DESIGN OF THE HIGH EMITTANCE OPTICS FOR THE STORAGE RING OF SPRING-8

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Abstract

Design of the high emittance optics (detuned lattice) for the storage ring of SPring-8 and simulation results of comissioning with this optics are described. The main purpose of the detuned mode is to provide a stable ring for the comissioning and the machine operation at begining stage. The designed lattice has fulfilled this requirement.

Introduction

The storage ring of SPring-8 is a 8 GeV Chasman Green type low emittance ring[1]. Electron beams in the ring are strongly focused to achieve low emittance. Consequently, the dynamic aperture of the ring is small and the sensitivity against errors is high compared to high emittance rings. The commissioning of such rings are then expected to be more difficult than high emittance storage rings. This difficulty leads to an idea that at first the commissioning should be done with detuned high emittance lattice instead of direct commissioning with the final goal lattice and as a next step it should be done with final lattice. The detuned lattice may be also used for the machine operation at begining stage. For these requirements, the detuned optics was designed and the simulation of comissioning with this optics was done.

Design criterion

Fig. 1 shows the lattice functions of low emittance mode. Lattice functions of detuned lattice need to be similar to this lattice functions because generation pattern of closed orbit needs to be similar to that of final lattice. If the generation parttern of closed orbit of detuned lattice is quite different from that of final lattice, we cannot relate the detuned lattice to final lattice and the meaning of detuned lattice is lost so far as the commissioning is concerned. Thus it is desirable to detune the lattice without breaking an achromat condition of both straight sections in a cell. However, lattice functions of detuned lattice which is designed by keeping this condition has different behaviour and strong sextupole magnets for chromaticity correction are required. Therefore, we decided to break the condition of achromat of one straight section in a cell; we detune the lattice with two cells as a unit.

Betatron functions of straight sections are decided to have medium value. On the basis of these criteria, we designed the detuned lattices of the emittance values from ~10 nm.rad to ~80 nm.rad .

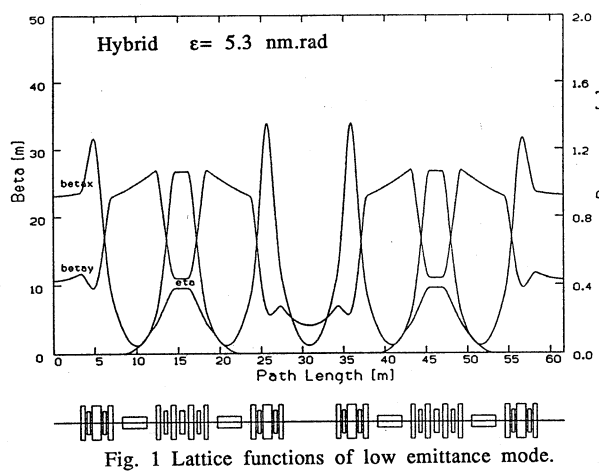


Fig. 1 Lattice functions of low emittance mode.

