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X-RAY BEAM POSITION MONITOR (XBPM) CALIBRATION AT NSRC SOLARIS*

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Abstract

During installation of Front-ends in sections 4th (XMCD beamline frontend) and 6th (PHELIX beamline frontend) at National Synchrotron Radiation Centre Solaris (NSRC Solaris), two units (one for each front end) of X-ray Beam Position Monitors (XBPM) have been installed as a diagnostic tool enabling for measurement of photon beam position. Hardware units of XBPM were manufactured, delivered and eventually installed in Solaris by FMB Berlin [1]. In order to get readouts of beam position from XBPM units, Libera Photon 2016 [2] controller has been used as a complementary electronic device. Since XBPM units are supposed to be used along with insertion device, an on-site Libera calibration was necessary. Libera's calibration required few iterations of scans involving gap and phase movement of insertion devices at 4th and 6th section of Solaris ring. Main focus was put onto derivation of Kx, and Ky coefficients. The content of this document describes step by step the procedure of Libera's Kx, Ky coefficients value derivation at NSRC Solaris.

GOAL OF XBPM'S CALIBRATION

Purpose of xbpm calibration is the determination of such two values of K_x and K_y coefficients so that physical shift of the photon beam in a given plane (horizontal X or vertical Y) by a certain amount (µm) will be reflected by the beam position controller in the ratio 1:1.

DETERMINATION OF K_x, K_y COEFFICIENTS VALUES THROUGH LONG TERM SCANS

At Solaris, to perform scans, which we determined K_x, K_y values from, we used data from: undulators, High Voltage power supply and motor positions of xbpm. For each gap and phase setting we made a long scan of xbpm motors to collect data from all 4 photo-blades. Then, based on the scan results we determined K_x, K_y values for X and Y planes. In Fig. 1, double bending achromat (DBA), xbpm, its photoblades and beam are shown schematically. Since the scans are time consuming, eventually we had to develop a fast method allowing for online calibration of K_x, K_y values using K_x, K_y values calculated from long run scans.

Scan Results

In Fig. 2 is shown an exemplary result of the motors scan, showing data from each photoblade. Map on the left is not

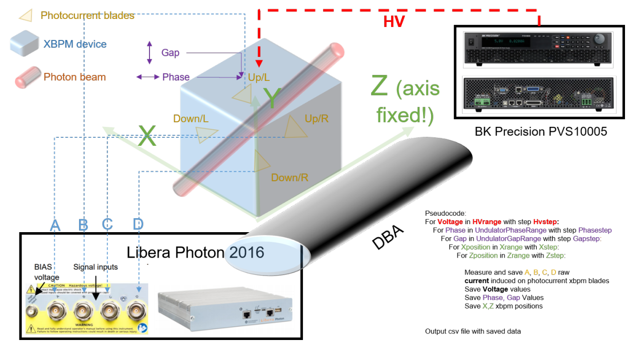

Figure 1: Scheme illustrating long run scans and involved devices.

normalized and map on the right shows normalized values. This is to show how incoming light evenly distribute each of the photo blade. Before we got this result, we had to make an effort to mechanically shift xbpm unit at the very beginning of its calibration. Based on these maps, we have the possibility to calculate K_x, K_y values. It is also worth noting that positive and negative values of the photo blades counts indicate different direction of the photo-current flow.

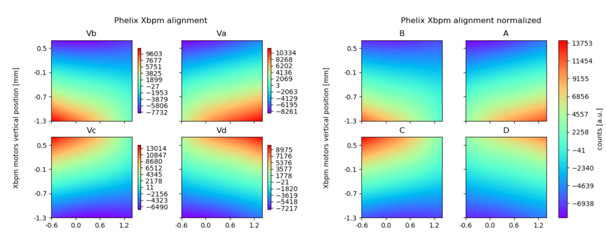

Figure 2: Photo-blades maps. Collected for Gap = 30 mm and $Phase$ = 0.0 mm.

