SOLEIL EMITTANCE REDUCTION USING A ROBINSON WIGGLER

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Abstract

For a storage ring equipped with zero-gradient bending magnets, installing a Robinson wiggler (RW) [1] in a non-zero dispersion section enables emittance reduction. For SOLEIL, the horizontal emittance can be divided by up to a factor of 2 by installing a single RW. In this paper, the concept of RW is described, the expected gain for SOLEIL storage ring with the impact on the photon flux, the brightness, and the beam size are presented. A preliminary magnetic design for the RW is also proposed.

INTRODUCTION

For both synchrotron light sources and colliders, the beam emittance is one of the key parameters to increase the photon brightness and the beam luminosity. For a light source, considering Gaussian distributions for photons and electrons, brightness is defined as [2]:

$$B = \frac{flux}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_z \Sigma_{z'}} \tag{1}$$

with Σ_x, Σ_z the horizontal and vertical photon beam sizes, $\Sigma_{x'}$ and $\Sigma_{z'}$ the angular photon beam divergences. Lowering the emittance, leads to a brightness enhancement. Emittance can be reduced by increasing the number of dipoles like MAXIV [3], by introducing a gradient in the dipoles like ALBA [4], or by installing damping wigglers in zero dispersion straight sections (SS), such as PETRA III [5], PEP-X [6] and NSLS II [7] in the near future. However, this solution requires very long insertion devices. In this respect, an alternative less expensive solution that can be used by both compact and large circumference machines, is to install in a non-zero dispersion SS a single RW comporting alternated gradient poles superimposed to the main field. First observations have been carried out with success at Cambridge electron accelerator [8], and in the PS at CERN [9] showing 50% horizontal emittance reduction.

SOLEIL is a low emittance storage ring [10] (3.9 nm.rad) operating at 2.75 GeV. The dispersion function is non-zero in all SS, in order to reduce the betatron horizontal emittance. The machine hosts three types of SS (see Table 1, η is the dispersion function, β the betatron function). The presence of non zero dispersion function is considered as an opportunity to reduce further the emittance at SOLEIL by the use of RW, even though the energy spread is increased.

THEORETICAL APPROACH

At equilibrium between quantum excitation and radiation damping, the natural horizontal emittance ϵ_{x0} and the natural energy spread σ_{e0} for isomagnetic lattice of horizontal damping partition number $J_x \approx 1$ are given by [11]:

Table 1: Length and optical functions of SS at SOLEIL.

SS	length (m)	η_x (m)	β_x (m)	β_z (m)
Long	11	0.206	5.58	8.03
Medium	6.2	0.165	4.6	2.24
Short	2.9	0.252	14.38	2.36

$$\epsilon_{x0} = \frac{C_q \gamma^2 \oint H(s) ds}{\rho_x} \tag{2}$$

$$\sigma_{e0}^2 = \frac{C_q \gamma^2}{J_s \rho_x} \tag{3}$$

with $C_q = 3.84 \times 10^{-13}$ m for electrons, γ the Lorentz factor, ρ_x the bending radius, $H(s)$ is the dispersion invariant, J_s the longitudinal damping partition number.

In an isomagnetic lattice, the damping partition D, which is related to J_x by $J_x = 1 - D$ is almost zero. Both horizontal emittance and energy spread could be modified by varying the damping partition numbers J_x and J_s, i.e. by varyring the damping partition D. The variation of the horizontal emittance ϵ_x and energy spread σ_e as a function of D can be written as follows [12]:

$$\epsilon_x = \epsilon_{x0} \frac{1}{1-D} \tag{4}$$

$${\sigma_e}^2 = {\sigma_{e0}}^2 \frac{2}{2+D} \tag{5}$$

from Eqs. 4 and 5, it can be seen that if D can get the value -1, the natural horizontal emittance can be divided by a factor 2 while the energy spread will be increased by $\sqrt{2}$. The damping partition D can be varied by inserting a high gradient wiggler of length L_w and peak field B_w in a non-zero dispersion SS, whose average dispersion function over the length of the wiggler is $\langle \eta_x \rangle$. In terms of the field gradient D can be expressed by:

$$D = \frac{\rho_x \langle \eta_x \rangle}{\pi (B\rho_x)^2} \int_0^{L_w} B_w \frac{dB_{w,z}}{dx} ds \tag{6}$$

For SOLEIL storage ring with magnetic rigidity ($B\rho_x = 9.17$ T.m), calculations are performed assuming the RW to be installed in a short SS (see Table 1) where the dispersion function is the highest. Hence, to reduce D from its usual value of ≈ 0 to -1 a wiggler of $\int B_w \, dB_w/dx \, ds = 193.4$ T^2 is required, enabling to reduce SOLEIL emittance from 3.9 nm.rad to 1.95 nm.rad, while the energy spread will be increased from 1.01×10^{-3} to 1.43×10^{-3}.

