NEW OPTICS FOR THE SOLEIL STORAGE RING

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Abstract

SOLEIL, the French 2.75 GeV synchrotron light source is delivering photons to 24 beamlines and is presently equipped with 24 insertion devices (ID) including a high field and small gap in-vacuum wiggler [1]. This paper presents the continuous work performed to reduce the strong non-linear effects of several IDs. On one side, the ID defaults have been accurately identified using on-beam measurements, and magnetic correction developments are going on and on the other side, a new optics has been optimised in terms of beta-functions (at the ID location) and non-linear dynamics in order to improve the injection efficiency and the beam lifetime in the presence of IDs. In parallel, an extensive experimental optimization has been performed to prepare the operation with an additional quadrupole triplet that provides double low vertical beta functions in one long straight section that will accommodate two canted in-vacuum undulators [2]. The paper presents also the dedicated "low-α" optics that has been optimised for short bunch production.

INTRODUCTION

The equipment of the storage ring with IDs is under progress. A small gap 50 mm period 2 T in-vacuum wiggler [1] and a 36 mm period 11.5 mm gap APPLE-II type undulator [3] have been installed respectively in June and October 2010 in short straight sections. In order to match with the user requests together with good performances of the machine, three new optics are now ready to be used in operation. First, the nominal optics has been modified to reduce the effect of IDs. Secondly, an additional quadrupole triplet is under installation to split a long straight section and provide a double low vertical beta function in order to accommodate two canted in-vacuum undulators for two long beamlines. The third optics is the dedicated "low-α" optics providing short electron bunches.

REDUCING IDS EFFECTS

As already presented [4], the large energy acceptance of the bare machine (-5 % / + 4%) is strongly reduced by the 10 m long HU640 undulator in the Linear Vertical (LV) polarization mode (because of strong field integrals at large horizontal amplitudes) and by the in-vacuum undulators (because of the high β_x-function value in short straight sections). A new optics has been optimized in terms of β-functions and non-linear dynamics in order to provide good injection efficiency and beam lifetime in the presence of IDs. The horizontal β-function has been reduced from 11 m to 5 m in the four long straight sections (including the injection section), keeping horizontal emittance and tunes constant. The effect of the 10 m long HU640 undulator in the LV polarization mode is then significantly reduced. The modified optics (Fig. 1) has been used daily in operation since November 2010 and ensures beam lifetime greater than 10 h and injection efficiency greater than 60 % for a multibunch 400 mA stored beam with the most usual ID configurations. Machine tests have shown that reducing the β_x-function in the short straight sections (14 m instead of 18 m) will also add some benefit.

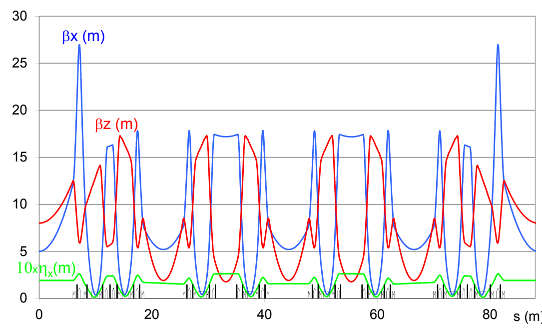

Figure 1: Modified nominal optics (one super period).

Using the 32 skew quadrupoles, it is planned to correct betatron coupling down to 0.1% and to restore the 1% natural coupling by increasing the vertical dispersion. This allows the coupling to remain constant during operation with IDs. Beam lifetime and injection efficiency also benefit from the correction of betatron coupling. Table 1 lists the measurements performed before and after coupling correction, with the bare lattice and with the more critical ID configuration (bold characters). The lifetime (measured at 400 mA) is normalized to 1 % coupling value.

Table 1: Effect of IDs versus coupling

	Natural coupling	Corrected coupling
Coupling (%)	1.0 / **1.9**	1.0 / **1.0**
Lifetime (h)	20.0 / **6.5**	20.5 / **7.7**
Injection rate (%)	91 / **43**	91 / **62**

The HU640 normal and skew integrated gradients have been cancelled by moving transversely the end correction coils. In order to reduce the vertical field integrals (up to 10 G.m) at large horizontal amplitude, a passive electromagnetic system, to be installed at the exit of the undulator and connected in series with the main undulator power supply, is under consideration. The effect of the in-vacuum wiggler WSV50 on beam lifetime is also significant in spite of magnetic correction that has reduced the vertical dynamic integrals by a factor of 3 [1].

Fig. 2 shows the vertical field integrals measured at large horizontal amplitudes using closed orbit bumps. The residual field integrals remain large as predicted by magnetic measurements and will be further reduced by additional magic fingers to be installed at entry and exit of the wiggler. For the HU36 undulator, a second set of magic fingers has been installed during magnetic measurements in order to reduce the horizontal field integrals at large horizontal amplitudes. Beam-based measurements have confirmed that the injection efficiency is improved by 15 % when using the second set of magic fingers, as predicted by beam dynamics calculations.

