LINEAR AND NON-LINEAR OPTICS MEASUREMENTS AT SOLEIL

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Abstract

The successful correction of non-linear resonances in DIAMOND [1] using the BPM turn-by-turn data has motivated testing this approach in SOLEIL in collaboration with CERN. We report on the first experiences towards the correction of non-linear resonances in SOLEIL.

INTRODUCTION

First exploratory experiments were performed at SOLEIL [2] in order to measure the leading driving terms of the storage ring beam dynamics. Several working points with and without undulators were chosen. A total current of 15 mA was stored in 53 subsequent bunches of the storage ring. These measurements rely strongly on turn-by-turn data of the transverse motion of the electron beam. This latter was kicked at various amplitudes simultaneously in horizontal and vertical planes using dedicated transverse kickers [3]. The 2000 turn BPM data acquired on all the 120 BPMs using a new turn-by-turn filter were Fourier analyzed using the SUSSIX [4] software.

LINEAR OPTICS

Linear optics is measured by the phase advance between adjacent BPMs. The phase-beat, which is the difference between measurement and model, is shown in Fig. 1. In both planes the phase-beat is relatively small ($\Delta\phi_{x,rms} = 0.32^o, \Delta\phi_{y,rms} = 0.44^o$). The vertical phase-beat shows some periodic high peaks at the low beta regions.

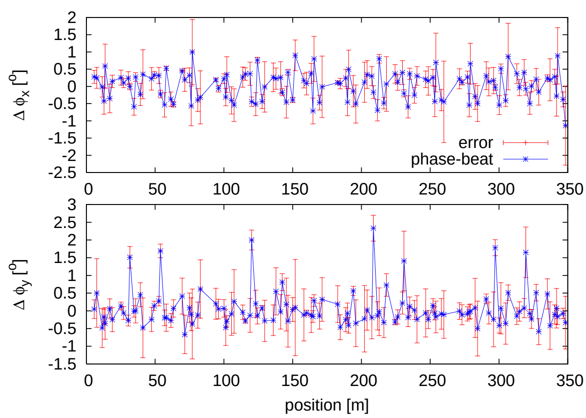

Figure 1: Phase beat for horizontal (top) and vertical (bottom).

The beta function is calculated from the phase-advances between three BPMs, as done in LEP [5].

The measured and model beta function for both planes is shown in Fig. 2. Both planes show a good agreement with the model, but in the horizontal plane the errorbars are larger than in the vertical plane.

The beta-beat, which is the relative difference between measurement and model, is shown in Fig. 3. It is an important indicator of optics distortion. Maximum beta-beat of $\sim 6\%$ and $\sim 20\%$, respectively in vertical and horizontal planes. The beta-beat is large and differs from the experience at SOLEIL, where the LOCO [6] algorithm is used. This discrepancy seems to be due to the sensitivity of the phase-based method, since also the relative measurement is in the same order.

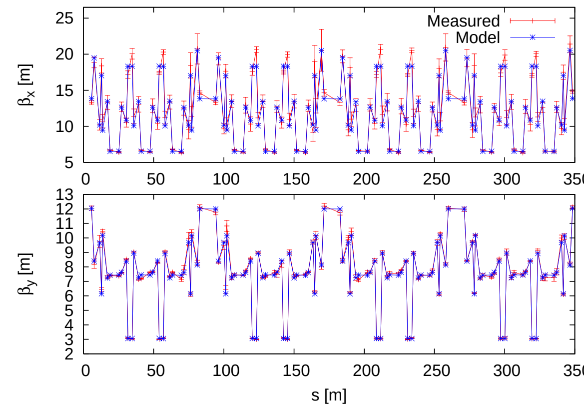

Figure 2: Measured and model betatron function for horizontal (top) and vertical (bottom) planes. The superperiodicity of the ring is four.

