BPM DATA CORRECTION AT SOLEIL

N. Hubert, B. Béranger, L. S. Nadolski, Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract

In a synchrotron light source like SOLEIL, Beam Position Monitors (BPM) are optimized to have the highest sensitivity for an electron beam passing nearby their mechanical center. Nevertheless, this optimization is done to the detriment of the response linearity when the beam is off-centered for dedicated machine physic studies. To correct for the geometric non-linearity of the BPM, we have applied an algorithm using boundary element method. Moreover the BPM electronics is able to provide position data at a turn-by-turn rate. Unfortunately the filtering process in this electronics mixes the information from one turn to the neighboring turns. An additional demixing algorithm has been set-up to correct for this artefact. The paper reports on performance and limitations of those two algorithms that are used at SOLEIL to correct the BPM data.

INTRODUCTION

BPM Block Description

SOLEIL BPM blocks have been designed to optimize the position measurement resolution for a centred beam. Its geometry is the same as the one that is generally used in the other parts of the machine (all arcs) for impedance reasons. Aperture is 84 mm in horizontal and 25 mm in vertical. Electrodes are circular buttons of 10 mm diameter spaced by 16 mm in horizontal and 25 mm in vertical (Fig. 1).

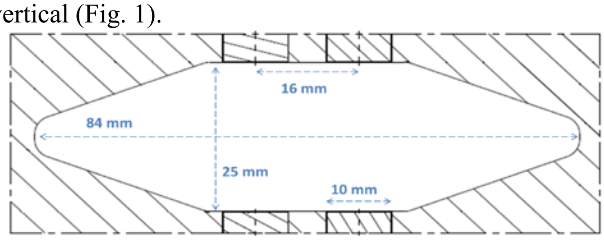

Figure 1: Cross section of a BPM. Design optimizes the resolution in the centre of the chamber.

Non Linear BPM Response

The beam position measurement is given by the usual "difference over sum" method:

$$X_{POS} = K_X \times \frac{(\Phi_A + \Phi_D) - (\Phi_B + \Phi_C)}{\Phi_A + \Phi_B + \Phi_C + \Phi_D} \quad (1)$$

$$Z_{POS} = K_Z \times \frac{(\Phi_A + \Phi_B) - (\Phi_C + \Phi_D)}{\Phi_A + \Phi_B + \Phi_C + \Phi_D} \quad (2)$$

With Φ_i the potential read on electrode (A, B, C and D), and K_X, K_Z the geometric factor for each transverse plane.

This commonly used formula is linear for a centred beam but becomes strongly nonlinear in the horizontal plane when the beam goes to large amplitudes, typically above ±2 mm (Fig. 2).

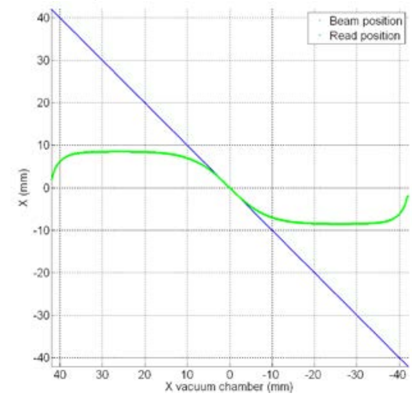

Figure 2: Read beam position (green) with respect to the real beam position (blue) in the horizontal plane for a centred beam in vertical plane. Linear region is limited to ± 2mm around the BPM centre.

CORRECTION OF THE NON LINEAR BPM RESPONSE

Theoretical Reconstruction

Beam position can also be reconstructed from the potential read on the four electrodes. The method used is based on a preliminary theoretical calculation of the BPM response [1, 2, 3]: knowing the theoretical beam position, potential on the four electrodes is calculated using the Poisson equation and the boundary element method. This step requires the definition of a mesh to slice the vacuum chamber wall into elementary parts. Then, in a second step the theoretical BPM response is inverted using the standard Newton method. This method gives a very good beam position reconstruction (Fig. 3) for a large area (~± 15 mm in H, ~±8 mm in V around the BPM centre), compared to the difference over sum method.

