POSSIBLE RETUNING OF THE ESRF STORAGE RING LATTICE FOR REDUCING THE BEAM EMITTANCE

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Abstract

The possibility of reducing the emittance in the ESRF storage ring in order to increase the brilliance of emitted photon beams has been investigated. In this paper, it is shown that by breaking the doubly achromatic condition of the Chasman-Green lattice, a reduction by a factor of about two of the horizontal emittance looks feasible.

1. INTRODUCTION

The possibility of reducing the electron beam emittance in the ESRF storage ring has been recently considered in order to increase the brilliance of X-rays emitted from insertion devices [1,2]. In principle, such an emittance reduction is possible by breaking the achromatic condition imposed in the expanded Chasman Green (ECG) lattice utilized for the ESRF and by giving an appropriate finite value to the dispersion function η_x and its slope η'_x at the entrance of each dipole magnet.

Under these conditions, the minimum achievable horizontal emittance is given by the expression :

$$\varepsilon_x = C_q \frac{\gamma^2}{J_x} \frac{\theta^3}{12\sqrt{15}}$$

where C_q= 3.84.10^{-13} m, θ is the dipole bending angle, γ is the relativistic factor and J_x is the lattice horizontal partition coefficient.

It follows that for the ESRF, an emittance of 1.1 nm.rad (one third of the ideal emittance of the Chasman Green lattice) can be theoretically contemplated.

In practice, such a value looks unrealistic and will be difficult to approach because there are many reasons why a real lattice cannot be operated at its minimum emittance.

In the case of the ESRF for instance, the design emittance has been fixed to 6.8 nm.rad which is about twice the minimum Chasman Green value in order to maintain the maximum β function values in focusing quadrupoles to reasonable values and therefore to avoid too large chromaticities [3].

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Nevertheless, as it will be demonstrated in what follows, an emittance reduction by about a factor 2 looks possible by only adjusting the strength of each quadrupole and sextupole within a realistic range of ± 10 % while maintaining a large dynamic aperture and a reasonable sensitivity to errors.

2. POSSIBLE CONFIGURATIONS ACHIEVING SMALL EMITTANCES

Different lattice configurations achieving smaller emittances than the present ECG lattice have been tested.

The 16-fold symmetry structure with alternating low beta straight sections (wigglers) and high beta straight sections (undulators) has been maintained together with the present number of quadrupole families. The fractional part of tunes ν_x and ν_z has been fixed to 0.4 in all cases in order to allow a comparison of performances in terms of sensitivity to errors and dynamic aperture.

Some figures of merit have been defined and evaluated in order to characterize the optical qualities of the considered configurations. These are :

- the maximum value of the horizontal beta function β_x in focusing quadrupoles which, combined with the quadrupole strengths, influences closed orbit distortions and natural chromaticities.

- the maximum value of the RMS closed orbit deviation $\langle \Delta x_{c.o} \rangle$ in the presence of the following error sources :

. quadrupoles : transverse displacement $\langle \delta x \rangle = \langle \delta z \rangle = 0.1$ *mm*
. dipoles : longitudinal displacement $\langle \delta s \rangle = 1$ *mm*
. rotation about beam axis $\langle \delta \varphi \rangle = 0.2$ *mrad*
. dipolar field error $\langle \delta BL/BL \rangle = 5.10^{-4}$

- the horizontal chromaticity $\xi_x = 1/\nu_x . \Delta\nu_x/(\Delta p/p)$ which determines the integrated strength of sextupoles used to compensate for it and therefore imposes severe limits on dynamic aperture optimization.

- the function noted B, proportional to the brilliance in the middle of high beta straight sections and given by :

$B = \frac{1}{\sigma_x \sigma_{x'} \sigma_z \sigma_{z'}}$ where σ_x , σ_z , $\sigma_{x'}$, $\sigma_{z'}$ are the RMS beam sizes and beam divergences defined as follows:

$$\sigma_x = [\beta_x \varepsilon_x + (\eta_x \sigma_p)^2]^{1/2} \qquad \sigma_{x'} = [\gamma_x \varepsilon_x]^{1/2}$$

$$\sigma_z = [\beta_z \varepsilon_z]^{1/2} \qquad \sigma_{z'} = [\gamma_z \varepsilon_z]^{1/2}$$

β_x, β_z, γ_x, γ_z being the first order lattice functions,
σ_p being the RMS value of the relative momentum spread,

ε_z being supposed to be equal to $\varepsilon_x/2$.

The dependence of these quantities on the achievable natural emittance ε_x is shown in figures 1-4.

Characteristics of the nominal ECG structure corresponding to $\varepsilon_x = 6.8$ *nm.rad* can be compared to 6 other configurations obtained by relaxing the constraints on the ECG achromatic condition.

The correlation between the plotted quantities and ε_x appears very clearly. We note that $\beta_{x\ max}$, $<\Delta x_{c.o}>$ and ξ_x increase rapidly when ε_x decreases especially in the region where ε_x is less than 4 nm.rad. In addition, it is found that within the possible range of quadrupole strengths, it is not possible to decrease ε_x below 3 nm.rad.