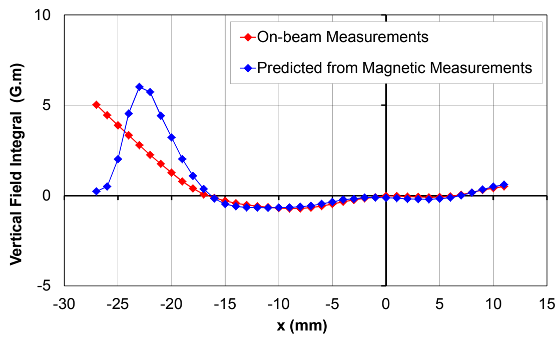

Figure 2: WSV50 vertical field integrals. The x-range is fixed by the maximum allowed orbit bump amplitudes.

DOUBLE LOW VERTICAL BETA FUNCTION OPTICS

The two canted-out beamlines are set up by means of a four permanent dipole magnet chicane that provides respectively +0.5 mrad and -6 mrad deviation from the central axe. The complete installation is presently under way and will be operational for the fall 2011.

The extra quadrupole triplet breaks the present four-fold symmetry and consequently spoils the beam dynamics in terms of beam lifetime as well as injection efficiency. In addition, the presence of IDs spoils the large energy acceptance and the lifetime is reduced by a factor of about two by off-momentum resonance excitation. In order to experimentally investigate the impact of the additional quadrupoles, we took an opportunity to install a set of three spare quadrupoles during the summer 2009 shut-down. We started to investigate a set of Working Points (WP) around the nominal one [2] and clearly put in evidence these systematic off-momentum resonances by simulations and experimentally. The best method to get rid of them was to shift a little bit the WP down to 18.17-10.25 together with an off- and on-momentum optimisation using both BETA and OPA codes.

The new optics with the additional triplet of quadrupoles is plotted in Fig. 3. The emittance is slightly increased from 3.7 up to 3.9 nm.rad. This optics also includes the horizontal betatron function reductions in the long and short straight sections in order to minimize the ID effects. An example of Frequency Map Analysis (FMA) is plotted on Figure 4 for the WP 18.17-10.25 where the energy acceptance reaches 4 % leading to a Touschek lifetime of about 40 h with a multibunch 400 mA stored current.

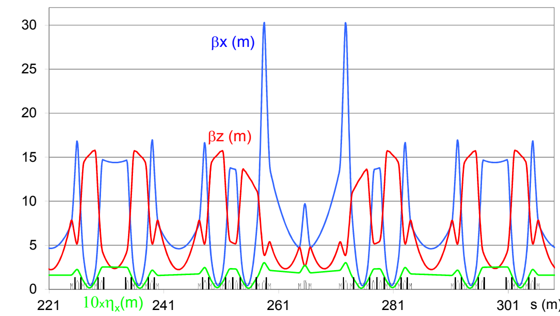

Figure 3: Optics in the modified long straight section.

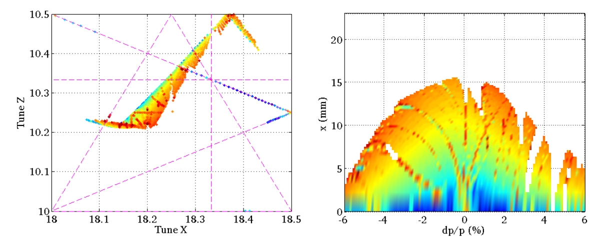

Figure 4: Off-momentum FMA on WP 18.17-10.25.

In parallel, a set of experimental tests has been carried out with this new optics. The 20 h total beam lifetime for the bare machine with a multibunch 400 mA stored current was very similar to the nominal one and is shared by 40 h from the vacuum and 40 h from Touschek collisions. Beside the injection efficiency was between 90 and 100 %. At this stage of optimisation, we pursued experimentally the effect of the main IDs (5 in-vacuum U20 undulators) that impact the machine performances. The results are plotted on Fig. 5 where we scan the injection efficiency and the beam lifetime versus tunes for both configurations: bare machine and with the 5 U20 closed at 5.5 mm minimum gap. Finally, a good WP, with a slightly lower vertical tune 18.17-10.24, preserves an injection efficiency of 70 % and a beam lifetime of 16 h with the presence of the 5 closed in-vacuum U20 undulators.

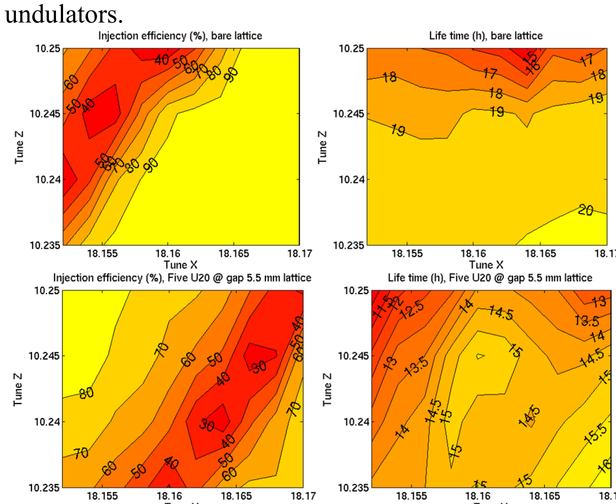

Figure 5: Experimental injection efficiency and beam lifetime scan versus WP with a multibunch 400 mA stored beam.

