NON LINEAR BEAM DYNAMICS STUDIES AT SOLEIL USING EXPERIMENTAL FREQUENCY MAP ANALYSIS

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Abstract

SOLEIL, the French 2.75GeV high brilliance third generation synchrotron light source is delivering photons to 20 beam lines and is presently equipped with 17 insertion devices. Significant reduction of injection efficiency and beam lifetime are observed when using specific undulator configurations in daily operation. Measurements on electron beam, such as beam lifetime versus RF voltage, have shown that the energy acceptance is strongly reduced by the combined non linear effects of the four U20 in-vacuum undulators and by the 10m long HU640 electromagnetic undulator when it is used in linear vertical (LV) polarization mode. This paper will present off-momentum frequency map measurements that have been performed in order to investigate such effects. These measurements confirm that the energy acceptance of the bare machine is very large as predicted by tracking calculations, and clearly exhibit the strong energy acceptance reduction due to undulators.

INTRODUCTION

Experimental Frequency Map Analysis (FMA) [1] is now used at SOLEIL as a privileged tool for investigating the on- and off-momentum non linear dynamics, especially in the presence of insertion devices. First on-momentum results, presented at EPAC08 [2, 3], confirmed the injection efficiency reduction due to in-vacuum undulators and showed a disagreement between measured and calculated tune shifts with amplitude, even for the bare lattice. The model of the bare machine has then been significantly improved in order to better fit the measurements [4]. More recently, experimental off-momentum FMAs has been performed in order to understand the energy acceptance reduction due to insertion devices such as the 10m long HU640 electromagnetic undulator and the five in-vacuum undulators. Presently, the storage ring is daily operating in top-up mode, with a multi bunch 400mA stored current. The 14h beam lifetime of the bare machine can drop down to 6h when these undulators are operating at their maximum field simultaneously, and the injection efficiency is strongly reduced from 90% down to 45%.

EXPERIMENTAL SETTING

Experimental setting has already been described in details in [2]. Two machine study kickers, horizontal and vertical, located in the long injection straight section, deliver a single turn kick to the electron beam. Both kickers are triggered in synchronism with the BPMs. Thanks to their Libera electronics, the 120 BPMs can run at 846kHz in turn-by-turn acquisition. Because of the large ratio between the horizontal and vertical vacuum chamber dimensions, the horizontal beam position saturate at about 6mm as shown on Fig. 1. A numerical treatment is under progress to restore the correct amplitude values (presently deduced from kicker magnetic measurements). The BPM data analysis was optimised in terms of turn number and BPM number because of the high decoherence effect. Presently, the 66 first turn data of four symmetric BPMs are used.

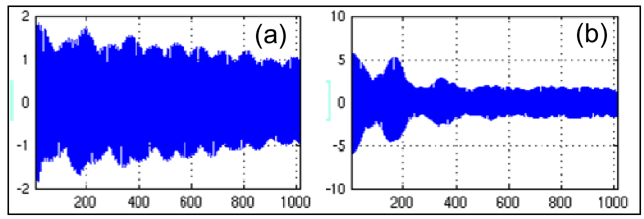

Figure 1: Horizontal position (mm) read on one BPM over 1000 turns. The correct maximum values should be (a) x=3.6mm (V_H=2.1kV) and (b) x=15.2mm (V_H=9.0kV).

The off-momentum frequency maps are generated using RF frequency variations. The frequency to energy conversion is done using Eq. 1 where α_1=4.410^{-4}, α_2=4.610^{-3} and f_0 is the initial RF frequency.

$$dp/p = \frac{-\alpha_1}{2\alpha_2}\left(1-\sqrt{1-\frac{4\alpha_2}{\alpha_1^2}\frac{\Delta f}{f_0}}\right) \quad (1)$$

Experimental FMAs have been performed for the nominal operating point whose main characteristics are given in Table 1. Horizontal amplitudes are transferred from kicker location to the middle of the injection straight section. The colour code in the next figures relates to the relative beam loss each time the beam is kicked for experimental maps, and to beam orbit diffusion rate for calculated maps (using the TRACYII code [5]). The induced horizontal amplitude is superimposed on off-momentum maps (black dashed line).