SPECTRAL PERFORMANCES

Radiation performances of some SOLEIL undulators have been calculated using SRW code [13] assuming emittance and energy spread changes imposed by RW, with 1% emittance coupling value, and 500 mA beam current while assuming unperturbed dispersion and betatron functions. Two undulators have been studied, the HU640 [14] for the low energy range in the linear horizontal polarization, and the U20 for high energy range (see Table 2).

Table 2: HU640 and U20 undulator parameters (B_v: vertical field, K: deflection parameter).

und.	type	B_v (T)	period (mm)	K
HU640	helical	0.15	640	8.95
U20	planar/in vac.	1.08	20	2.02

Flux at Low Photon Energy Range

Figure 1 shows that RW has an extremely small effect on the flux of HU640 in the spectral range of interest for the users. A 0.5% flux reduction for the harmonic H1, and 2.3% reduction for the harmonic H3 occurs as a result of increasing the energy spread.

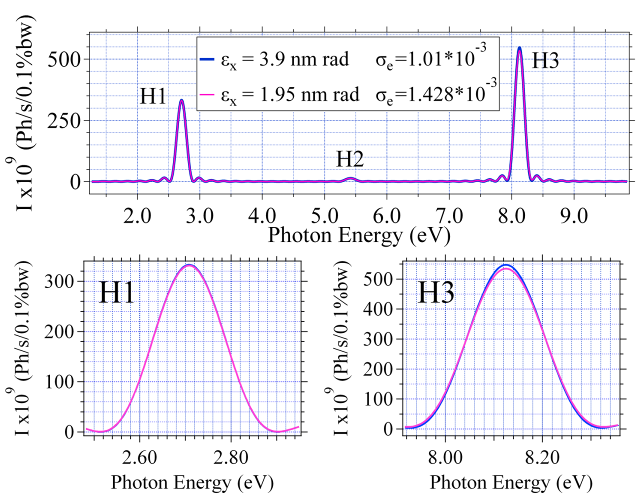

Figure 1: Flux calculation with SRW for HU640 through an aperture $0.1 \times 0.1\ mm^2$ located at 10 m from the source.

Flux at High Photon Energy Range

Figure 2 shows that RW decreases the flux emitted by U20 of about 18% for the harmonic H11, while a negligible reduction of 0.2% for the harmonic H1 is noticed. The flux reduction is due to the increase in the energy spread.

BRIGHTNESS PERFORMANCES

Beam Size Calculation

The horizontal and vertical beam sizes and divergences were studied with and without RW. Figure 3 shows that RW

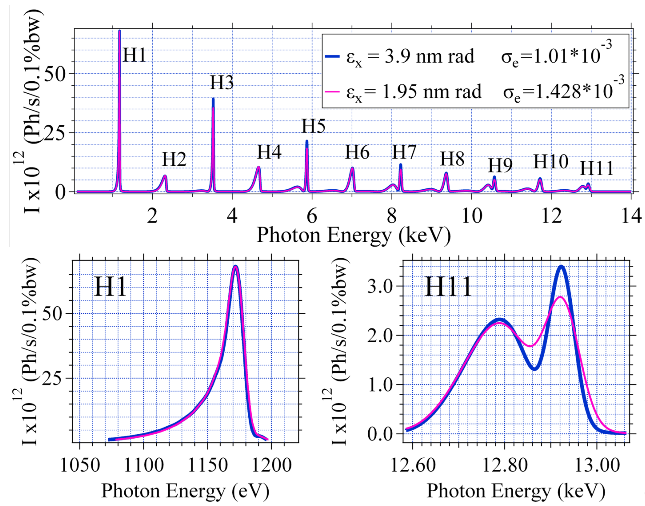

Figure 2: Flux calculation with SRW for U20 through an aperture $0.1 \times 0.1\ mm^2$ located at 10 m from the source.

increases the horizontal beam size for both undulators due to the increase in the energy spread. Regarding the high photon energy undulator U20, the vertical beam size and divergences in both planes decrease.