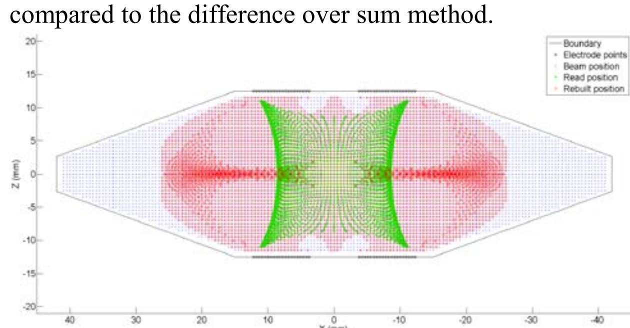

Figure 3: Reconstruction of the position of the beam (blue points) using the difference over sum method (green points) and the Newton inversion (red points).

In small areas (lob shapes) close to the buttons, the convergence does not work. It is because one of the points in the iterative process goes outside the vacuum chamber and in this case, convergence is lost. An additional checking has been implemented in the algorithm to retrieve any iterative point from the outside to the internal side of the vacuum chamber. With this correction, reconstruction in all the centre area of the BPM is almost perfect with an error close to the numerical resolution (Fig. 4).

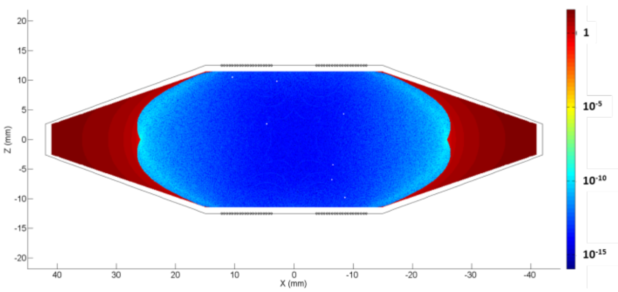

Figure 4: Error between the theoretical beam position and the rebuild position using boundary element and Newton inversion method with the additional lob correction. In the area of interest (±15mm in H, ± 10 mm in V around the BPM centre), the error is below 10^{-10} mm

At large horizontal amplitudes the iterative process for Newton method cannot converge as it has to cross an area (crescent-like shape on left and right sides on Fig. 4) where the Jacobian cancels out in the mathematical resolution: because of this singularity no mathematical solution is founded. Nevertheless by choosing a starting point (for the iterations) on the good side of the crescent, the reconstruction works fine. The number of iterations to reconstruct with an error below 10^{-6} is less than ~15 for any point in the vacuum chamber except on this crescent (Fig. 5). Overall this method is much faster than directly solving the Poisson equation using a mesh code for static electromagnetic problem.

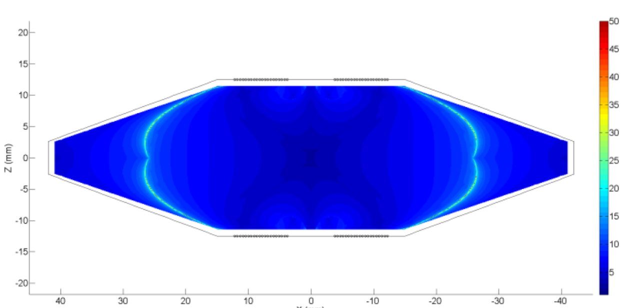

Figure 5: Number of iterations required to reach a reconstruction with an error below 10^{-6}. The convergence cannot be reached for the points located on areas with a crescent shape.

