A Low Emittance Optics for a Pure Insertion Device Lattice

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Abstract

The pure insertion device (PID) lattice is a novel concept for a sinchrotron light source, in which all possible light ports are irradiated by insertion devices. Up to 40% of the ring is available for insertion devices. A low emittance optics for a 3 GeV light source with a PID lattice is presented. With 24 straight sections of 3m each it has a circumference of 202m and an emittance of 15 nm.rad. Tracking studies show excellent dynamic properties of the lattice.

I. INTRODUCTION

Third generation synchrotron radiation storage rings are characterized by an optics which minimizes the emittance in order to obtain a high brilliance. However, there are many experiments, where only the total photon flux integrated over the angular acceptance of the beamline is important, as long as the beam spot size is smaller than the sample size. Most common X-ray beamlines, which use only mirrors for focussing, don't reduce the spot size below 1 mm^2 because of manufactoring tolerances. Those experiments would still profit from the high fluxes provided by insertion devices, but they are usually placed at bending magnet ports, because the number of insertion devices is limited.

The idea of having one insertion device per bending magnet port was first realized by the SuperACO storage ring [1]. The conventional Double-Bend-Achromat (DBA) structure was designed such that there is additional space for a short insertion device in the dispersive section. In this paper we present the pure insertion device (PID) lattice which extends this idea by abandoning the constraint of dispersion-free sections completely. Thus there is no need for achromatic arcs. The storage ring is composed of an arbitrary number of simple unit cells containing only one bending magnet accompanied by two quadrupoles on each side. The insertion devices are placed between neighbouring unit cells.

The expense of having dispersion also in the straight sections does not affect the aforementioned type of experiments. The big advantage is that now up to 40% of the ring circumference can be used for insertion devices. In addition, by allowing dispersion in the straight sections, the emittance can be reduced more than in the case of the DBA thus partially compensating the increase of the brilliance due to the dispersion. The concept of allowing dispersion in the straight sections between double bend achromats in order to reduce the emittance is being investigated at the ESRF [2].

II. THE PURE INSERTION DEVICE (PID) LATTICE

The key elements of a third generation light source are undulators and wigglers and at the position of these insertion devices, in the long straight sections, the dispersion has to be zero. The simplest arrangement which achieves this is the double bend achromat (DBA) structure [3] with two dipoles and one quadrupole in between them. Implicit to the DBA structure is the requirement that the phase advance of the horizontal betatron oscillation from the beginning of the first to the end of the second dipole has to be π. This is only possible if the distance between both dipoles is very large [4] or there are at least two more quadrupoles in between the dipoles, as for the ELETTRA design [5].

Be it either way, the constraint of dispersionless straight sections results in two disadvantages, which we aim to avoid with our proposed lattice:

- the minimal emittance can not be reached by almost an order of magnitude because the dispersion does not follow the optimal curve;
- only up to 20% of the ring circumference is availabe to insertion devices, the rest is used up to provide suitable optics;

The second disadvantage remains also for other types of lattices, where emittances lower than the one for the DBA lattice have been obtained, such as the modified quadrupole bend achromat [6,7,8] and the modified multiple bend achromat (MBA) [9,10].

Both aforementioned disadvantages can be avoided if a ring is composed only of unit cells of the modified MBA lattice with one straight section between each pair of unit cells. Although there is a small dispersion in the straights which contributes to a slightly broader beam, this is partially compensated for by a smaller emittance which is the result of the Twiss functions following the optimal curve much closer. A less tight lattice allows for up to 40% of the circumference to be used for insertion devices.

The unit cell consists of one bending magnet with a superimposed defocussing gradient and two quadrupoles on each side of the bending magnet (see the insert of figure 1). In principle, one quadrupole on each side is sufficient to obtain the low emittance. The second quadrupole has been added to allow for greater flexibility and in particular for the compensation of linear tune shifts by insertion devices. Such a unit cell is small, therefore it doesn't unnessecarily increase the total circumference. In addition, the partition number J_x is larger than 1 which further reduces the emittance.

Since the phase advance in one unit cell is rather small, there are not many choices for the tunes in order to avoid resonances within both the unit cell and the complete ring. The two quadrupoles have to set the right tunes of the unit cell and of the ring simultaneously. An alternative possibility is to optimize their strengths to avoid resonances in the unit cell and then choose the number of unit cells in the ring such that the total tunes are in a resonance-free region, too.

III. A STORAGE RING WITH THE PID LATTICE

As an example, we present a 3 GeV light source (table 1) for material science, with similar characteristics of the radiation as a previously proposed light source ROSY[9]. The ring has a 24 - fold symmetry (figure 1). A 3 GeV lisource is interesting in particular for material science as it bridges the gap between existing 2 GeV (UV optimized IDs) and 6 GeV sources (hard X-ray optimized IDs) third generation light sources.