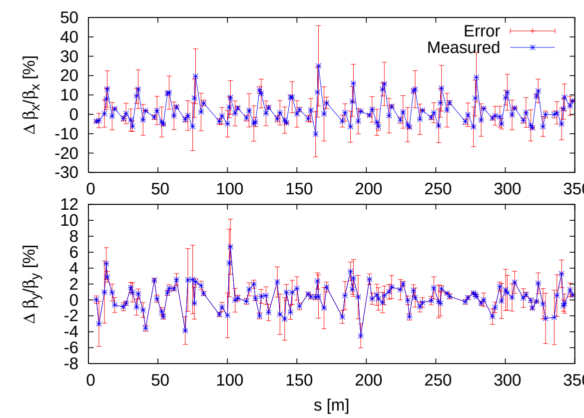

Figure 3: Beta-beat for horizontal (top) and vertical direction (bottom). Maximum beta-beat of $\sim 6\%$ and $\sim 20\%$, respectively in vertical and horizontal planes.

Figure 4 shows histograms of the relative measurement error of the beta functions. The maximum error on the vertical plane is 4.0%.

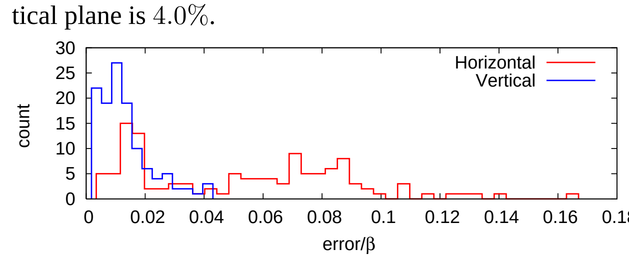

Figure 4: Histogram of the beta function error bar normalized to the beta.

THIRD ORDER RESONANCE

The horizontal spectral line with frequency $2Q_x$ is used to prove the beam dynamics of sextupolar order. Figure 5 shows a plot of Amp_{20} versus the longitudinal location, for two working points $Q_x = 18.21, 18.273$. Amp_{20} we define as the height of the spectral line at the frequency $2Q_x$. The measurement is scaled with a factor of three to fit the simulation. Three reasons for the scale difference are the decoherence factors [7], possible kicker calibration error and synchrotron radiation damping. The decoherence factor, however, should be around two for the $2Q_x$ line. The local variations of the $2Q_x$ line around the ring show a qualitative agreement with the model. The sources for local discrepancy could be, BPM non-linearities [8] and real errors such as optical and sextupolar errors. Before attempting nonlinear corrections it should be verified that the effect of BPM nonlinearities operating with this new filter in turn-by-turn mode are negligible.

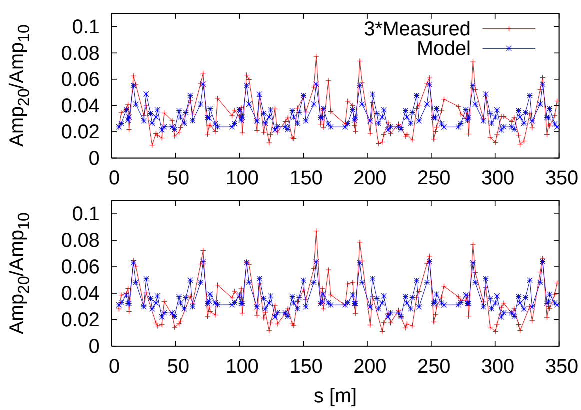

Figure 5: Normalized Amp_{20} for $Q_x = 0.21$ (top) and $Q_x = 0.273$ (bottom).