Experimental Reconstruction

Reconstruction of theoretical data is done using the same mesh as the one used to calculate the BPM response. In this case, whatever the mesh granularity, the reconstruction error is always very good. Nevertheless, in the case of experimental data, the mesh granularity that is chosen impacts the results of the reconstruction because of self-consistency between the simulation and the reconstruction model. The area where the reconstruction is the most sensitive to the mesh definition is on the horizontal wall (few % errors), then on the oblique wall (~ % errors), and has finally little influence far from the BPM centre on the vertical wall. The reconstruction dependence to the mesh definition shows an asymptotic value when the mesh becomes infinitely thin (Fig. 6).

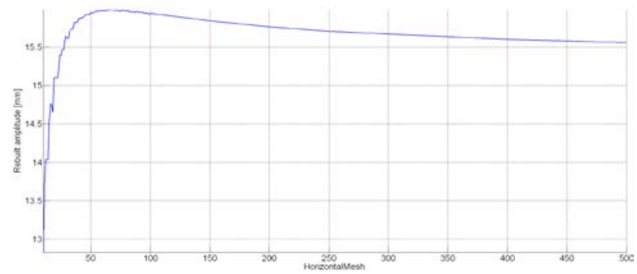

Figure 6: Dependence of the reconstruction to the mesh definition. Case of the horizontal plane reconstruction for a mesh between 10 and 500 points on the horizontal wall. Reconstruction reaches an asymptotic value for an infinitely small mesh granularity.

Intuitively, the most accurate reconstruction is done for an infinitely thin mesh. But the computation time needed to reconstruct with a large number of points (>200) to define the mesh increase drastically. Nevertheless, this dependence can easily be fitted by equation (3):

$$f(x) = C_1 + \frac{C_2}{x + C_3} \qquad (3)$$

where x is the number of points in the mesh. Actually, the reconstruction can be done with a reasonable (~100) number of points in the mesh and then post-corrected.

A dedicated experiment on the machine has been carried on to verify the efficiency of the reconstruction: horizontal beam position has been scanned from 0 to 15 mm with static bumps (limited to 15 mm by the horizontal physical acceptance), and reconstructed position has been compared to how much the scraper has to be moved to maintain a lifetime (on purpose) reduced to 1 hour (case 1) or 2 hours (case 2) (Fig. 7).

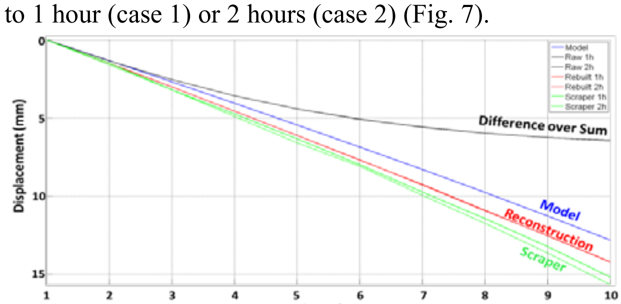

Figure 7: Good agreement between the position reconstruction (red) and an experimental check using the

ISBN 978-3-95450-141-0

scraper (green) or the model (blue), compared to the usual difference over sum method results (black).

DEMIXING OF THE TURN-BY-TURN BPM ELECTRONICS DATA

SOLEIL BPM Electronics is able to provide position data at the revolution frequency sampling rate. Nevertheless, due to internal filtering when decimating ADC samples (at 109 MHz) down to turn-by-turn data (at 846 kHz), those samples are not independent and contain information from more than one turn. This phenomenon can be seen looking at the impulse response of the BPM electronics. This has been registered on the sum signal of the BPMs when the beam is doing only one turn in the storage ring, and killed at the end of the turn (Fig. 8).

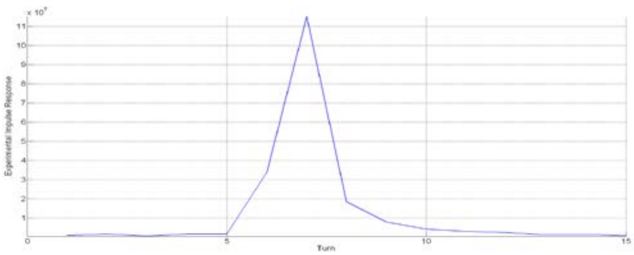

Figure 8: Impulse response of the BPMs measured when the beam is doing only one turn in the storage ring. Electronics filters over ~6 turns to produce turn-by-turn samples.

