PERFORMANCE OF THE BEAM POSITION MONITOR SYSTEM IN SOLARIS SYNCHROTRON

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Abstract

The Beam Position Monitor (BPM) system in the Solaris National Synchrotron Radiation Centre consists of 8 striplines along a linear accelerator with a transfer line and 36 buttons around the storage ring. The beam position measurement in the linac is handled by 15 cm quarter wave directional striplines connected to Libera Single Pass E modules as readout devices. The circulating beam in the storage ring is monitored by set of 45 degree diagonal buttons in two geometries connected to Libera Brilliance+ devices. Properly configured BPM setup allows for direct measurement of the beam position stability, closed orbit, current of single train and the stored beam. Moreover, the slow acquisition and turn-by-turn data stream from BPMs in the storage ring are used for the automatic orbit correction, computing beam lifetime on each button, measuring an orbit response, the beta function and other physical parameters of the electron beam. In order to improve the measurement reliability the beam based alignment has been performed. Within the paper the performance of the BPM system during commissioning phase is discussed.

INTRODUCTION

The project of building the first synchrotron facility in Poland was initiated by a group of scientists in 2010. An unprecedented cooperation between the Jagiellonian University (JU) and the MAX-Lab in Lund (Sweden) allowed to build two twin, third generation light sources: Polish Solaris and Swedish MAX-IV. The Solaris light source consists of 600 MeV linear accelerator, dog-leg transfer line and 1.5 GeV storage ring. The designed parameters of 1.5 GeV storage ring are presented in Table 1. A detailed description of the machine and the layout can be found in [1–4].

One-year period dedicated for the installation of the whole machine began in May 2014 and after this time the commissioning phase has started. By this time the machine has been run reaching 525 MeV injection energy, around 200 mA beam current ramped to the final beam energy of 1.5 GeV. Machine optics was corrected closely to the designed values as described in [5, 6].

An essential part of the beam diagnostics subsystem used during the commissioning is to monitor the position of the electron beam along the linac and the storage ring. Two different types of BPMs are used for this purpose — striplines for the single pass measurements and buttons for the circulating beam monitoring. BPMs are also valuable in terms of the beam loss detection by triggering the *post mortem* data acquisition when any unexpected event occurs. The system can also detect where the position exceeds safety limits and generate an interlock signal to protect sensitive components like the Insertion Devices (ID) from an excessive beam deposition. All of this features are provided by dedicated readout electronics — Libera SinglePassE and Libera Brilliance+.

Table 1: Solaris Storage Ring Design Parameters

Parameter	Value
Energy	1.5 GeV
Beam current	500 mA
Circumference	96 m
Number of bending magnets	12
Main RF frequency	99.931 MHz
Number of bunches	32
Horizontal emittance (bare lattice)	6 nm rad
Tune Q_x, Q_y	11.22, 3.15
Natural chromaticity ξ_x, ξ_y	-22.96, -17.4
Corrected chromaticity ξ_x, ξ_y	+1, +1
Beam size (straight section) σ_x, σ_y	184 µm, 13 µm
Beam size (dipole) σ_x, σ_y	44 µm, 30 µm
Total lifetime	13 h

BPM ARCHITECTURE IN SOLARIS

A position of the beam passing through the linear accelerator and transfer line is monitored by eight quarter wave directional striplines with 15 cm length and 50 Ω impedance. The resonant frequency of stipline sensors is 500 MHz matched to the narrow bandpass frequency of Libera's ceramic SAW filter in analogue front-end readout. To provide 500 MHz harmonics in the beam spectrum the chopper device is used. Due to ongoing rearrangement of chopper architecture precise tuning of single pass BPMs is postponed.

The beam in the storage ring is monitored by 36 quarter wave diagonal button pickups connected to 12 Libera Brilliance+ units. Solaris storage ring consists of 12 Double-Bend Achromat (DBA) magnets containing 3 BPMs each in two different architectures. The first type of buttons (BPM I) is placed at the ends of DBA and its sensor heads are aligned directly along diagonal coordinates. Other button type (BPM II) is placed at the centre of each DBA. The only one difference is in placing sensor heads along the vertical axis on top and bottom of the vessel. It implies a slightly different performance of measuring largely off-centred beam and requires separate calibration.