The other interesting point is that the brilliance can be increased by about a factor 3 (without taking into account the effects of insertion devices) for a configuration yielding an emittance of about 4 nm.rad and having optical qualities very similar to the present ECG lattice. Usual lattice functions obtained in this case are shown in figures 5 and 6.

3. CHROMATICITY CORRECTION AND DYNAMIC APERTURE OPTIMIZATION

In ECG lattice, only 2 families of sextupoles located in the achromats are used for the chromaticity correction. Their strength is thus automatically determined and their adverse effect on dynamic aperture has to be compensated for by other sextupoles installed in dispersion free straight sections.

When the achromatic condition is broken so that the lattice does not have zero dispersion straight sections, all sextupoles act simultaneously on chromaticities and on dynamic aperture. This situation may provide a higher flexibility for non-linear effects correction.

The method which has been adopted to optimize the dynamic aperture is based on works presented in [4] and [5]. It consists in minimizing horizontal and vertical amplitude distortions and adjusting the linear dependence of tunes on amplitudes in order to avoid the crossing of low order non linear resonances.

Figure 7 illustrates this procedure for the lattice presented in Figure 5 and generating an emittance ε_x of 3.9 nm.rad.

One sees that the largest stable region is obtained when $\partial \nu_x/\partial \varepsilon_x$ has a rather large negative value which stabilizes motion at medium amplitude and which compensates for positive non linear terms contributing to the tune shift at large amplitude.

From the computation time viewpoint, the fitting procedure adopted to determine the sextupole strengths is relatively rapid because only first order lattice functions are utilized to calculate chromaticities, tune shifts and amplitude distortions.

Figure 8 shows the optimized dynamic aperture without momentum errors *($\Delta p/p = 0$)* of optics having an emittance which is less than 4 nm.rad. For comparison, an improved dynamic aperture of the nominal ECG lattice obtained with the procedure described above is also presented.

As only sextupole strengths are adjusted whilst maintaining the initial number of families, it becomes more and more difficult to obtain large stable regions when ε_x decreases. For $\varepsilon_x = 3.9$ *nm.rad,* dynamic aperture can be easily enlarged to a level comparable to that of the ECG lattice with $\varepsilon_x = 6.8$ *nm.rad.* For optics with smaller emittance, it shrinks progressively and some sextupole families need a strength which exceeds the present possibilities. One way to overcome these difficulties is to increase the number of quadrupole and sextupole families, but results obtained in this case and presented in [1] are not exposed here.

Finally, effects of momentum deviations of ± 2% on dynamic aperture have been investigated in the case of the optics with an emittance of 3.9 nm.rad. Results have shown that stability of motion was not significantly affected even at large horizontal and vertical amplitudes.

4. CONCLUSION

The possibility of reducing emittance in the ESRF storage ring has been studied in order to increase brilliance. The method used here is to reduce the contribution of the dispersion function to the radiation excitation by breaking the doubly achromatic condition of the Chasman Green structure.

We found that an emittance ε_x of about 4 nm.rad can be obtained by adjusting the strength of each quadrupole within a realistic range (± 10 % of the present values) and that the dynamic aperture of the new optics can be kept as large as that of the ECG lattice for sextupole strengths which do not exceed the allowable maximum values.

As this new optics is very similar to the present one from the viewpoint of closed orbit sensitivity to errors, tunes, quadrupole and sextupole strengths, it is expected that the dynamic aperture reduction due to field errors is comparable to that of the actual ECG lattice.

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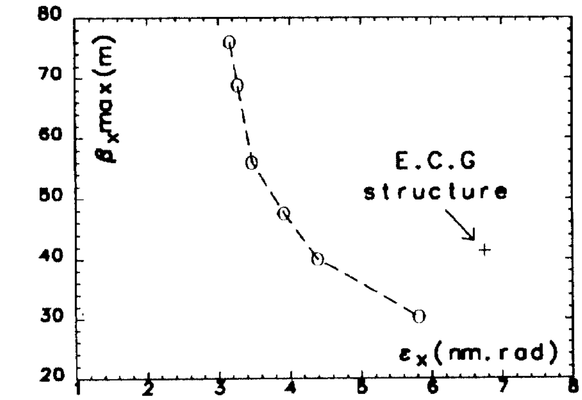
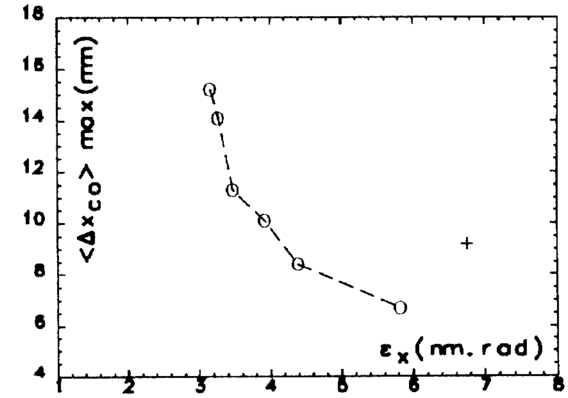


