EXPERIMENTAL CHARACTERIZATION OF THE INSERTION DEVICE EFFECTS ON BEAM DYNAMICS AT SOLEIL

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Abstract

SOLEIL, the French 2.75 GeV third generation light source, is delivering photons to beam lines in routine operation since January 2007. The storage ring is presently equipped with 14 insertion devices. Commissioning the insertion devices consists in characterizing all the effects on beam dynamics in terms of closed orbit distortion, focusing, chromaticity, coupling, injection efficiency, beam lifetime and sensitivity to working point. We will focus here on the significant effects observed with some undulators.

INTRODUCTION

The SOLEIL storage ring is now operating with 11 insertion devices (IDs) and 3 new ones have been installed during the last shutdown period in May 2008 (Table 1). During operation, the Users have the full control of their undulators [1]. It is then important to identify expected and unexpected effects for each undulator and all together in different configurations. The first step was to compensate for orbit distortions introduced by residual first order field integrals in order to reach the required μm position stability during field variations. This significant work is still in progress and reported in detail in [2] and [3]. In parallel, a systematic characterisation of each undulator is performed for each configuration of field and phase. We will present here the more significant effects, their analysis in terms of beam dynamics and a comparison with calculation (using field maps generated by RADIA code [4]) and magnetic measurements.

Table 1: Insertion device main characteristics.

Number	Name	Type	Period (mm)	Length (m)
4	U20	In vacuum	20	2.0
1	HU44	Apple II	44	1.6
2	HU52	Apple II	52	1.6
3	HU80	Apple II	80	1.6
3	HU256	Electromagnetic	256	3.1
1	HU640	Electromagnetic	640	10

LINEAR EFFECTS

U20 in Vacuum Undulator Physical Aperture

At first, measurement of the physical vertical aperture and centring of in vacuum undulators were done. This was performed by scraping a very low current beam on the undulator jaws, using two methods. (1): the undulator was remotely moved in vertical plane, up and down. (2): the beam was displaced in the undulator straight section using vertical closed orbit bumps. For the 3 U20 IDs, the physical aperture was found significantly smaller than the 5.5mm magnetic gap: 3.6mm for two and 3mm for the third. These apertures are not fully consistent with the physical gap obtained after adding shims and copper sheets for protecting permanent magnets.

Undulator Induced Focusing

The measured focusing effect of the Apple II type HU80 undulators is in good agreement with calculation and magnetic measurements. It is described in detail in [3]. The small focusing effect of the electromagnetic HU256 undulators is much closed to the one expected from design. For the U20 and HU640 undulators, significant additional focusing effects have been observed. The 3 U20 undulators [5] have been built using the same design which predicted only a vertical tune shift. Focusing effect versus gap seen by the e-beam is rather different from calculation and from one undulator to the other (Fig. 1). The additional focusing is due to construction errors and is emphasized by the high β_x function (18m) in short straight sections. In order to identify this contribution, the residual vertical field integral was measured when making horizontal closed orbit bumps in the undulator at minimum gap, and compared with magnetic measurements (an example is given on Fig. 2). The two curves lead to the same integrated gradient which is in rather good agreement with the measured tune shifts.

The focusing effect of the HU640 10m long electromagnetic undulator [5] was also unexpected. Because of its low field value and good field homogeneity, simulation predicted negligible effects on the beam. Magnetic measurements were not reproducible and accurate enough to be analyzed. Yet its very significant focusing effect was unexpected, especially in the Vertical Linear polarization mode where the horizontal field is generated by the so called PS1 power supply. The measured tune shifts are about five times larger than the expected one (Fig. 3). These tune shifts vary linearly with the field and overcome the expected ones (squared variation versus field due to field value and homogeneity). As shown on figure 4, the integrated gradient increases linearly with field value, in agreement with the tune shift measurements. However, the origin of these unexpected high field integral values is not fully understood. Note that in the vertical field mode (Horizontal Linear polarization) no additional focusing was measured.

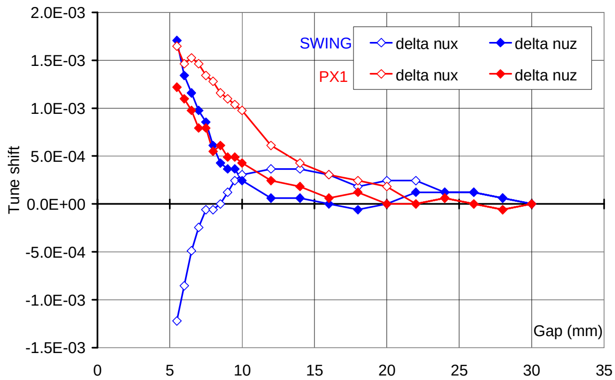

Figure 1: Measured tune shifts versus gap for two different U20 undulators. The expected tune shifts at minimum gap are 0 in horizontal and 1.55 10^{-3} in vertical.