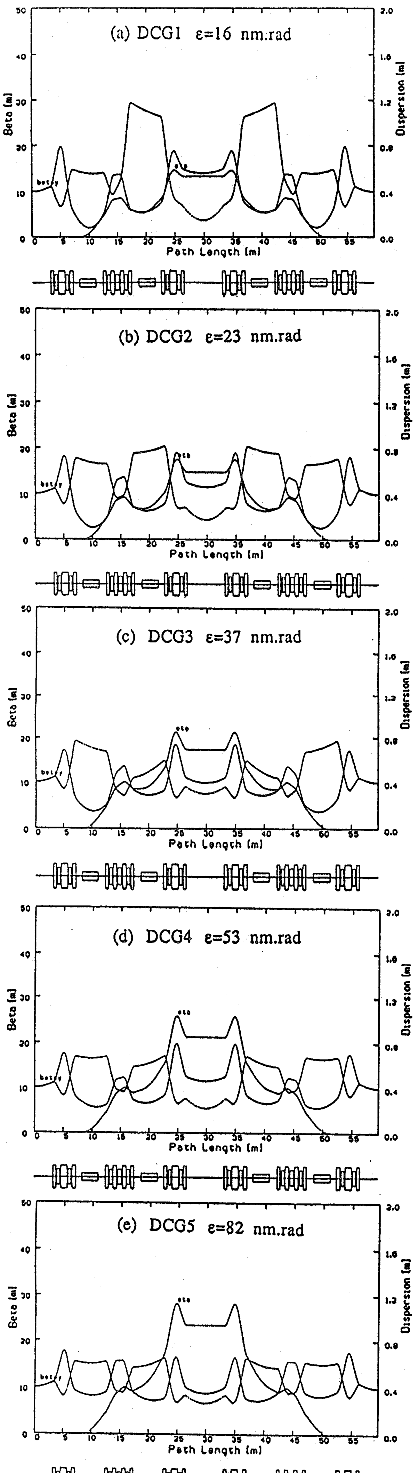


Fig. 2 Lattice functions of detuned mode.

Lattice functions and dynamic apertures

Lattice functions and ring parameters are shown in Fig. 2 and Table 1, respectively. Fig. 3 shows the relation of horizontal betatron tune and emittance. This figure shows that emittance is uniquely determined according to the horizontal tune value.

Table 1 Ring parameters of detuned Chasman Green lattice.

		DCG1	DCG2	DCG3	DCG4	DCG5
Emittance(nm.rad)		16	23	37	53	82
Tune	ν_x	33.20	31.20	28.20	25.20	22.80
	ν_y	21.15	21.15	21.15	21.15	20.85
	ν_{xc}	1.38	1.30	1.18	1.05	0.95
	ν_{yc}	0.88	0.88	0.88	0.88	0.87

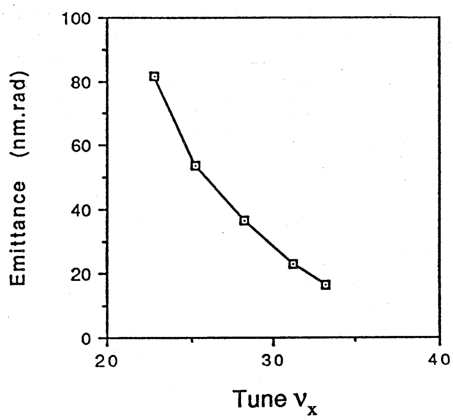


Fig. 3 Relation of horizontal betatron tune and emittance.

The dynamic apertures are calculated by particle tracking[2]. Fig. 4 shows the obtained results for each lattice. These dynamic apertures are dominated by the first and third order resonances driven by the strong sextupole fields for chromaticity correction. Square mark is the dynamic apertures only with sextupoles for chromaticity correction. Solid line is the enlarged dynamic apertures with additional sextupoles (harmonic sextupoles) which are placed in a non-dispersive section. Fig. 5 shows operating points of each lattice on a tune diagram. Tunes of ν_{xc} and ν_{yc} are for one superperiod.

The dynamic apertures of the lattices which have emittances for 80 nm.rad level to 50 nm.rad level (DCG5, DCG4) are limited by the resonances of ν_{xc}= 1 and $3\nu_{xc}$= 3. However the driving term of these resonances can be

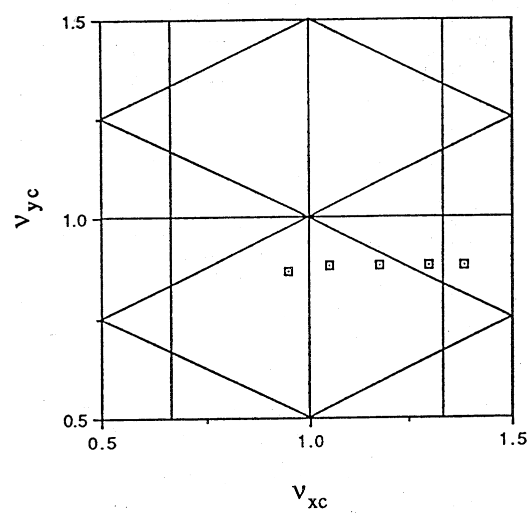
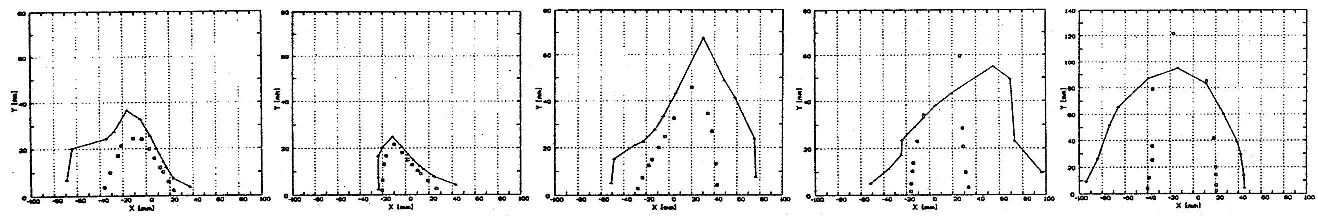