Figure 1



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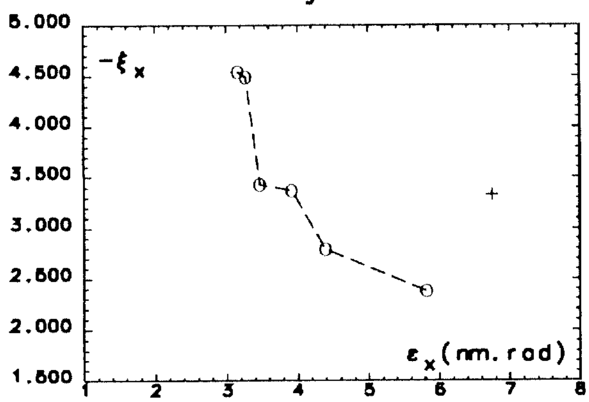

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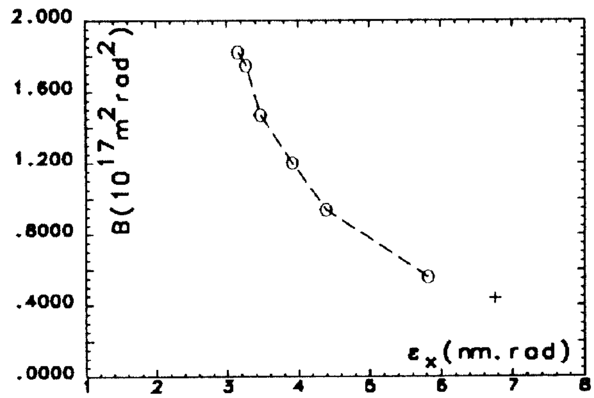

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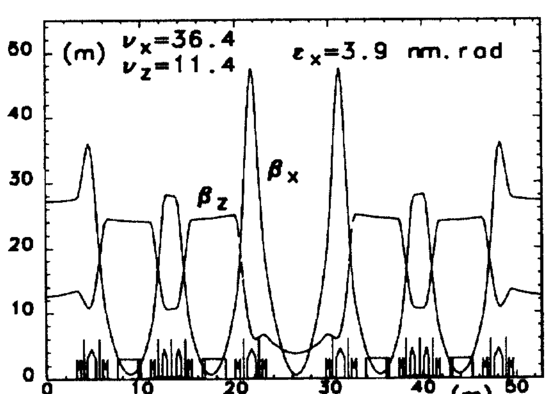
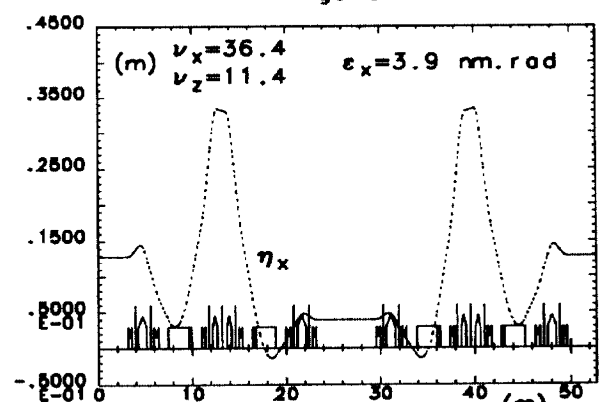


Figure 5



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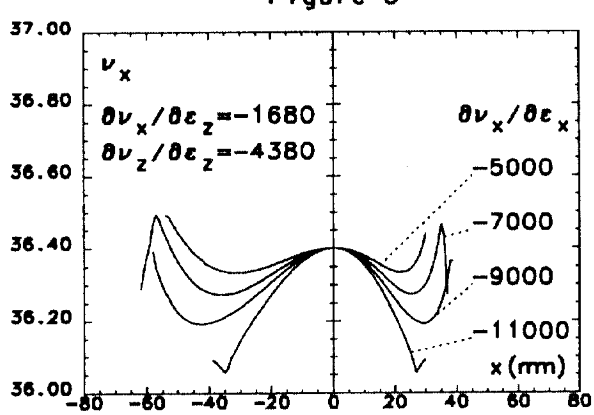

Figure 7

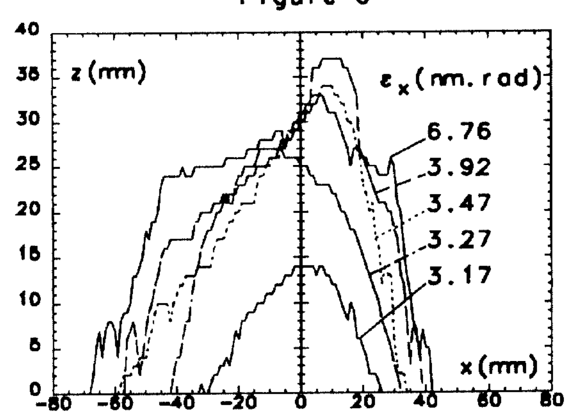

Figure 8