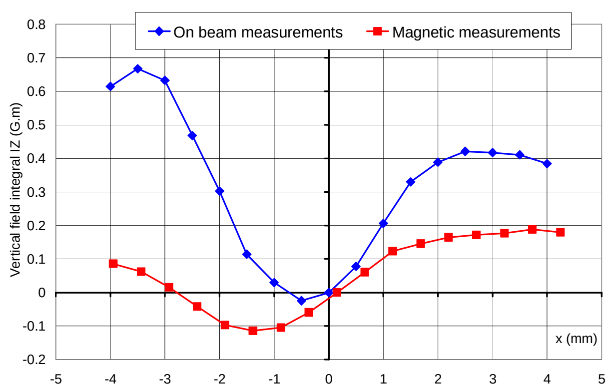

Figure 2: Vertical field integral variation versus horizontal position for the SWING U20 undulator at minimum gap.

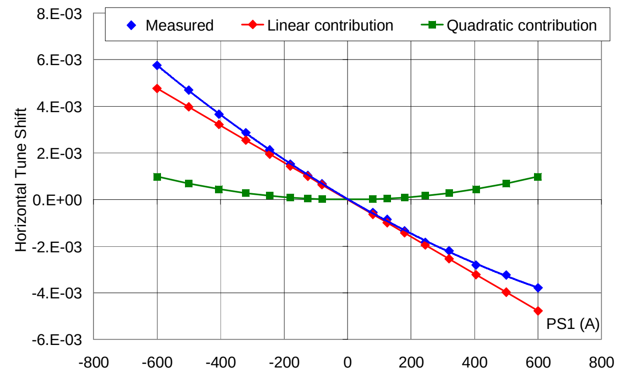

Figure 3: Measured horizontal tune shift versus horizontal field (PS1) value for the HU640 undulator in the horizontal field mode.

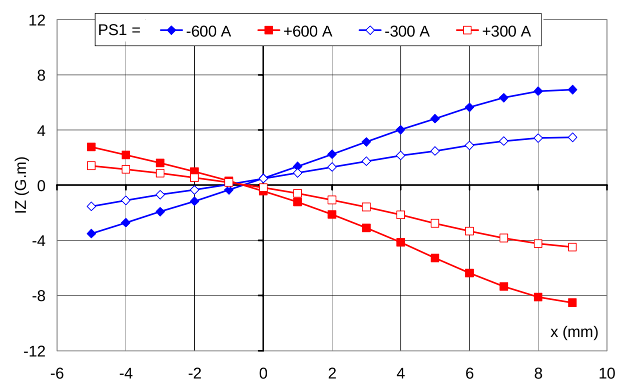

Figure 4: On-beam measurements of vertical field integral variation versus horizontal position for different horizontal field (PS1) values of the HU640 undulator.

Chromaticity and Coupling

Chromaticity variations at maximum field are less than 0.3 for all IDs except for the SWING U20 undulator that shifts the horizontal chromaticity by -1 (when closed at minimum gap) as expected from the integrated sextupolar component deduced from integral measurements (Fig. 2). Magnetic measurements predicted smaller chromaticity variation.

Coupling variations are less than 0.1% for all IDs except for the HU640 undulator that can increase the coupling by 0.7% at maximum horizontal field value. Note that for this ID, on-beam measurements have shown a strong dependence of horizontal field integrals versus horizontal amplitude.

NON-LINEAR EFFECTS

Non-linear effects can significantly reduce the injection efficiency and beam lifetime because of dynamic aperture and energy acceptance reductions. Among the 11 undulators, 5 have significant impacts: the 3 U20, HU640 and HU80 PLEIADES IDs, especially when they are together at maximum field. Frequency Map Analysis has been used to explore non-linear dynamics [6].

Injection Efficiency

The injection efficiency at the nominal working point [6] (WP) ν_x=18.20/ν_z=10.30 and without undulator fields is 98%. During injection, the gaps of the in vacuum U20 undulators are open to 10mm to protect the permanent magnets from possible demagnetization. Table 2 summaries some significant reductions measured with different undulator configurations at nominal WP.

Table 2: Injection efficiency with undulators

Undulators	Injection efficiency
1 x U20 @ gap 5.5mm	85 %
3 x U20 @ gap 5.5mm	**50 %**
HU640 @ PS1=-600A	61 %
HU640 @ PS1=+450A + HU80 PLEIADES @ Minimum gap/Phase=0 + 3 x U20 @ gap 10mm	40 % and **80** % when tunes are shifted to 18.202 / 10.317

The injection efficiency reduction observed with 3 U20 undulators closed at minimum gap is not due to a vertical aperture limitation but is rather coherent with the measured dynamic aperture. The horizontal aperture is significantly reduced by non-linear effects (Fig. 5) as predicted by simulations [7]. This is due to the peak field roll off (imposed by the pole width) that acts on beam dynamics as a strong decapolar component. FMA measurements show the aperture reduction due to a 5th order resonance that becomes excited when the 3 U20 undulators are closed (Fig. 6).