SHORT BUNCH PRODUCTION

In order to satisfy the user requests in terms of short bunches, the nominal momentum compaction factor α_1 (α_{nom}=4.4 10^{-4}) has been reduced by a factor up to 100 using the so-called "low-α" optics [5]. Setting up the optics on the machine requires reversing one quadrupole family and one sextupole family power supplies. The horizontal emittance is kept small and the value of α_2 is small enough to get a large longitudinal energy acceptance. As a consequence, optical functions (Fig. 6) are very large in vertical plane, leading to small on- and off- momentum dynamic apertures and therefore to low injection efficiency and poor lifetime. Main characteristics of the $\alpha_{nom}/10$ optics are listed in Table 2.

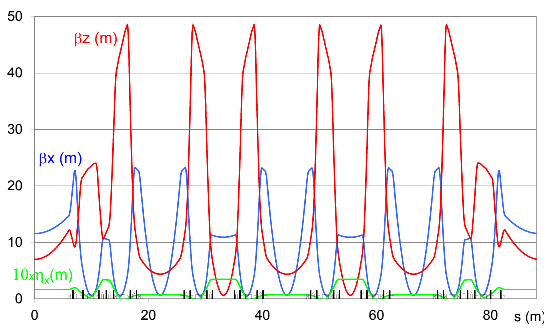

Figure 6: "Low-α" optical functions (one super period).

Table 2: Measured characteristics of the $\alpha_{nom}/10$ optics

α_1, α_2	4.3 10^{-5}, -5.7 10^{-5}
Horizontal emittance	8.0 nm.rad
Tunes X/Z	20.40 / 8.30
Synchrotron frequency (V_{RF}=4 MV)	1.7 kHz
Transverse energy acceptance	± 1.5 %
Controlled coupling	4.4 %
Injection Efficiency	10 %
Beam lifetime (70 µA per bunch)	20 h

The value of α_1 can be further reduced keeping tunes and optical functions unchanged by using three quadrupole families. Two critical points have been studied: the transverse beam position stability and the low injection efficiency. The transverse beam position is stabilized by the two orbit feedback systems (slow and fast). Horizontal (vertical) beam noise is reduced down to 4.1 µm (800 nm) on the 0.01-500 Hz frequency range. Concerning the injection efficiency, on-axis injection was tested to get rid of the on-momentum dynamic aperture limitation. The injection efficiency was then improved only to 40 %, proving that another limitation comes from the small transverse energy acceptance. To avoid frequent injections with poor performance, beam lifetime is increased to 20 h when increasing the vertical beam dimension by the mean of vertical dispersion in addition to betatron coupling correction. A series of bunch length measurements versus α_1-value and bunch current have been performed with a streak camera (Fig. 7). RMS bunch lengths down to 3.5 ps have been measured, the natural bunch lengthening occurs from 50 µA per bunch and the benefit of the reduction of α_1, below $\alpha_{nom}/10$ is maintained until 100 µA per bunch.

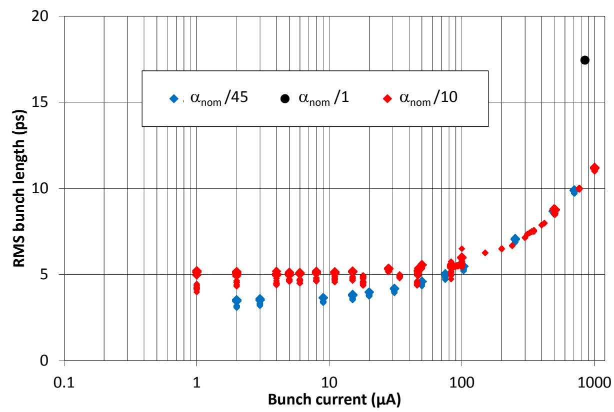

Figure 7: RMS bunch length variation versus bunch current for $\alpha_{nom}/10$ and $\alpha_{nom}/45$ (RF voltage = 4 MV).

CONCLUSION

Thanks to optics changes, the effect of the IDs has been significantly reduced but the effect of the in-vacuum 2 T wiggler remains significant and magnetic correction is under consideration. The long straight section installation for the two canted long beamlines is now complete and the new optics is also ready for commissioning this fall. The production of Coherent Synchrotron Radiation in the THz region has been successfully tested on the AILES Infrared beamline [6], with a momentum compaction factor reduced by a factor of 25 and a RMS bunch length reduced to 4 ps for a 70 µA bunch current. Operation with the "low- α" optics is planned to be used in December 2011 with a hybrid filling pattern (20 mA in 312 bunches and one 70 µA isolated bunch) in order to satisfy X-ray time resolved experiments as well.

ACKNOWLEDGMENTS

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