K_x, K_y Calculation Method

The primary equation used for K_x, K_y calculation can be found in Libera Photon 2016 user's manual [2]. These equations cover calculation of single values of K_x, K_y. At Solaris, we made scans so we needed to adapt user's manual formulas to its iterative versions. Below are the equations for calculating the photon beam position in both planes:

$$x_{ij} = K_x^{ij} \frac{M_x^{ij}}{S_x^{ij}} - x_0^{ij} \tag{1}$$

$$y_{ij} = K_y^{ij} \frac{M_y^{ij}}{S_y^{ij}} - y_0^{ij}, \tag{2}$$

where

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$M_x^{ij} = \left(V_a^{ij} + V_d^{ij}\right) - \left(V_b^{ij} + V_c^{ij}\right)$, $M_y^{ij} = \left(V_a^{ij} + V_b^{ij}\right) - \left(V_c^{ij} + V_d^{ij}\right)$, $S_x^{ij} = S_y^{ij} = V_a^{ij}+V_b^{ij}+V_c^{ij}+V_d^{ij}$, $V_a^{ij}, V_b^{ij}, V_c^{ij}, V_d^{ij}$ - matrices of raw signals from A, B, C, D XBPM channels - directly from scans. Since in equations for beam position calculation Eqs. (1) and (2) we already use initial K_x, K_y coefficients, it is not straightforward how to get correct K_x, K_y using possibly inaccurate predefined K_x, K_y values. However, from scans there are known two things:

1. relative X and Y position of XBPM
2. Difference in milimeters between two consecutive positions of XBPM motors

Based on 2., we can calculate K_x, K_y for given pair of points, e.g. pair: $[(i,j),(i-1,j+1)]$. We know how much XBPM was moved, either in X or Y plane, so we can use this XBPM position difference in beam position Eqs. (1) and (2) to determine correct K_x, K_y values. For convenient matrices indexing and iterating over their elements, we constructed the meshgrids of X and Y XBPM motor positions. The meshgrids X^{mesh}, Y^{mesh} are given as:

$$X^{mesh} = \begin{pmatrix} X_1 & \cdots & X_n \\ \vdots & \ddots & \vdots \\ X_1 & \cdots & X_n \end{pmatrix}, Y^{mesh} = \begin{pmatrix} Y_1 & \cdots & Y_1 \\ \vdots & \ddots & \vdots \\ Y_n & \cdots & Y_n \end{pmatrix}.$$

Then, we can put difference of XBPM position movement as beam position difference and calculate correct K_x, K_y values for X, Y planes, as follows:

$$K_x^{\beta} = \frac{\left(X_{\beta}^{mesh} - X_{ij}^{mesh}\right)\left(S_x^{\beta} S_x^{ij}\right)}{\left(M_x^{\beta} S_x^{ij} - M_x^{ij} S_x^{\beta}\right)} \tag{3}$$

$$K_y^{\beta} = \frac{\left(Y_{\beta}^{mesh} - Y_{ij}^{mesh}\right)\left(S_y^{\beta} S_y^{ij}\right)}{\left(M_y^{\beta} S_y^{ij} - M_y^{ij} S_y^{\beta}\right)}, \tag{4}$$

where

$$\beta \in \{(i-1,j-1),(i-1,j),(i-1,j+1),(i,j-1),\\ (i,j+1),(i+1,j-1),(i+1,j),(i+1,j+1)\}.$$

Equations (3) and (4) provide a compact way of writing 8 points in the neighbour of point (i,j) of the motors scan. This is being done to enable calculation of mean $\overline{K}_{ij}$ out of 8 neighboring K_{β}. It can be rewritten in a form, independent of plane which we are currently calculating $\overline{K}_{ij}$ mean for:

$$\overline{K}_{ij}^{p} = \frac{1}{8}\sum_{\beta} \frac{\left(P_{\beta}^{mesh} - P_{ij}^{mesh}\right)\left(S_p^{\beta} S_p^{ij}\right)}{\left(M_p^{\beta} S_p^{ij} - M_p^{ij} S_p^{\beta}\right)}, \tag{5}$$

where $P^{mesh} \in \{X^{mesh}, Y^{mesh}\}$, $p \in \{x,y\}$. p - plane that we are currently calculating $\overline{K}_{ij}^{p}$ for. Equation (5) assumes that the mean $\overline{K}_{ij}^{p}$ is calculated at specific point (i,j) of the xbpm motors scan. General algorithm calculating $\overline{K}_{ij}^{p}$ from Eq. (5) was shown schematically in Fig. 3.