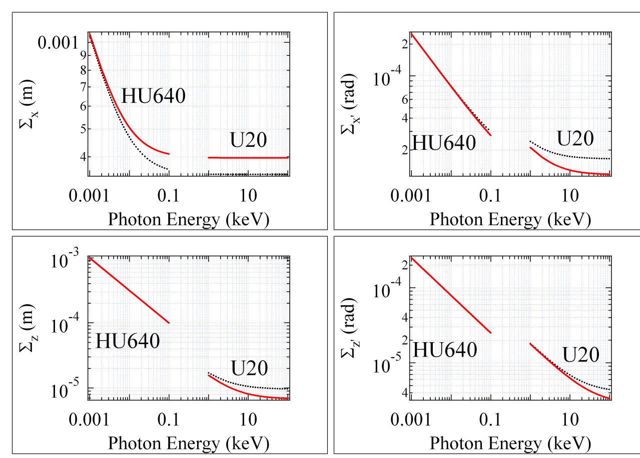

Figure 3: Beam size calculation with SRW for HU640 and U20. Red: with RW. Black: without RW

Brightness at Low Photon Energy Range

Figure 4 shows the ratio between the brightness assuming the presence of RW and the present brightness of the photon beam (brightness gain) emitted by the HU640. Brightness reduction is noticed for the harmonics H1 and H3. Actually, a small flux reduction and beam size increase were predicted in Fig. 1 and Fig. 3, leading to decrease in the photon beam brightness.

Brightness at High Photon Energy Range

Figure 5 shows that the photon beam brightness emitted by the U20 is significantly enhanced under the effect

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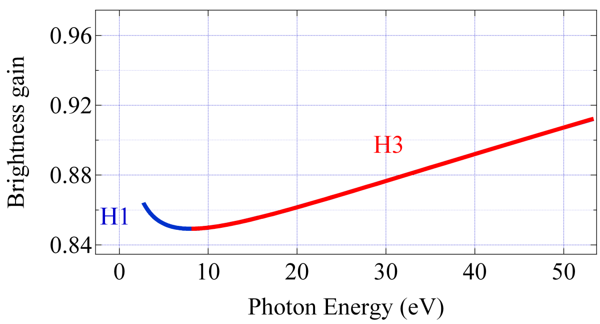

Figure 4: Calculated brightness gain using SRW versus photon energy for HU640.

of the modified emittance and energy spread. The brightness of H11 for example is increased by more than 70 %, due mainly to the significant reduction in the vertical beam size, horizontal and vertical beam divergences. The RW is more efficient for brightness increase at high photon energy because the electron beam sizes and divergences get more dominant.

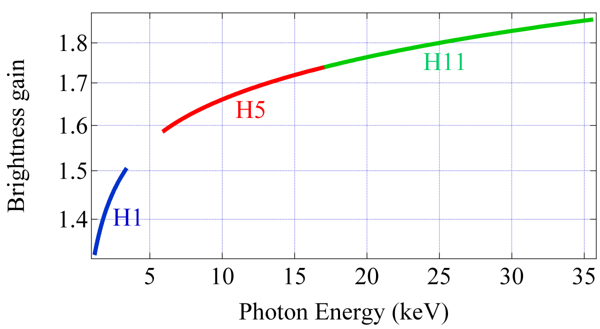

Figure 5: Calculated brightness gain using SRW versus photon energy for U20.

PRELIMINARY MAGNETIC DESIGN

To achieve a high $\int B_w \frac{dB_w}{dx}\, ds$ of 193 T^2 at 6 mm gap, a magnetic structure based on 35 mm wide, 90 mm deep main magnets made of NdFeB (1.33 T remanence), and side magnets of the same characteristics were chosen. Curved surface vanadium permendur poles of 50 mm deep are immersed in the middle of the side magnets to assure a high saturation field of 2.35 T. An in vacuum magnetic system of 164 mm period, 2 m long is proposed. Figure 6 shows the magnetic field and the term $\int B_w \frac{dB_w}{dx}\, ds$ versus horizontal excursion. The end sections have not been studied yet.

CONCLUSION AND OUTLOOK

Considering a RW at SOLEIL reduces the photon flux especially in high photon energy range due to the increase in energy spread. However, it increases the photon beam

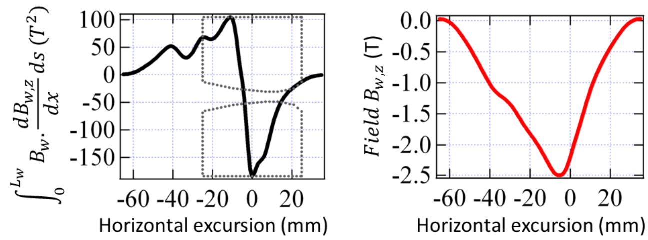

Figure 6: Left: the magnetic field times the field gradient of the proposed wiggler. Dashed lines show the transverse position of the poles. Left: the magnetic field.(RADIA calculation [15]).

brightness in high photon energy range thanks to the reduction of both divergences and the vertical beam size despite the increase of horizontal beam size and the decrease of the photon flux. Fisrt next step is to confirm the analytical predictions of the effects of RW on the horizontal emittance by a tracking code. Second step is to improve the magnetic design, to study the effects of RW on the focusing, lifetime, longitudinal stability, also to consider the flux change in the conditions of operation of each beamline.

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