BEAM BASED ALIGNMENT FOR THE STORAGE RING MULTIPOLES OF SYNCHROTRON SOLEIL

A. Madur*, P. Brunelle, A. Nadji, L.S. Nadolski
Synchrotron SOLEIL, Gif sur Yvette, France

Abstract

First beam-based alignment (BBA) measurements have been carried out during the commissioning of the SOLEIL Storage Ring that started in May 2006. The results will allow calibrating the zero reading of the 120 Beam Position Monitors (BPMs) with respect to the magnetic centre of the adjacent quadrupoles or sextupoles. We plan to use two different BBA methods related to each multipolar magnet BPMs being either adjacent to quadrupoles or sextupoles. Moreover, multiple different experiments will favour results cross-checking. As we did not have enough time to validate our algorithms, we present here only the automated methods we plan to apply and the MATLAB user interface dedicated to BBA.

INTRODUCTION

In spite of all the care provided to multipole magnets design [1], measurements, magnetic axis tuning [2], and installation, there are unavoidable alignment offsets that have to be corrected. The first action is to use the 112 dipolar correctors to get at best an orbit within few hundred microns. Then errors on magnets and beam position monitors (BPMs) alignment must be measured and taken into account to attain a micrometer orbit. To reach such a performance we will use beam-based alignment (BBA) methods. These methods will be applied for both quadrupoles and sextupoles, and as there are many elements to control and command, the beam-based alignments are automated by means of a MATLAB graphical user interface depicted in this paper.

BEAM-BASED ALIGNMENT METHODS

The purpose of Storage Ring (SR) BBA is to make the beam going through magnetic axis of multipole magnets to minimize harmful defects related to off axis beam excursions. Indeed, as shown on figure 1, if the BPM frame is taken as reference, the beam position measurement will be shifted of the BPM to quadrupole offset $\Delta\ Mag\_\ BPM$. From the BBA point of view, SOLEIL SR is made of 160 quadrupoles, 120 sextupoles, 112 dipolar correctors (half for each plane) and 120 BPMs. All the quadrupoles were measured and tuned (magnetic axis) at SOLEIL whereas only some SIGMAPHI sextupoles characterization and tuning were checked.With offsets obtained from multipole magnet BBA, a whole survey can be performed to validate the magnet magnetic axis measurements and tunings, the BPM electrical axis characterizations and also the mechanical alignments of these elements. The idea is to apply one main method for each multipole magnets and to implement other methods to perform cross-check measurements.

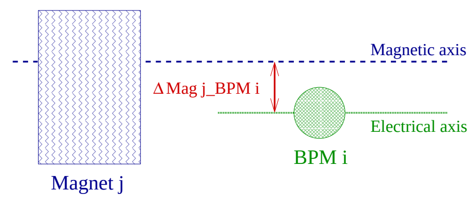

Figure 1: Alignment Offsets

Quadrupole Magnets

SOLEIL SR quadrupole magnets are all provided with independent power supplies. A beam that enters off a quadrupole magnetic axis undergoes a dipolar kick. For the same reasons if the beam located on the golden axis enters a misaligned quadrupole, the kick will generate a distorted orbit due to betatron oscillations (see figure 2).

Indeed the change in the orbit observed at a point s related to a change of a quadrupole strength at s_0 is expressed by the next formula [3]:

$$\Delta w(s) = +\Delta K \cdot w(s_0) \left(\frac{1}{1 - K\ \frac{l_{mag}\ \beta_w(s_0)}{2\ tan(\pi\ \nu_w)}} \right) \qquad (1)$$
$$* \frac{\sqrt{\beta_w(s)\ \beta_w(s_0)}}{2\ sin(\pi\ \nu_w)}\ cos(|\phi_w(s) - \phi_w(s_0)| - \pi\ \nu_w)$$

For the vertical plane case "w" letters must be replaced by "z" and for the horizontal plane case w becomes "x" and "$+\Delta K$", "$-\Delta K$". w is the orbit location in the studied plane (x or z), K the quadrupole strength, ΔK the change in quadrupole strength, l_{mag} the quadrupole effective length, β the beta function, ν the tune number and ϕ the betatron phase. The equation (1) confirms that if the beam goes through the quadrupole magnetic axis ($w(s_0) = 0$), there is no orbit variation ($\Delta w(s) = 0$).