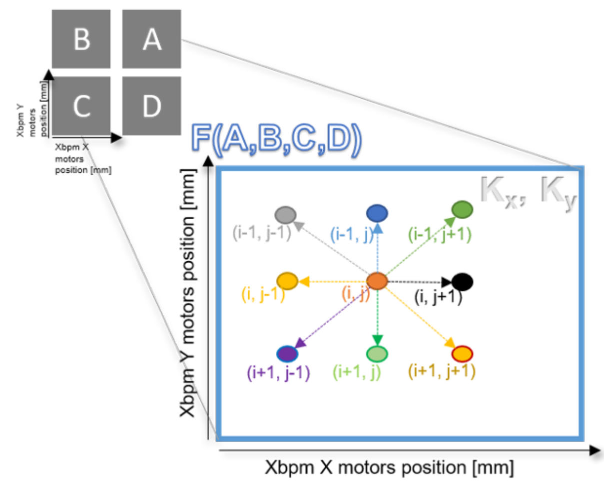

Figure 3: Schematic presentation of algorithm calculating $\overline{K}_{ij}^{p}$ from Eq. (5).

Guidelines to Optimally Choose $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ Values

Since we know how to create a map of means $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ for each scanned point, we are now facing an issue how to choose the $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ values optimally. To do that, we defined four main guidelines which we should follow while determining optimal $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ values:

- Preferably, $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ values should be chosen in the middle point of the scan.
- The ratio of the $\delta\overline{K}_{ij}^{p}$ to $\overline{K}_{ij}^{p}$ should not exceed 20%. $\delta\overline{K}_{ij}^{p}$ - standard deviation of mean $\overline{K}_{ij}^{p}$ at point (i,j) of the xbpm motors scan.
- XBPM motors position should be selected in a way so that $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ values are as close to each other, as possible - independently of the $[gap, phase]$ pair, which $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ values were calculated for.
- xbpm motors positions are kept at fixed positions, regardless of the current undulator setting.

The calculation $\overline{K}_{ij}^{p}$ was done for all measured $[gap, phase]$ pairs. Measured pairs $[gap[mm], phase[mm]]$ are:

$$[14,-29],[30,-29],[50,-29],[14,-16.77],\\ [30,-16.77],[50,-16.77],[14,0],[20,0],[30,0],\\ [40,0],[50,0],[14,16.77],[30,16.77],[30,16.77],\\ [50,16.77],[14,29],[30,29],[50,29]$$

$\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ as a Function of Gap and Phase

Calculated $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ work fine for all 17 measured $[gap, phase]$ pairs but they might give unreliable beam position values for $[gap, phase]$ pairs which were not measured explicitly. Thus, an online calibration procedure was developed to adapt $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ coefficients values for $[gap, phase]$

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pairs which haven't been measured. The calibration procedure is using lookup table as a reference for starting/defaults $\overline{K}_{ij}^{p}$ values in order to apply $\Delta\overline{K}_{ij}^{p}$ correction at unknown/unmeasured $[gap, phase]$ pairs. The characteristics of $\overline{K}_{ij}^{x}$, $\overline{K}_{ij}^{y}$ as a function of gap and phase were shown in Fig. 4

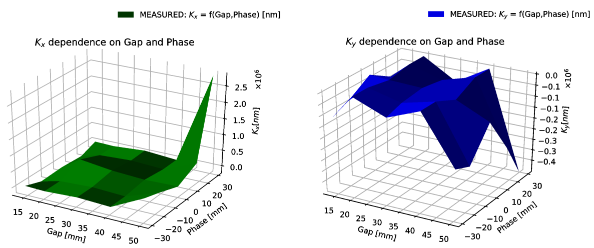

Figure 4: characteristics of $\overline{K}_{ij}^{x}$ (left), $\overline{K}_{ij}^{y}$ (right) as a function of gap and phase.

ONLINE CALIBRATION ALGORITHM

The online calibration algorithm can be broken down into three main steps:

- At unmeasured undulator pairs, the default $\overline{K}_{ij}^{p}$ value is used at the beginning of calibration
- Using default $\overline{K}_{ij}^{p}$ values at unmeasured pair, algorithm performs 10s cross scan with XBPM motors in both planes
- If linear response on default $\overline{K}_{ij}^{p}$ value does not give a slope close to 1 between xbpm motors and libera controller readouts, then the correction factor $\Delta\overline{K}_{ij}^{p}$ is being calculated and recalibrated $\overline{K}_{ij}^{p}\Delta\overline{K}_{ij}^{p}$ value is implemented into beam position controller.

