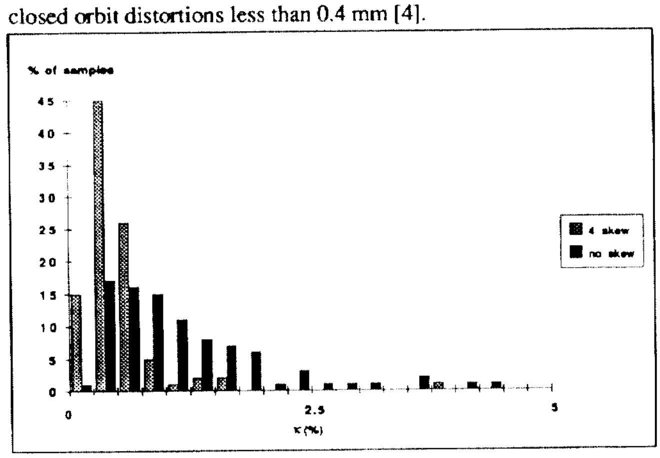

Fig. 7. Horizontal-vertical coupling after closed orbit correction

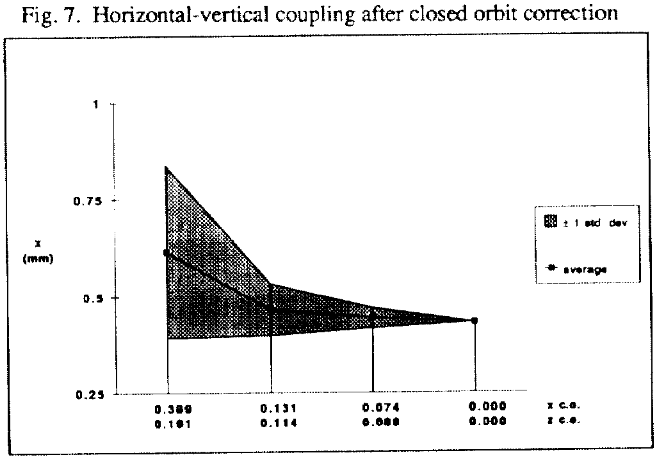

Fig.8. Beam sizes as a function of closed orbit correction quality

Conclusion

Tolerances on field quality are quite standard for accelerator magnets and the expected errors cause acceptable reduction of the dynamic aperture. The challenging issue is the increased sensitivity to quadrupole positioning which implies tight constraints on alignment precision and a very effective closed orbit correction scheme.

References

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