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REDUCING CURRENT DEPENDENCE IN POSITION MEASUREMENTS OF BPM SYSTEMS BY USING PILOT TONE: QUASI-CONSTANT POWER APPROACH

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Abstract

In BPM systems, the dependence of measured position on beam current is a well-known behaviour due to many factors. Measurements were carried out at Diamond Light Source with the pilot-tone compensated RF front end developed at Elettra and they evidenced a strong link between that issue and the integral non-linearity (INL) of the ADCs. A potential way to reduce this dependence is to change the gain of the preamplifiers following the beam current variation, trying to coerce the ADC into working as close as possible to a specific level. In this paper, along with the results of the tests performed at Diamond, which confirm once again the effectiveness of the front end and of the compensation strategy, an alternative technique is proposed to mitigate the current dependence by using the pilot tone itself. The idea is to maintain constant the total amplitude at the input of the ADCs, which is composed of the signal from the beam plus the pilot tone. Our data demonstrate how, by changing the latter in a convenient way during the current variations, we can achieve a reduction of the dependence by a factor of 10 considering an equivalent current ramp from 10 to 300 mA.

INTRODUCTION

The analog front end developed at Elettra for electron BPM applications has already been presented in previous papers [1, 2]. The proposed compensation strategy used has proven its effectiveness in several tests both on bench and on the storage ring during the normal operation of the machine.

In order to verify the excellent performances on different accelerators with different parameters, a new measurement session was carried out at Diamond Light Source. The results are reported in the first part of this manuscript, while the second part is focussed on some unexpected behaviours, mainly related to the integral non-linearity of the ADCs.

TESTS AT DIAMOND

A first test was realized in the laboratory of Diamond's Beam Diagnostics Group to ensure the correct operation of the system: a fixed beam was emulated by an RF generator and a 4-way splitter connected with semi-rigid coaxial cables to the front end. This last one was coupled with a Libera Spark as a fast 4-channel digitizer and the decimated IQ data were used for the analysis, calculating the FFT and working on carrier and pilot amplitudes.

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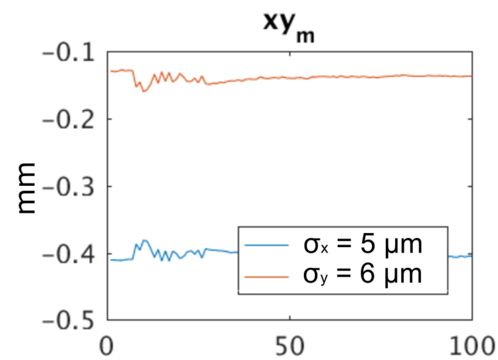

Figure 1: Calculated position while wobbling cables.

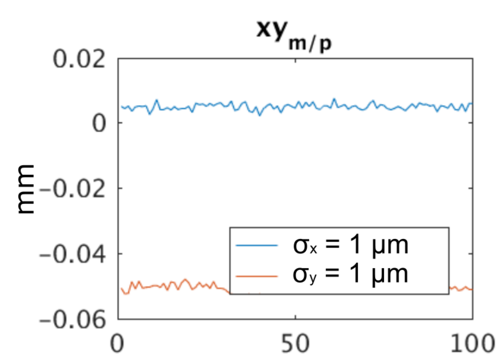

Figure 2: Compensated position while wobbling cables: note the different *y* scale.

During the acquisitions, the cables from the front end to the Libera Spark were twisted and wobbled: Figure 1 shows the calculated position with the movements due to the cables and Figure 2 illustrates the compensated position using the pilot tone. An improvement of a factor of 5 on the standard deviation has been obtained, and more than a factor of 10 considering the peak-to-peak value, virtually cancelling the shifts introduced by the cables. Note the different *y* scales of the two figures.

Results with Beam

The analog front end was subsequently placed in Diamond storage ring tunnel and connected to button BPMs (radius of 10.3 mm, scale factor $K_x = 10.3$ mm, $K_y = 10.4$ mm) by means of four 2-metres cables to detect the signal at 499.680 MHz. Power and communications were supplied by an Ethernet cable (PoE equipped). The output of the front

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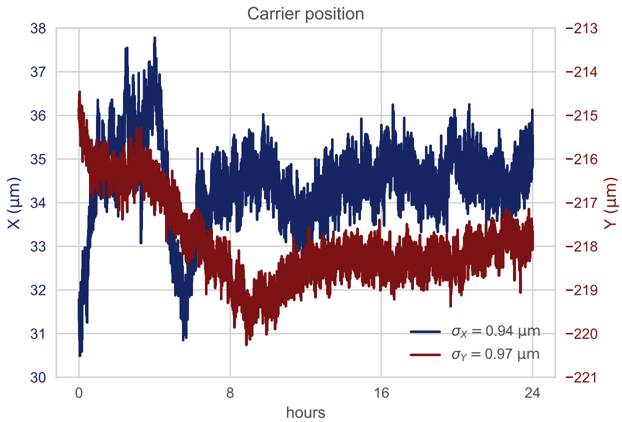

Figure 3: Beam position in a time window of 24 hours.