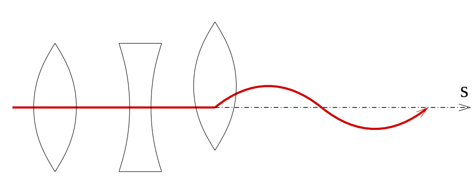

Figure 2: Effect of a quadrupole misalignment

The closed orbit (W_i) read by the closest BPM_i to the quadrupole "j" can be expressed like:

$$W_i = w_j + \Delta_{Mag\, j\_BPM\, i} \quad (2)$$

Where w_j is the orbit location at the quadrupole "j" from its magnetic axis and $\Delta_{Mag\_BPM\, i}$ the offset between the BPM_i and the closest quadrupole. By varying W_i, when the cancellation of w_j occurs, the BPM_i reading is the researched offset.

In our case, two methods will be used to vary the orbit in the quadrupole "j": the main one which only need one corrector and the second which requires 4 correctors for local orbit bumps (position and angle).

Most Effective Corrector Using the correctors response matrix, it is easy to find the corrector which gives the biggest orbit variation at the quadrupole "j": it is the most effective corrector for that quadrupole. For different corrector strength values (or currents), the quadrupole strength is varied twice ($\pm\Delta K$) and the difference of related closed orbits read by the BPMs is performed. The closer to the magnetic center is the orbit $W_i(s)$, the lower is the closed orbit variation. A merit function depending on the corrector current and taking into account the quadrupole strength is computed.

$$f(I_{cor}) = \sum_{i=1}^{N_{BPM}} (W_i(+\Delta K) - W_i(-\Delta K))^2 \quad (3)$$

Where I_{cor} is the current in the corrector used to modify the beam closed orbit, N_{BPM} the number of BPMs, and w_i the position of the beam read by the BPM number i. The minimum of this function (a parabola) represents the lowest closed orbit variation and it is related to a corrector current value ($I_{cor\, Offset}$). Then the BPM_i response versus the corrector values follows a linear relation.

$$W_i(I_{cor}) = a\, I_{cor} + b \quad (4)$$

Using equation (4), $W_i(I_{cor\, Offset}) = \Delta_{Mag\, -BPM\, i}$.

On figure 3 are plotted in red the experimental value of the merit function, in dashed line the parabola fit to evaluate numerically the minimum, in blue the BPM_i response versus the corrector "j" current and the black circle shows the offset value. This result was obtained with a MATLAB program that is described further in the paper.

Four Corrector Bumps To check the offsets obtained with the most effective corrector method, it is sometimes possible to use 4 correctors to perform a pure local position bump in the studied quadrupole. The main advantage of this method is that it enables us to master both beam position and angle in the magnet. However, due to the small number of correctors in the SOLEIL SR (56 for each plane), it may occur that a quadrupole cannot see a bump. That is why this method will be only used to check the previous results. The algorithm principle is the same, the variable of the merit function "I_{cor}" must be replaced by the bump amplitude.

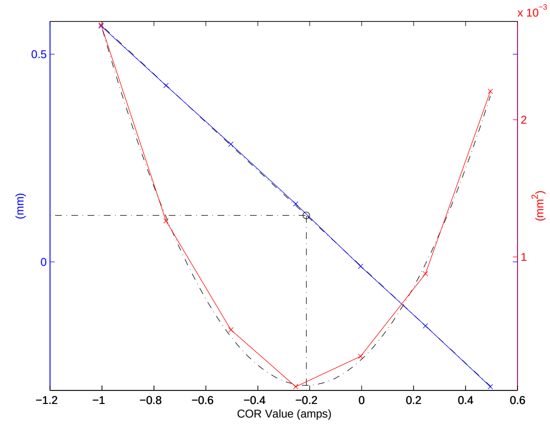

Figure 3: Merit function and BPM_i response

K modulation K-modulation method cannot be applied in the present state of the power supplies. SR quadrupole magnet power supplies are not able to deliver varying current with few tens of hertz frequency. But from the statistical point of view, a third independent method could strongly confirm the previous measurements. That is why, we will try to apply this method to a few number of magnets with a power supply dedicated to this experiment.

The principle is to send a sinusoidal current into the magnet and to measure the beam position at the closest BPM. After a Fourier analysis of the signal seen by this BPM, the spectrum obtained shows peak at excitation frequency and its amplitude is proportional to the offset.

Sextupole Magnets

Another point of view could be to align the BPMs reading with respect to the sextupole magnet axis. A beam that is off a sextupole axis generates tune shift, betatron coupling and beating, dispersion and orbit distortion. There are also many methods to characterize the BPM to sextupole axis offsets.