Table 1: Nominal Operating Point Characteristics.

Horizontal tune ν_x	18.202
Vertical tune ν_z	10.317
Horizontal chromaticity ξ_x	2.0
Vertical chromaticity ξ_z	2.0
Natural coupling (%)	0.5
RF voltage (MV)	2.1

BARE MACHINE

The measured off-momentum map for the bare machine (Fig. 2) confirms the large +/-4% energy acceptance predicted by tracking calculations. As the RF frequency is shifted, a cut-off is obtained at dp/p=-4.8%, due to the non linear synchrotron motion instability that occurs for a +4kHz frequency variation (cf. Eq. 1). On the other side, the stability limitation measured at dp/p=+4% is due to 3rd order resonance $3\nu_x=55$. Horizontal amplitude reductions obtained at dp/p=+/-3% are due to 3rd order resonances $2\nu_x-\nu_z=26$ and $2\nu_x+\nu_z=47$, as predicted by 4D calculations (Fig. 2, 3 and 4, circles).

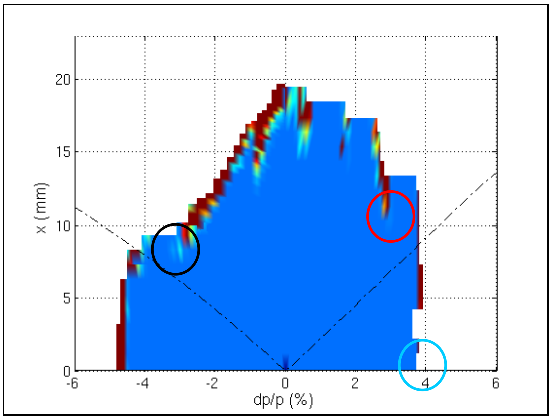

Figure 2: Experimental off-momentum (dp/p, x) map for the bare machine.

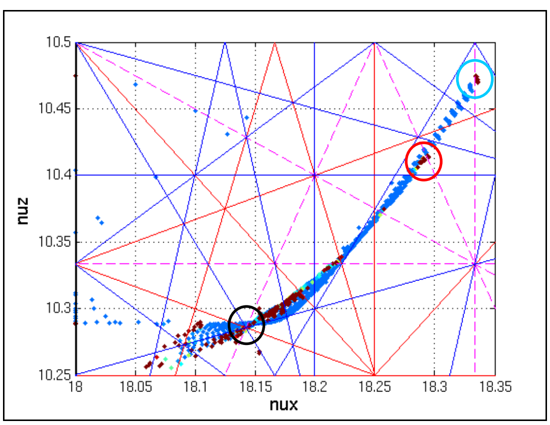

Figure 3: Corresponding experimental frequency map (ν_x, ν_z) for the bare machine. Pink dashed (red solid, blue solid) lines for 3rd (4th, 5th) order resonances.

EFFECT OF THE HU640 ELECTROMAGNETIC UNDULATOR

The effect of the HU640 undulator is drastic in the LV mode when the horizontal field is set to its maximum value. In this case, the measured off-momentum map (Fig. 5) highlights the effect of the undulator on the dynamics. Taking into account the induced amplitude, the energy acceptance is reduced to less than +/-3%. Main horizontal reductions are due to 4th order resonances $3\nu_x+\nu_z=65$ and $4\nu_x=73$, and to the 5th order resonance $4\nu_x+\nu_z=83$. The 3rd order resonance $2\nu_x+\nu_z=47$ reduces the positive energy acceptance down to dp/p=+3% (Fig. 5 and 6, circles).