Fig. 5 Operating points on a tune diagram.

easily canceled by only one harmonic sextupole. For the lattice which has emittance of 30 nm.rad level (DCG3), the operating point is the middle of resonance lines ν_{xc}= 1 and $3\nu_{xc}$= 4. Resultantly, the dynamic aperture is not small even though the emittance is smaller than the former two lattices. Tune of the lattice of 20 nm.rad level emittance (DCG2) approaches to the resonance line of $3\nu_{xc}$= 4 and the dynamic aperture is not large enough. Main driving terms are ν_{xc}= 1 and $3\nu_{xc}$= 4. In this case it is difficult to cancel both driving terms with harmonic sextupoles. If the emittance reaches to 10 nm.rad level (DCG1), tune becomes larger than the resonance line of $3\nu_{xc}$= 4. In this case, the dynamic aperture could be enlarged by two kinds of harmonic sextupoles. Dynamic apertures of these detuned lattices are large enough for injection of electron beams from the synchrotron.

Sensitivity against the errors

Fig. 6 shows the closed orbit distortions (Xcod, Ycod) arising from random quadrupole displacements (dX,dY). Thus, we can find the expected values of closed orbit distortions are 7.0 mm and 8.2 mm for 0.2 mm alignment errors of quadrupole magnet for the ring of 80 nm.rad emittance. These values become 17.6 mm and 12.0 mm for the ring of 5 nm.rad emittance. Sensitivity of horizontal direction increases gradually when emittance decreases from 80 nm.rad to 16 nm.rad and it changes from 41 to 88 for the final lattice. This shows that we may not need step by step commissioning from the ring of 80 nm.rad emittance to the final lattice.



(a) DCG1 ε=16 nm.rad (b) DCG2 ε=23 nm.rad (c) DCG3 ε=37 nm.rad (d) DCG4 ε=53 nm.rad (e) DCG5 ε=82 nm.rad

Fig. 4 Dynamic apertures of detuned mode (□ : without harmonic sextupoles, ☆ : with harmonic sextupoles).

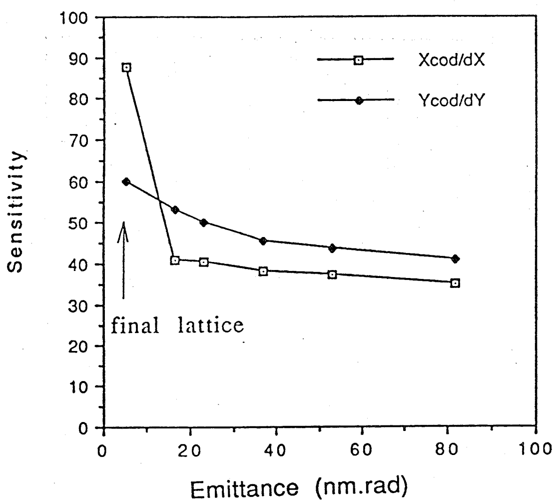


Fig. 6 Closed orbit distortions arising from random quadrupole displacements.

Commissioning of low-emittance modes via detuned mode

A simulation study has been performed to examine the effectiveness of using the detuned modes to commission the low-emittance modes. As mentioned earlier, our central interest is to find the feasibility of commissioning the detuned mode itself as well as to find the validity of performing the closed orbit correction with the detuned modes before switching over to the low-emittance modes. Simulation has been made using the computer code RACETRACK.[3]

Choosing DCG5 as the commissioning ring, we provided ourselves with 10 different machines each having a random quadrupole misalignment of 0.2 mm rms. The value 0.2 mm may be slightly pessimistic, since with the exisiting alignment technology, achievement of alignment within 0.1 mm rms is known. Field errors of 0.1% and tilt errors of 0.3 mrad are also assumed for quadrupoles and dipoles, and all the sextupoles are turned off. Two hundred particles are injected via a bumped orbit and tracked for 50 turns. Particles are lost if they hit the vacuum chamber wall (±40 mm $\times$ ±20 mm) assumed in the computation. A more detailed description of the calculation is found in Ref. 4.