Simulations of Buttons Geometrical Scale Factors

The position of electron beam is calculated by combining the amplitudes of four signals from sensors — V_A, V_B, V_C, and V_D. Horizontal and vertical components of this signal in diagonal oriented piuckup can be derived by solving linear equations:

$$X = K_x \frac{(V_A + V_D) - (V_B + V_C)}{V_A + V_B + V_C + V_D} + X_{off} \quad (1)$$

$$Y = K_y \frac{(V_A + V_B) - (V_C + V_D)}{V_A + V_B + V_C + V_D} + Y_{off} \quad (2)$$

where K_x and K_y are scale factors determined by the pickup geometry, X_{off} and Y_{off} are zero-position offsets determined by finding magnetic centres of quadrupole magnets.

In order to obtain reliable measurements, simulation of buttons geometry were performed using Matlab boundary element solving routines [7]. In Table 2 the simulation results for BPM I with buttons diagonally aligned are shown. In Figure 1 the beam position lattice distortion in a non-linear operation area of buttons is presented.

Table 2: Simulation Results for BPM I

Parameter	Value
Capacitance	0.56 pF
Power per button	1.4 µW (-28.6 dBm)
Noise power	-121.0 dBm
Estimated resolution X/Y	0.081 µm / 0.22 µm
Loss factor	2.4 mW/pC
H/V sensitivity S_x / S_y	0.149 mm^{-1} / 0.055 mm^{-1}
H/V gain factor K_x / K_y	6.7 mm / 18.0 mm

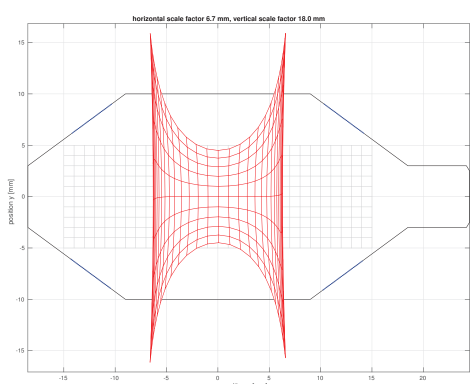

Figure 1: Lattice distortion for BPM I.

Table 3 presents simulated parameters for BPM II with buttons pitched vertically. Figure 2 shows how much the lattice is distorted at corners of the operational area.

POSITION-DEPENDENT MEASUREMENTS

After the scaling factors calibration of all BPMs in the storage ring, the orbit and optics optimisation could be performed. By embedding Matlab Middle Layer (MML) routines in the control system (CS) architecture several measurements were done.

Table 3: Simulation Results for BPM II

Parameter	Value
Capacitance	0.56 pF
Power per button	2.2 µW (-26.5 dBm)
Noise power	-121.0 dBm
Estimated resolution X/Y	0.081 µm / 0.22 µm
Loss factor	3.8 mW/pC
H/V sensitivity S_x / S_y	0.080 mm^{-1} / 0.085 mm^{-1}
H/V gain factor K_x / K_y	12.4 mm / 11.7 mm

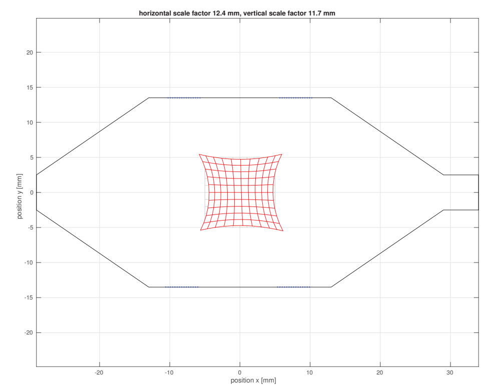

Figure 2: Lattice distortion for BPM II.

BPM Response Matrix

To enable effective orbit correction provided in MML the response matrix were measured. By altering the current in each of the corrector magnet and monitoring the orbit response the response matrix, presented in Figure 3, was constructed. The amplitude of X/Y crosstalks are negligible in comparison with horizontal and vertical oscillations.