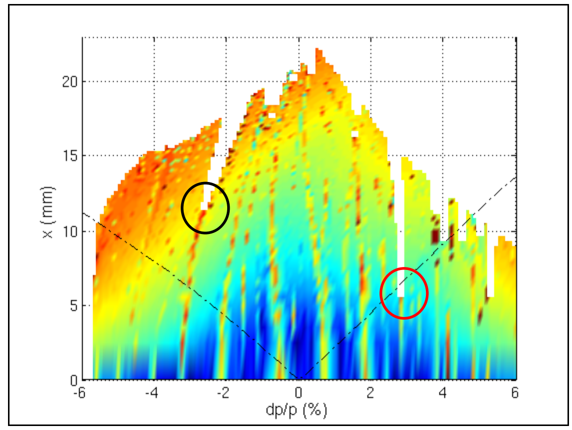

Figure 4: Calculated off-momentum (dp/p, x) map for the bare lattice. Calculations include the optimized non linear model [3, 4]. No synchrotron motion instability occurs at dp/p=-4.8% because the RF frequency is not shifted. The 3rd order resonance $3\nu_x=55$ does not limit the positive energy acceptance.

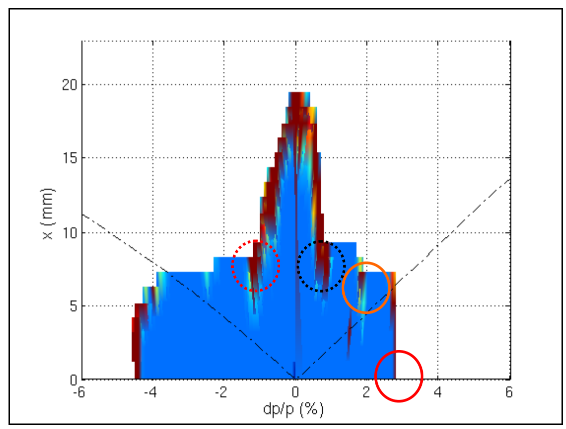

Figure 5: Experimental off-momentum (dp/p, x) map for the HU640 at maximum field in LV mode.

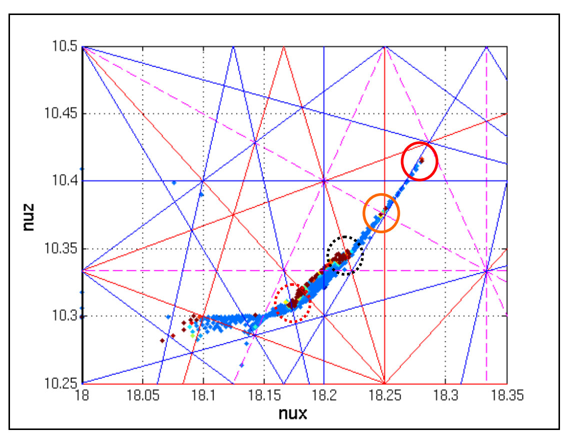

Figure 6: Corresponding experimental frequency map (ν_x, ν_z) for the HU640 at maximum field in LV mode. Pink dashed (red solid, blue solid) lines for 3rd (4th, 5th) order resonances.

The on-beam measurements of HU640 vertical field integral transverse variation (Fig. 7) confirm the presence of strong octupolar and decapolar components at maximum field. The octupolar component (-350T/m^2) comes mainly from the undulator design (RADIA second order kick map [6]) and the decapolar one (-10^4T/m^3) comes from construction errors.

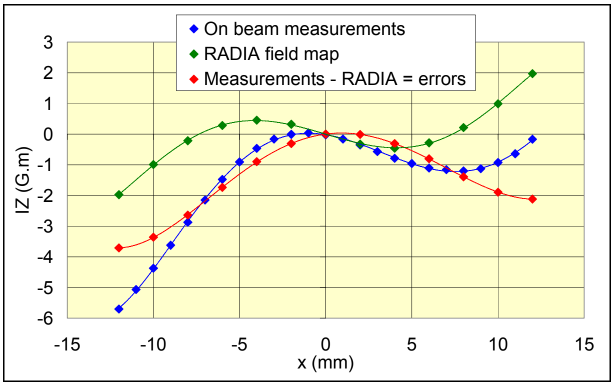

Figure 7: On-beam measured vertical field integral transverse variation for the HU640 at maximum field in LV mode.