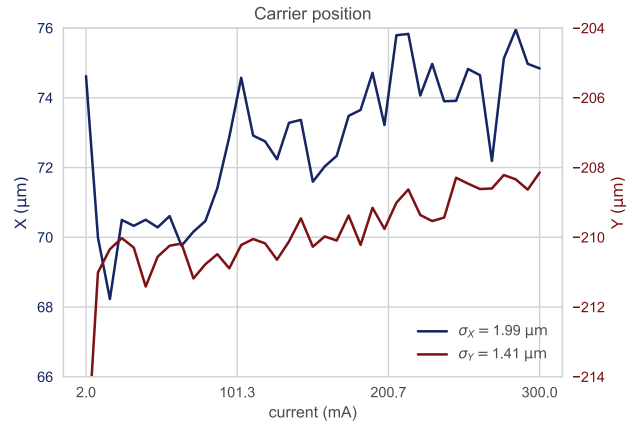

Figure 4: Beam position during a current ramp.

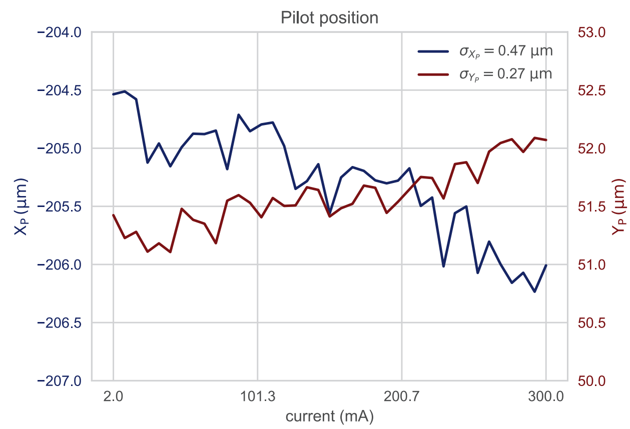

Figure 5: Pilot position during a current ramp.

end was connected to the 16-bit, 160 MS/s assembled digitizer [2] located in the CIA (Control and Instrumentation Area) with more than 20 metres of cables. A clock conditioner ensured the correct synchronization of the system clocks with the storage-ring clock (533.8 kHz), generating both a low-jitter sampling clock for the ADCs and a reference clock for the pilot-tone synthesizer. Every position sample was calculated through an FFT of 2.4 million samples.

A long-term acquisition has been captured in a time window of 24 hours, while the machine was running for the users in top-up mode (3 GeV and 300 mA): Figure 3 illustrates the compensated beam position with a standard deviation less than 1 µm for both horizontal and vertical coordinates.

Then, we used a machine-dedicated beamtime to test the system with various machine conditions, in particular to investigate the beam current dependence without changing the gain of the preamplifiers. Figures 4 and 5 show the positions of the carrier and of the pilot respectively during a current ramp from 2 to 300 mA in a short time (about six minutes).

While a different thermal load of the machine could explain the small drift in the carrier position (real different orbit) during the ramp, the position shift of the pilot should not be related to the current. The signal levels were far from saturation and intermodulation points, so our suspicion pointed to ADCs behaviours.

ADC NON-LINEARITY

A dedicated testbench for the ADCs was prepared to better understand the described specific behaviours. It was composed of two RF generators with the same reference oscillator (one for the pilot, one for the carrier), a passive combiner, a passive 4-way splitter, four rigid cables and four 6 dB attenuators at the ADCs input stages for wideband impedance matching purposes. The positions were calculated in the same way as the measurements at Diamond Light source, except for the radius of the pick-ups. The scale factor was fixed at 20 mm as the BPM buttons located in Elettra storage ring, so all the standard deviations and the detected movements have a factor of two respect to Diamond's ones.

First of all, an equivalent current ramp from 10 to 310 mA was generated with the carrier only: results in Figure 6 show a significant variation in position due to integral nonlinearity within the range specified by the manufacturer of the ADCs [3].