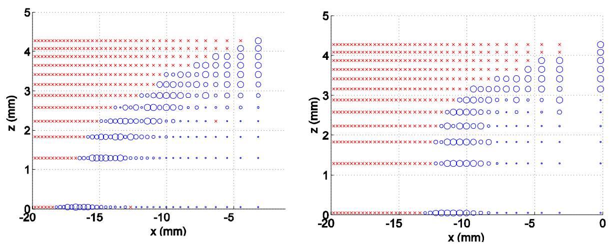

Figure 5: Measured dynamic apertures for the bare lattice (left) and with 3 U20 IDs (right). Blue circle for stable amplitude, red cross for total beam loss. Nominal WP, $\xi_x=\xi_z=2$.

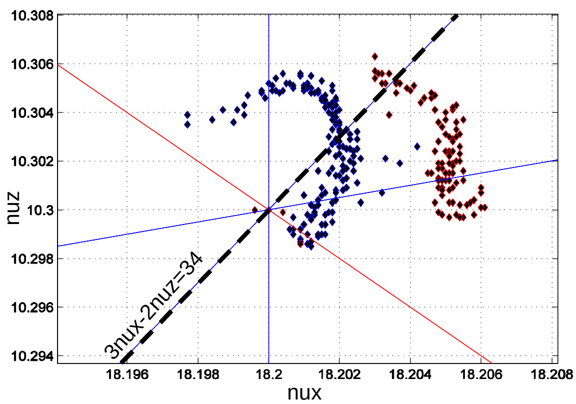

Figure 6: Measured frequency map for the bare lattice (blue) and with 3 U20 IDs (red). Nominal WP, $\xi_x=\xi_z=2$.

A similar reduction of the horizontal aperture is observed for the HU640 undulator in the horizontal field mode [6]. This is not predicted by simulation and may be due to high field integrals experienced at large horizontal amplitudes. Therefore the effects of several undulators when together at maximum field are drastic and the particle loss rate at injection becomes too high. A new working point with ν_x=18.202/ν_z=10.317 is now used which restores good injection efficiency by staying away from excited resonances (see Table 2).

Beam Lifetime

The previous non-linear effects impact also off momentum dynamics and can reduce significantly the beam lifetime. With a 250 mA multibunch stored beam the vacuum pressure is now 1.110^{-9} mbar and the 18 h lifetime of the bare machine becomes sensitive to Touschek scattering. The lifetime is reduced by 3% when one U20 undulator is closed at minimum gap and by 30% when the 3 undulators are closed together. The effect of the HU640 undulator on beam lifetime depends on the horizontal field polarity. Figure 7 displays the measured beam lifetime and coupling variations versus field (PS1). For positive field, the coupling is not changed, the non linear effects reduce the lifetime by 30%. For negative field, the lifetime reduction due to non-linear effect is compensated by the lifetime increase due to coupling value increase. For both undulator types, the reduction of beam lifetime is due to an energy acceptance reduction.

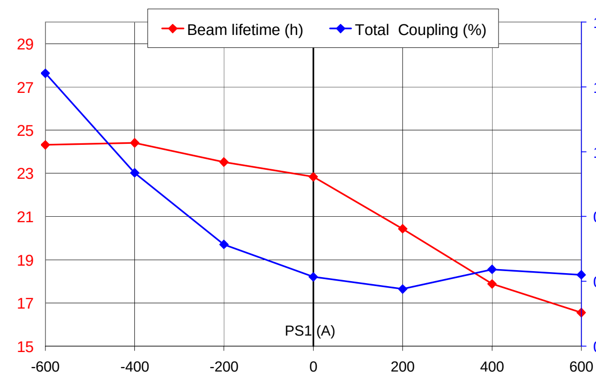

Figure 7: Measured beam lifetime and coupling versus undulator field (PS1) with a 200mA stored current at nominal working point with 2.8MV RF voltage.

FUTURE IMPROVEMENTS

The commissioning of the first IDs has shown that unexpected effects could affect significantly beam lifetime and injection efficiency and some of them are not yet understood. In order to determine a robust working point, measured field integral variations versus amplitude will be included in the lattice model for each ID. Off-momentum FMA measurements are in progress to confirm and understand energy acceptance reduction due to undulator fields. Finally a new shimming method including control of skew and normal integrated gradients will be applied for next IDs [8] in order to cancel the whole focusing effect of undulators.

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