IN-VACUUM U20 UNDULATORS ADDITIONAL EFFECT

In addition to the HU640 undulator (at maximum field in LV mode), when at least three in-vacuum U20 undulators are closed at minimum gap, the measured off-momentum map is furthermore reduced (Fig. 8). The 4th and 5th order resonance effects are reinforced and the energy acceptance is reduced to about +/-1.5%, which strongly reduces the beam lifetime.

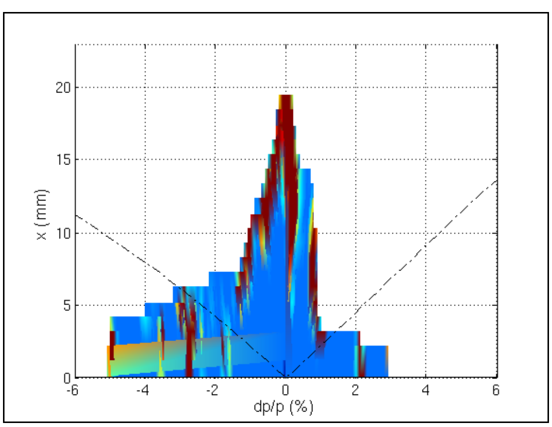

Figure 8: Experimental off-momentum (dp/p, x) map for the HU640 at maximum field in LV mode + 3xU20 undulators closed at minimum gap configuration.

ENERGY ACCEPTANCE

Another way to determine the energy acceptance limitation due to insertion devices is to measure the variation of beam lifetime with RF voltage for various undulator configurations. Measurements have been performed with a 200mA current stored in 208 bunches, keeping current, closed orbit and tunes constant. Taking into account the variation of the bunch length with RF voltage (measured with streak camera), Figure 9 shows the variation of the parameter "(current x lifetime)/bunch length", which is directly proportional to the energy acceptance. Below 1.2MV (dp/p=+/-1.2%), the energy acceptance is limited by the RF system. Above 1.2MV, off-momentum non linear dynamics make the beam lifetime saturate and become independent of RF voltage. This saturation effect is obtained at 2.6MV for the bare machine, at 2.0MV with HU640 at maximum field in LV mode and at 1.4MV with HU640 at maximum field in LV mode + 3xU20 undulators at minimum gap. These RF voltages correspond to energy acceptances of +4/-5%, +3/-3.6% and +/-1.8% respectively and are in good agreement with the dynamic limitations measured with off-momentum FMA.

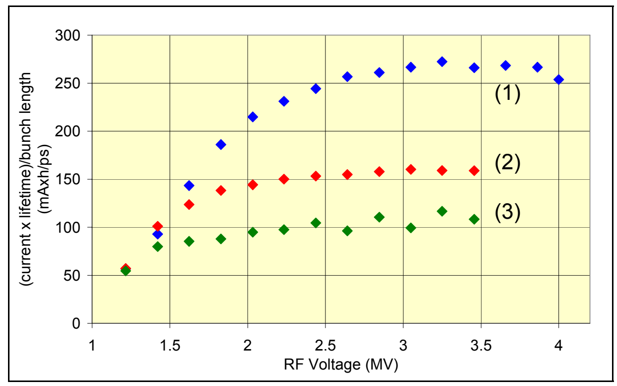

Figure 9: Variation of the product (current x lifetime) normalized by bunch length versus RF voltage. (1): Bare machine. (2): HU640 at maximum field in LV mode. (3): HU640 at maximum field in LV mode + 3xU20 at minimum gap.

CONCLUSION

Off-momentum frequency map measurements clearly exhibit the drastic energy acceptance reduction due to undulators and the effect of 4th order resonances. These results are confirmed by beam lifetime variation versus RF voltage measurements. Studies are under progress to find a way to compensate for these strong effects, either by magnetic shimming (to compensate for undulator multipolar components), or by adding multipolar magnets in the ring (to cancel 4th order resonance effects).

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