FOURTH ORDER RESONANCE

The horizontal spectral line $3Q_x$ is used to prove the beam dynamics of octupolar order. When approaching the fourth order resonance one, naively, would expect an increase in Amp_{30}. Amp_{30} we define as the height of the spectral line at the frequency $3Q_x$. Figure 6 the spectrum of the motion for measured and simulated data, for three working points $Q_x = 18.21, 18.241, 18.245$. The simulation consits of a single particle tracked for 2000 turns, therefore zero tune spread in the spectrum. The observed coupling in the measurement (Q_y) seems to come from electrical coupling. In Fig. 7 the normalized Amp_{30} is shown versus the longitudinal location for the tunes, measurement and simulation show different longitudinal variation. In both figures and both for measurement and simulation, the variation of the octupolar lines when approaching the fourth order resonance (18.25) is negligible. Phase_{10} and phase_{30} are evaluated, in figure 8 for both measured and simulation. Phase_{m0} is corresponding to the phase of the spectral line at the frequency mQ_x. For both data sets phase_{10} is multiplied by three, from the measurement it can be seen that $\mathrm{phase}_{30} = 3\mathrm{phase}_{10}$. Figure 8 indicates that the octupolar line is dominated by the third order response of the BPMs. See last section BPM calibration.

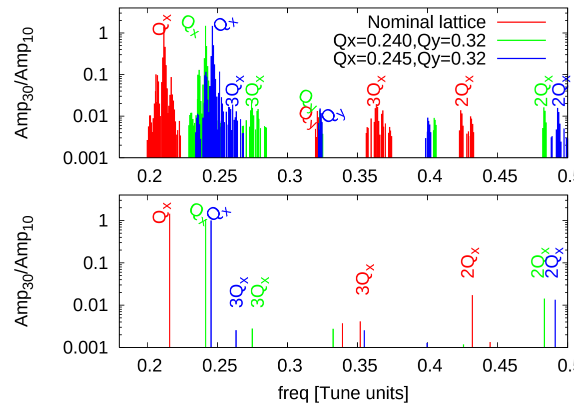

Figure 6: Frequency spectum for horizontal tune approaching 4^{th} order resonance. For measured (top) and simulation taking into account the decoherence (bottom).

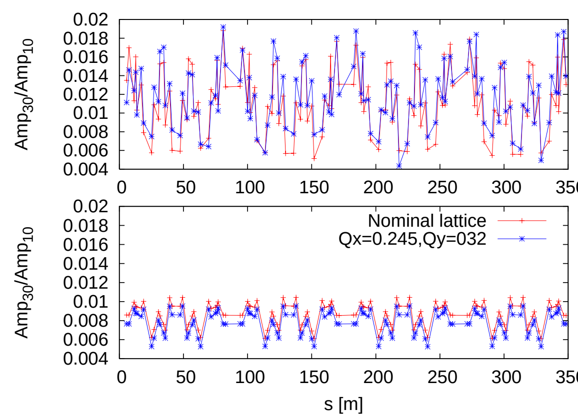

Figure 7: Normalized Amp_{30} for measured (top) and simulation (bottom) approaching 4^{th} order resonance.

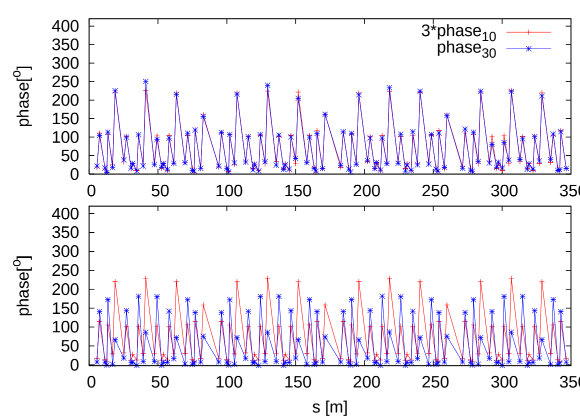

Figure 8: Phase_{10} and phase_{30} plotted versus longitudinal location for both measured (top) and simulation (bottom) for $Q_x = 0.21$.

UNDULATORS

SOLEIL is equipped with three in-vacuum (located at 121.67,210.11 and 232.43 m) and one long undulator (located at 88.52 m). The two different types were examined separately. Figure 9 shows the difference of the $2Q_x$ spectral line between the lattice with and without undulators. In both cases a small effect can be observed in the sextupolar line ($2Q_x$), indicating that the undulator could have sextupolar errors. However the striking similarity between the two cases cannot be yet understood.