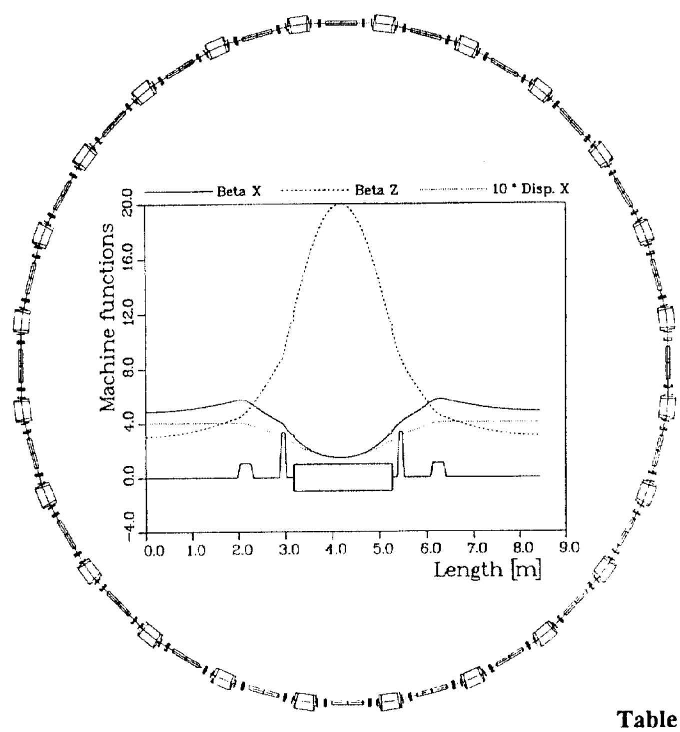

Figure 1: A bird's eye view of the storage ring with 24 IDs. Inserted are the horizontal and vertical beta functions and the dispersion of the unit cell.

General:		
Structure		Doublett
Number of unit cells		24
Circumference (m)	c	203
Momentum compaction	α	$0.584\ 10^{-2}$
Beam current (mA)	I	250
Beam energy (GeV)	E	3
Natural emittance(mrad)	$\varepsilon_{x,y}$	$0.132\ 10^{-7}/0.132\ 10^{-8}$
Natural energy spread	$\sigma_{E/E}$	$0.165\ 10^{-2}$
Optics:		
Betatron turnes	Q_x/Q_y	9.15/6.30
Beta functions (m/rad)		
(a) Straight section	β_{xss}/β_{yss}	4.88/3.08
(b) Bending magnet	β_{xbm}/β_{ybm}	1.45/19.96
(c) Maximal	$\beta_{xmax}/\beta_{ymin}$	5.72/19.96
(d) Minimal	$\beta_{xmin}/\beta_{ymin}$	1.45/3.08
Dispersion (cm)		
(a) Straight section	η_{ss}	40.55
(b) Bending magnet	η_{ss}	15.21
Natural chromaticities	ξ_x/ξ_y	-7.82/-14.6
Source size (µm)		
(a) Straight section	$\Sigma_{xss}/\Sigma_{yss}$	714/63.7
(b) Bending magnet	$\Sigma_{xbm}/\Sigma_{ybm}$	286/162
Magnets:		
Number of bending magnets		24
Bending field (T)	B	1.25
Gradient (T/m)	g	4.69
Bending radius (m)		8.00
Number of quadrupoles		96
Max. Gradient (T/m) gmax		33.5
Radio frequency:		
Harmonic number	k	338
Radio frequency (MHz)	f	500

Table 1: The main parameters of the storage ring with PID lattice

A. Optimizing the Emittance

Figure 2a demonstrates that the emittance depends mainly on the strength of the outer quadrupole (Q1). Changing the defocussing strength of the bending magnet by +/- 10% does not significantly change the emittance. However, one can not simply take the Q1 strength which gives the lowest emittance, because the phase advance in one unit cell and hence the tune depends almost linearly on it (figure 2b) and it is more important to get the tunes right. The tune can be adjusted also by means of the quadrupole next to the bending magnet (Q2), but also then the minimum of the emittance is not reached.

A shorter straight section or a longer bending magnet would have resulted in an even smaller emittance. The optics shown in table 1 and in the insert of figure 1 are a good compromise between a low emittance, good working point and reasonably long straight sections. More than 35% of the circumference is availabe for IDs. The beta functions in the straight section are rather low in both planes, which is particularly suited for wigglers. The dispersion increases the horizontal r.m.s. to 740 µm. However, this is still smaller than a typical beam line spot.