Second order methods Methods developed previously for the quadrupoles (most effective correctors, 4 corrector bumps) can be applied but they are less sensitive since there are only second order effects. Two methods are available and are similar to the most effective corrector method used for quadrupoles. The merit function can be evaluated with orbit distortion measurements but also with tune measurements.

Ugly quadrupole SOLEIL correctors are located in SR sextupole magnets by means of additional coils (horizontal & vertical corrector, skew quadrupole corrector). Assuming that the magnet magnetic axes are mostly related to the magnetic circuit geometry, corrector coils could be used to provide a quadrupolar magnetic field. As SOLEIL Magnetism and Insertion Devices group has developed a rotating coil bench that measures accurately multipole magnet magnetic axis location and orientation (tilt angle), measurements are planned to validate the assumption. Once the assumption is true, sensitivity of quadrupole beam-based alignment is reached and can be exploited. Moreover, the 10 independent SOLEIL sextupole families are connected in series, using corrector coils to get a quadrupole magnetic field enables us to use the individual power supply of corrector for each sextupole. However corrector coil connections changing must be done manually, it is the main drawback of this method.

USER INTERFACE

As there are many multipole to align (160 quadrupoles + 120 sextupoles), an automated program is requisite. Then since BBA will be often operated during the machine life, a graphical user interface could help to manage it. Consequently a user interface has been developed in MATLAB environment [4]. MATLAB environment is used at SOLEIL since the MATLAB Middle Layer enables development of high level beam physics applications [5]. As this environment is interfaced with TANGO, it can control and command the optical elements of the machine.

The interface developed for BBA is shown on figure 4. Quadrupoles are grouped in families (10) and can be selected individually, by families and all together. Both plane (yellow panel) and method (red panel) can be selected. The right part of the interface is dedicated to result display. The plot shown on figure 3 is displayed in the middle and the offset numerical value of the studied BPM is written just below. Of course all the data collected are saved in a directory to enable deeper data analysis.

FIRST PRELIMINARY RESULTS

Moreover the simulator Accelerator Toolbox [6] is also implemented in MATLAB which gives the advantage of testing the algorithm without taking time on machine commissioning. For the first on-line tests, few tens of minutes were dedicated to time response tuning (power supplies, BPMs) and then algorithm could operate all the steps of BBA for one quadrupole for the first time (Most effective corrector method & horizontal plane). The help provided by the BBA MATLAB programs coming from ALS and the simulator explain the saving of time obtained for the different device time response tuning. The order of magnitude of the offset got was coherent (few hundreds of microns). Since the program operation is validated, the present task is to tune the BBA parameters like ΔK and corrector current steps to get the required reproducibility and sensitivity. Presently the standard deviations of the BPM noise is not at an acceptable level for the expected resolution ($0.2\,\mu m$ r.m.s) but solutions will be applied soon. Once the BPM noise will be reduced, we expected to know quadrupole to BPM offset within few microns. Moreover, current cycling will be necessary to minimize hysteresis effect in quadrupoles.

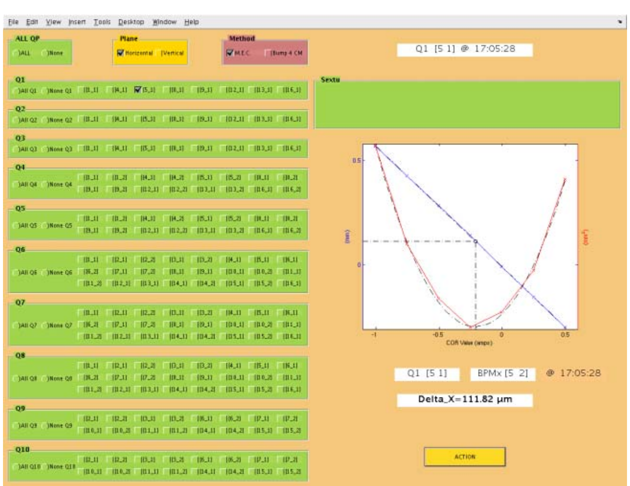

Figure 4: MATLAB Graphical User Interface for BBA

CONCLUSION

Beam-Based Alignment is an important step in a machine commissioning and operation for several reasons. First it enables to finely correct the machine closed orbit. Then with all the data collected, statistics can be computed to qualify all the optical element alignment steps: multipole magnets magnetic axis measurements and tuning, BPM electrical axis measurements, and of course the mechanical alignment during installation. And finally, BBA alignment of multipole magnet are often performed during the machine life and an available easy to use MATLAB interface will strongly facilitate its operation.

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