Beam Position Controller Response after the Calculation of Correction Factors at Unmeasured $[gap, phase]$ Settings

Once we know how to determine $\Delta\overline{K}_{ij}^{p}$, we can check how the response between XBPM motors position and beam position controller look like, now using the corrected $\overline{K}_{ij}^{p}\Delta\overline{K}_{ij}^{p}$ value. In both planes, it is clear that online calibration works well, since the slope from linear fit is close to one and squared correlation coefficient also shows a high-quality match between data points and the fit. The response between beam position controller and xbpm motors positions is shown in Fig. 5. Still, we need to keep in mind that default values already provide linear response between physical beam shift and libera output, however, this shift is not always characterized by the slope close to 1.

Corrected $\overline{K}_{ij}^{x}$ and $\overline{K}_{ij}^{y}$ Characteristics as a Function of Undulator's Gap

Since at specific $[gap, phase]$ setting the online calibration takes roughly 10 s and involves both default $\overline{K}_{ij}^{p}$ values

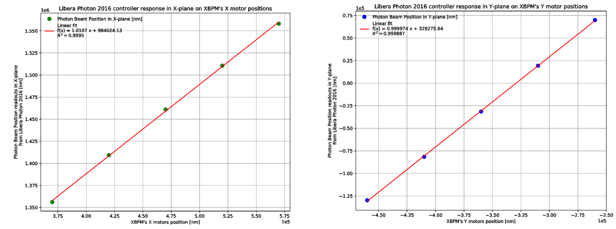

Figure 5: response between beam position controller and xbpm motors positions. Left, right: X, Y plane, respectively.

from long term scans and xbpm's motors movement, it enables quicker scans of yet unmeasured gap and phases resulting in more accurate than defaults $\overline{K}_{ij}^{p}$ values. Additionally, it adapts $\overline{K}_{ij}^{p}$ values to the actual value of the beam current in storage ring. Below, in Fig. 6 are shown two $\overline{K}_{ij}^{x}$ and $\overline{K}_{ij}^{y}$ characteristics as a function of the gap values, ranging from 200 to 14 mm at phase 0. Time of the scan of gap values takes around 2 hours. In Solaris, we measured similar characteristics for 5 mostly used undulator's phases. In order not to use online calibration each time and save XBPMs motors lifetime, we decided to implement these characteristics as a lookup table for XBPM calibration and keep XBPM motors position constant. Nevertheless, whenever needed, online calibration can be run as a verification tool or for any other reasons.

The asymptotic blow up in $\overline{K}_{ij}^{x}$ characteristics in Fig. 6 is probably due to very wide horizontal beam profile above 100 mm gap value. In opened undulator's gap, the beam profile is filling the whole horizontal range of xbpms motors scan. It begins to be more compressed below 75mm gap values. Based on the observations, the asymptotic blow up can shift a bit depending on the beam current in the ring and on the undulator's phase which scan is being done at.

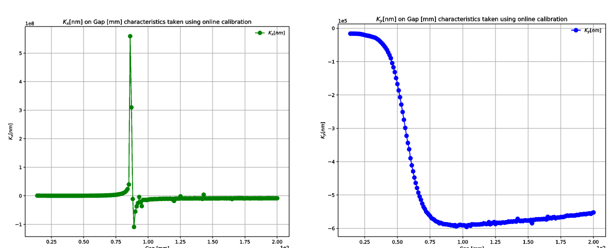

Figure 6: $\overline{K}_{ij}^{x}$ (left), $\overline{K}_{ij}^{y}$(right) characteristics as a function of gap values collected at constant phase = 0 mm.

SUMMARY

Based on shown methods and results, calibration of XBPM was completed. It consisted of two main parts: long scans and online calibration. To save xbpm motor's lifetime a trade off between calibration accuracy and utility must have been made. The linear response between beam position controller and xbpm motor positions was ensured in the total range of 200 µm in horizontal and vertical planes.

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