Results of the simulation are summarized in terms of the injection efficiency in Table 2. We find that, even for detuned modes, commissioning without any orbit steering is difficult for 0.2 mm misalignment. Maximum closed orbit distortions in a ring, shown in Fig. 7, further give this indication. The situation is better for 0.15 mm, but still there are 3 unsuccessful cases. Nevertheless, as compared to the low-emittance modes, the injection efficiency is much improved reflecting the reduction of sensitivies against misalignment.

Table 2. Injection efficiency% for 10 different machines.

Number of error seed	1	2	3	4	5	6	7	8	9	10
Uncorrected DCG5: (Q-misalign.)rms = 0.20 mm	0	46	0	0	88	100	0	0	76	0
Uncorrected DCG5: (Q-misalign.)rms = 0.15 mm	0	-	100	6	-	-	0	0	-	100
High β mode: with correctors determined by DCG5. (Q-misalign.)rms = 0.2 mm	100	100	100	95	100	100	100	0	100	100

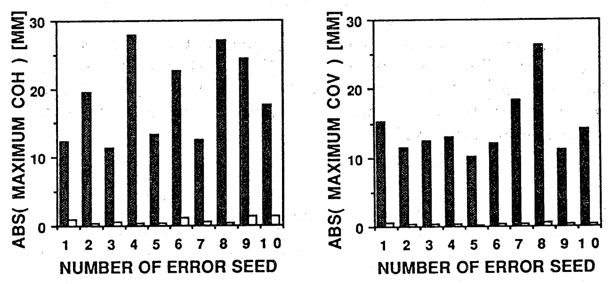


Fig. 7 Maximum closed orbit distortion in a ring with 0.2 mm quadrupole misalignment before (dark bars) and after (white bars) the closed orbit correction. Optics mode: DCG5.

Followingly, correction of closed orbit distortion has been made with steering magnets to the maximum extent (mostly within 0.1 mm rms at the monitors). By keeping these corrector strengths fixed, we switched the optics to the "high β" mode (emittance = 5.7 nm·rad) in which low β sections of the hybrid mode (Fig. 1) are replaced by high β sections. As seen in Table 2, the beam was very successfully injected for all cases but one. The effectiveness of the correctors can be clearly seen in Fig. 8 where we compare the maximum closed orbit in a ring with and without correctors. Similar procedure was made between the high β mode and the hybrid mode and was found to be equally successful.[4]

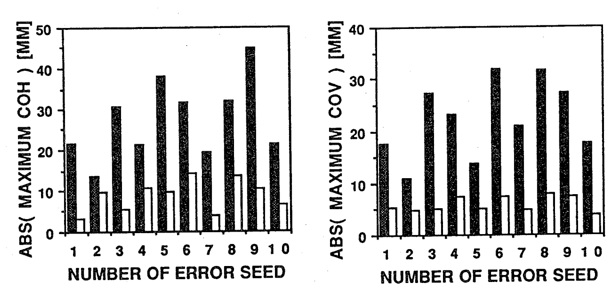


Fig. 8. Maximum closed orbit distortion in a ring with (white bars) and without (dark bars) corrector strength determined with DCG5. Optics mode: High β.

Conclusion

We have designed the detuned lattices of emittance values from ~10 nm.rad to ~80 nm.rad. The dynamic apertures were large enough for injection and the sensitivity against the errors were remarkably low compared to the lattice of low emittance mode. The simulation results of comissioning showed that if the orbit correction for single turn and the following correction of closed orbit distortion are done for a lattice of detuned mode, the particles can circulate a ring of low emittance mode and the closed orbit correction can be done.

References

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3. A. Wrulich, DESY Rep., 84-026 (1984).
4. R. Nagaoka et al., in this report.