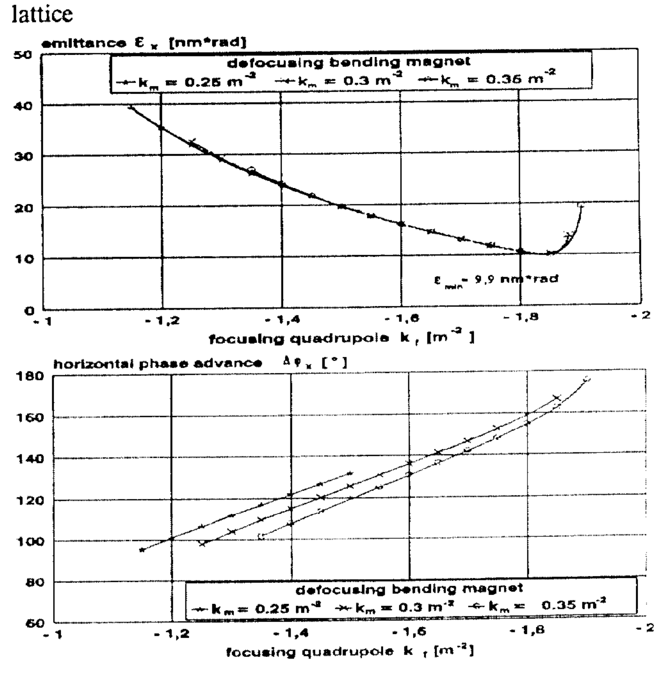

Figure 2: The emittance (a) and horizontal phase advance (b) as a function of the Q1 strength at several defocussing strengths of the bending magnet.

B. Dynamical Properties of the Optics

The natural chromaticities are small (-8 horizontal and -15 vertical).The sextupoles are placed in well decoupled regions and have very modest strengths. One is superimposed on Q1, the other one is next to the bending magnet. No harmonic sextupoles were necessary to compensate the nonlinearities of the chromatic sextupoles.

The results of tracking one particle over 100 turns through the bare ring without insertion devices are shown in figure 3. The dynamic aperture is large and does not differ for particles in the range of +/- 4% of the nominal energy.

In order to investigate the behaviour of the optics with insertion devices, a worst case was studied, where all 24 straight section were occupied by wigglers with a period of 12cm and a magnetic field on axis of 1.5 T. The dynamic aperture was initially reduced to zero. But just by using the two quadrupoles Q1 and Q2 to compensate the integral tunes back to the original values, the dynamic aperture became large again, proving the flexibility and the good dynamic properties of the lattice.

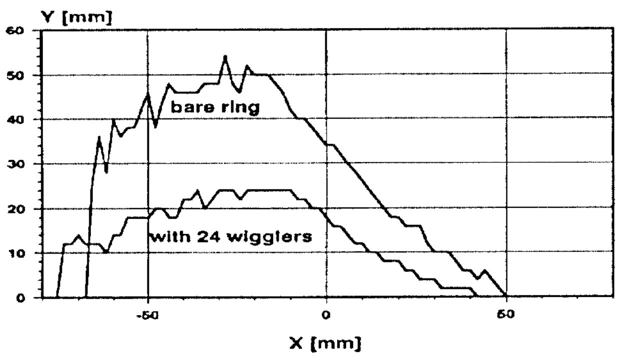

Figure 3: The dynamic aperture for the bare ring and with 24 wigglers.

C. The Radiation Produced

As has been pointed out in the introduction, most experiments do not make use of the ultra-high brilliances provided by third generation light sources. In fact, there is no single parameter which would be the figure of merrit for all synchrotron radiation experiments. The only common requirement is that they get as many photons per second as possible within the acceptance of their beamline and experimental set-up. The acceptance has to be estimated for each experiment separately. Often the brilliance of the source turns out to be of no relevance, as long as it is below a limiting brilliance that is determined by the acceptance.

It is therefore misleading to compare brilliances of light sources in general without having in mind specific types of experiments that make full use of the brilliance delivered. Since the PID lattice addresses specifically the average type and not the state-of-the-art experiments it makes more sense to confront its output with the output of other sources by means of the spectral flux, although even the spectral flux may not be the correct parameter. Continuing the example with 24 wigglers given above the flux produced by a wiggler with a period of 12cm and a magnetic field on axis of 1.5 T is shown in figure 4. It is higher than the fluxes of comparable existing (DORIS III) and proposed (ROSY) machines in its energy range.

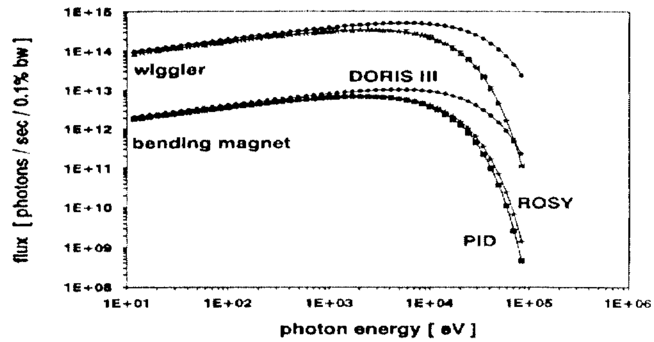

Figure 4: The spectral flux of the PID lattice.

IV. CONCLUSIONS

The pure insertion device (PID) lattice allows for a simple storage ring with very few different components thus reducing cost. It provides one insertion device per light port thus giving up to 40% of the ring circumference for IDs. Although it abandons the conventional constraint of zero dispersion in the place where the IDs are located, the total source size is still below typical spot sizes of X-ray beamlines and thus sufficient for most experiments. The presented exemplary storage ring shows excellent dynamical behaviour proving that the PID concept can be effectively realised.

V. REFERENCES

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