Orbit Correction

The orbit response matrix is an essential reference measurement for the automatic orbit correction to work effectively. MML provides a tool that uses this matrix to perform a singular value decomposition (SVD) algorithm for driving correctors to obtain minimal RMS orbit value. Applying the correction improves the orbit significantly reducing it from initial value of c.a. 700 µm to 180 µm in the horizontal and from 1000 µm to 170 µm in the vertical plane. An example of differences between the raw and corrected orbit in the horizontal plane is presented in Figure 4.

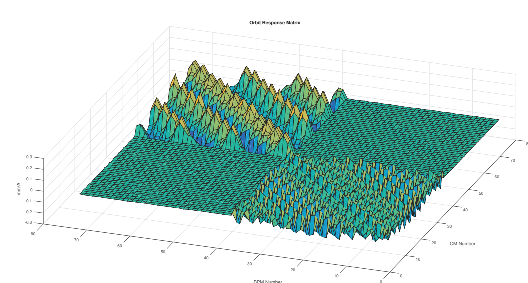

Figure 3: BPM response matrix.

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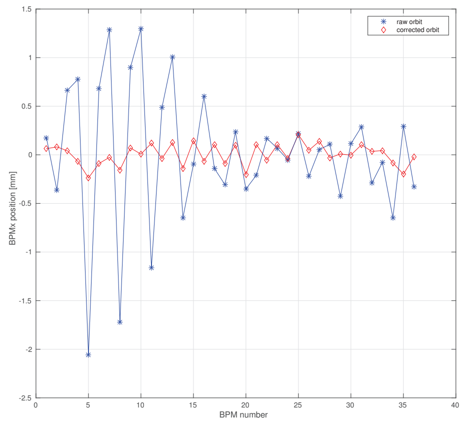

Figure 4: Closed orbit with and without correction.

Indirect Measurements

Moreover, the position monitoring is used to compute some machine parameters like: the beam current of a single train in the linac or the average current in the storage ring (as a sum of signals from buttons), a fractional tune (Fourier transform of turn-by-turn data), a lifetime (linear regression of sum of the channels), dispersion (position response to RF change), beta functions. More detailed results can be found in [6].

BEAM BASED ALIGNMENT

In order to reduce the orbit and improve the BPM measurement accuracy, the Beam Based Alignment (BBA) procedure has been performed. The aim is to setup BPM offset values (X_{off} and Y_{off} coefficients in equations 1 and 2) by finding the magnetic centre of the quadrupole nearest to each BPM sensor. When the beam passes through the centre of the quadrupole magnet, a quadrupole strength change does not affect the beam position. BBA routine for Solaris includes monitoring the changes in the beam position, local orbit correction and changing quadrupole strength by shunting 1% of supplying current.

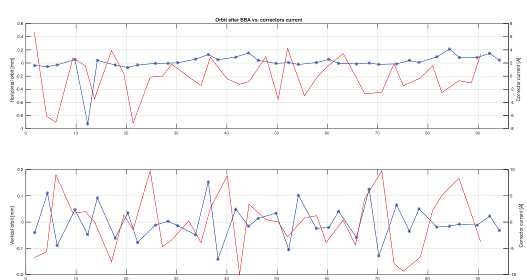

Figure 5: Comparison of orbit and corrector currents after BBA.

Figure 5 presents the impact of BBA measurement on the orbit with respect to the applied correctors current. This procedure revealed some problems with the BPM in the second DBA centre. The horizontal position differs significantly in comparison to the other ones and has the strongest impact on an overall RMS. BBA allowed to reduce RMS values to 97.67 µm in the horizontal and 88.81 µm in the vertical plane. However, when position readouts of the centre BPM in the second DBA are neglected, RMS values can reach 66 µm and 60 µm respectively. A physical realignment and geometry verification is required to solve the problem with this beam monitor.

CONCLUSION

During the commissioning phase of the Solaris synchrotron the beam position monitoring system was turned into operation and calibrated. It allowed to perform several measurements essential for machine optimisation like the orbit response and correction, thw fractional tune, beta functions, etc. Along with MML routines further improvements of the orbit RMS including BBA value were performed. Additional work with both the BPM instrumentation and the physical alignment is necessary to provide the most optimal beam orbit. Last months of the operation have shown that the whole BPM system works properly, but still need fine-tuning, especially after each intervention in the machine geometry. It is important to assure a good performance as well as a reliable toolbox dedicated to the operation with this system, therefore MML routines are still under development to improve their efficiency.

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