Moreover, we tried to keep a constant total amplitude at the input of the ADCs, simultaneously changing the power of both RF generators during the current ramp. The strategy

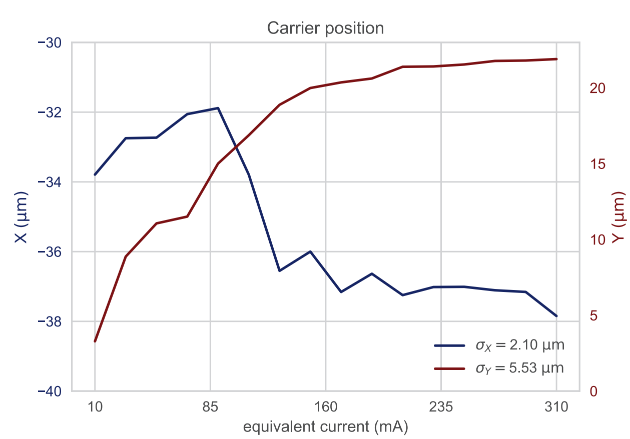

Figure 6: Carrier position during an equivalent current ramp of 10-310 mA.

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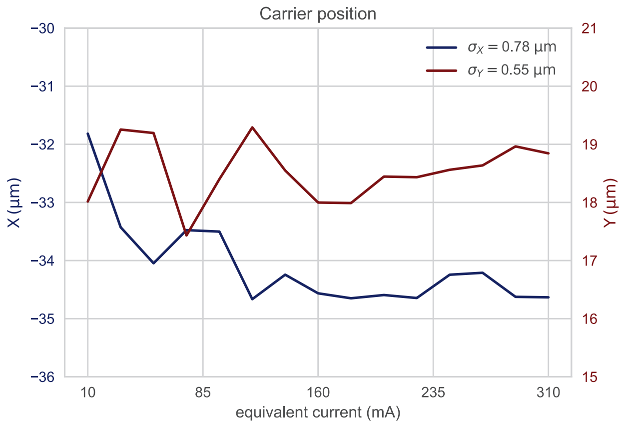

Figure 7: Constant amplitude at ADCs input: carrier position during an equivalent current ramp of 10-310 mA.

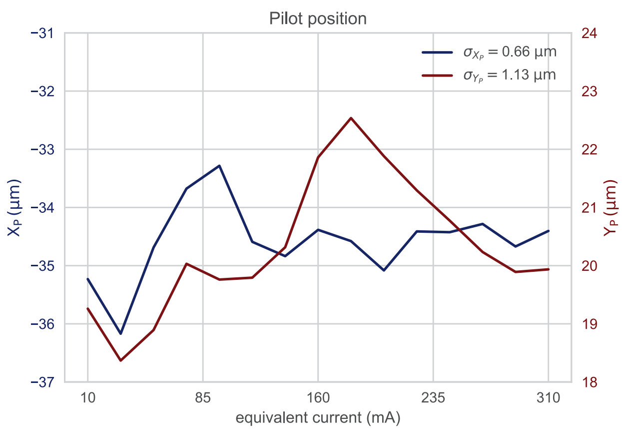

Figure 8: Constant amplitude at ADCs input: pilot position during an equivalent current ramp of 10-310 mA.

followed was to decrease the pilot amplitude while the carrier amplitude increased. An improvement in accuracy is clearly visible in Figures 7 and 8: in particular the standard deviation of the y coordinate has been reduced by a factor of 10, with values similar to the drifts with the real beam noted in Figure 5.

We measured the integral non-linearity of the ADCs using the same testbench. The results confirmed that the ADCs exhibit this behaviour, which, although better than the manufacturer's specifications, is large enough to affect the calculated position at micrometre scale.

CONCLUSION

In this paper we reported the correct functionality of the front end and also of the compensation on a machine different from Elettra. Sub-micron resolution and good long-term stability has been achieved on measurements performed at the Diamond storage ring. In addition, some issues related to the behaviour of the ADCs have been investigated, in particular the integral non-linearity. The latter is known to strongly influence beam position measurements, and its effects can be mitigated in several modes, such as controlling the amplitudes of the signals in order to coerce the ADC to work at an optimum level (automatic gain control, AGC).

However, the idea of maintaining constant amplitude at the ADC inputs by varying the pilot tone has been proven to be useful in reducing these unwanted effects. This technique can be considered as another tool that can help to achieve the desired linearity, particularly when a gain variation is not feasible (gain already at maximum).

Nevertheless, these analyses confirm once again that BPM systems are extremely sensitive to a wide range of parameters that cannot be overlooked. If a well-designed analog front end is mandatory to achieve the required performances, it needs to be coupled with an adequate digitizer in order not to lose most of the benefits gained from the former.

ACKNOWLEDGEMENT

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