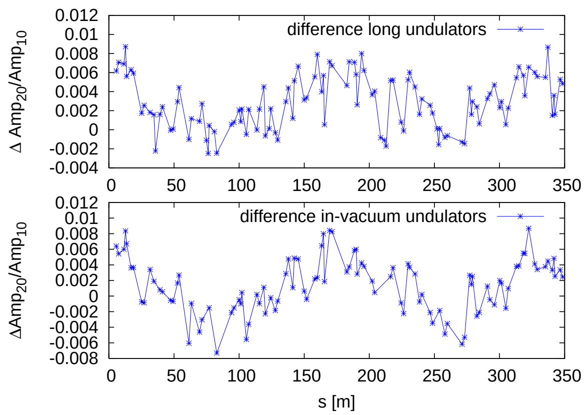

Figure 9: Plot showing the effect of the undulators on the Amp_{20}. Long undulator (top) and in-vacuum undulators (bottom).

BPM CALIBRATION

It is suspected that the BPMs could have a third order response to the beam position, of the form:

$$x_{obs} = k_{lin} x_{real} + k_{non-lin} x_{real}^3 \qquad (1)$$

With x_{real} being approximated by $A * cos(2\pi QN + \phi)$, the k values are found by measuring the oscillation amplitude and fitting a cubic polynomial with the expected amplitude from the kicker calibration:

$$A_{obs} = k_{lin} A_{real} + k_{non-lin} A_{real}^3 \qquad (2)$$

The data reconstruction is done by the approximate relation:

$$x_{real} = \frac{1}{k_{lin}} x_{obs} - \frac{k_{non-lin}}{k_{lin}^4} x_{obs}^3 \qquad (3)$$

Figure 10 shows a plot of the calibration factors for the horizontal plane. The measured k_{lin} (~ 0.45) represents the error in the linear calibration of the BPMs. From simulation, the $k_{non-lin}$ comes from beam dynamics effects and is clearly smaller than the observed one. From the reconstructed data a decrease in Amp_{30} for both working points is observed, again suggesting that the octupolar line is dominated by the BPM non-linearities.

SUMMARY AND OUTLOOK

The phase-beat measurement shows a good result. However, the beat-beat measurement seems to be too large compared to the experience at SOLEIL. This could be due to the quality of the BPM data or to the technique used [5].

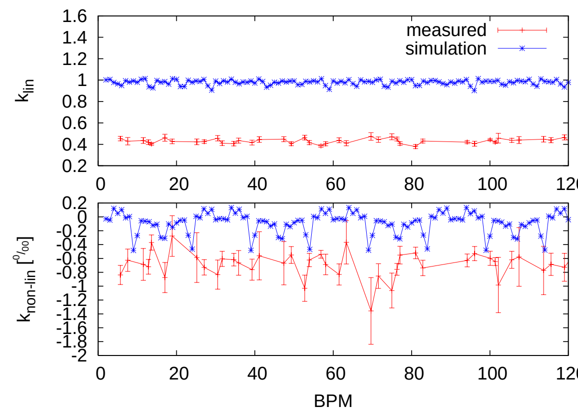

Figure 10: Linear and non-linear factor for BPM non-linearty in the horizontal plane.

The measurement of the sextupolar line ($2Q_x$) is showing promising results. The measurement of the octupolar line ($3Q_x$) seems to be dominated by BPM non-linearities. When looking at the undulators an effect on the $2Q_x$ spectral line was observed, but further analysis is necessary. A first attempt is made to reconstruct the BPM response, assuming a BPM non-linear response of the 3^{rd} order. The new BPM turn-by-turn filter still needs further tuning in order to improve its calibration and reproducibility. Moreover the flat chamber of the storage ring is the source of strong non-linearities and saturation of the BPM, and BPM electronic induces 5% crosstalk. Linear and non-linear corrections of the storage ring should be considered and investigated in the future.

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