A correction algorithm has been developed in order to correct for that "mixing", based on the method described in [4]: as each turn-by-turn sample is a linear combination of ADC samples, a correction filter can be built from the impulse response. This is done in the frequency domain by inverting the Fourier transform of the impulse response. Then, going back to the time domain the resulting filter can be convoluted with the position data to make the turns independent (Fig. 9).

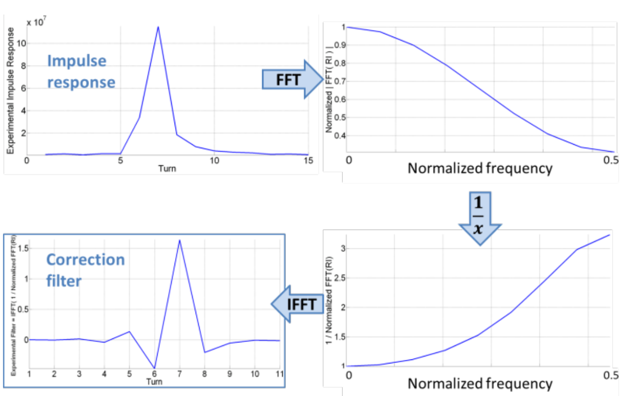

Figure 9: Construction of the correction filter. The fast Fourier transform of the impulse response is inverted and then brought back to the time domain to obtain the correction filter to be convoluted with the turn-by-turn data.

This demixing correction can be combined with the correction of the nonlinear BPM response in the case the turn-by-turn data are used to measure the beam position at large amplitudes (Fig. 10).

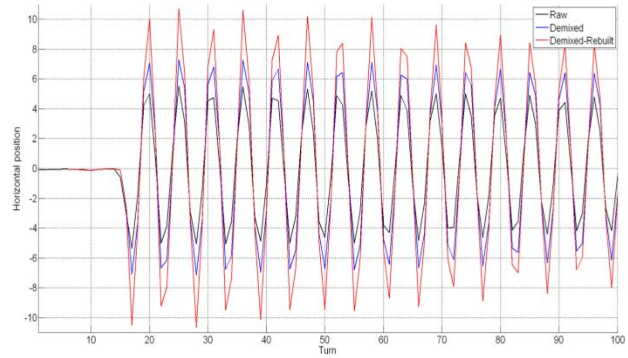

Figure 10: Turn-by-turn BPM corrections in the case of a response to a pinger magnet in the horizontal plane. Raw data (black curve) are first demixed (blue curve) and then corrected for the non-linearities (red curve).

CONCLUSION

Dedicated algorithm have been developed to correct for: the non-linearities induced by the BPM block geometry when the beam is at large amplitude, and for the mixing of the information between neighbouring turns for turn-by-turn data that are computed by the electronics. Both corrections give satisfactory results and are used for the machine physics studies.

ACKNOWLEDGMENT

This paper reports the result of the work performed by Benoît Beranger during its Master-internship at SOLEIL. The authors would also like to thank Guenther Rehm for the helpful discussions about demixing principle and trainee Foued Talbi for his initial work on the BPM response based on boundary condition method.

REFERENCES

[1] T. SHINTAKE et al., «Sensitivity calculation of beam position monitors using boundary element method,» *Nuclear Instruments and Methods in Physics Research,* pp. 146-150, 1987.

[2] A. Stella, «Analysis of the Dafne beam position monitor with a boundary element method,» *Dafne Technical Note CD-10, December 19th,* 1997

[3] R. W. Helms et al, Phys. Rev. ST Accel. Beams 8, 062802 (2005).

[4] R. Bartolini et al., "Calibration of the nonlinear ring model at the Diamond Light Source", Phys. Rev. ST Accel. Beams 14, 054003 (2011).