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ON-LINE BEAM CONTROL WITH OCELOT AT SIBERIA-2

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Abstract

Siberia-2 is a synchrotron light source with electron beam energy up to 2.5 GeV, currently undergoing upgrade of controls hardware and software. Ocelot, an accelerator physics framework, was integrated with the new orbit correction system for high level beam control. We describe the steps taken for simulation studies of orbit correction strategies on a virtual machine model, integration of the software into the control system and experimental results.

INTRODUCTION

Siberia-2 storage ring is Light Source of second generation, which consists of 6 superperiods. Each superperiod includes one zero dispersion drift section and one non-zero dispersion drift section with lengths of about 3 m. Circumference of the ring is 124 m and the designed natural emittance is 98 nm·rad (see Table 1). The injection of electron beam from the booster Siberia-1 into Siberia-2 occurs at 450 MeV.

Table 1: Main Parameters of Storage Ring

Energy, GeV	2.5
Horizontal emittance, nm·rad	98
Circumference, m	124.13
Coupling	0.01
Betatron tunes, ν_X / ν_Z	7.775/6.695
Natural chromaticities	-16.9/-12.9
Revolution time, nsec	414
Energy loss per turn, MeV	0.675

The magnet alignment errors produce closed orbit distortions, which lead to decreasing of dynamics aperture of the storage ring and beam lifetime. Another very unwanted effect is a changing of the photon beam position at the front-end of beamline. This effect reduces the brightness of photon beam on the sample at experimental station. Therefore, the closed orbit correction is one of the most important systems needed for normal operation of a synchrotron.

Resent upgrade of electronics of the closed orbit correction system [1, 2] required software upgrade as well. As a basis for developing of the new orbit correction software was chosen OCELOT. OCELOT is a novel multiphysics simulation toolkit, which has been in development at European XFEL in collaboration with NRC Kurchatov Institute and DESY since 2011. This program was already used for beam dynamics simulation of Siberia-2 storage ring [3,4]. Popular method of the singular value decomposition (SVD) is implemented in the new software. This approach allowed putting into operation the new orbit correction system very quickly.

HARDWARE OVERVIEW

The main ring consists of 24 dipole magnets, 72 quadrupole lenses combined with vertical and horizontal correctors, 24 sextupole lenses and 24 BPMs. Every dipole magnet consists of two parts – the longest part (1.3 m) has 1.7 T on the full energy and smallest part (0.23 m) has ¼ part of main field. The low field part of dipole are intended for generation of soft X-ray and combined with horizontal corrector. Thus the closed correction system can used 48 vertical correctors and 48 horizontal correctors and 24 BPMs. The optics functions of the superperiod and layout of magnets are shown on Fig.1.

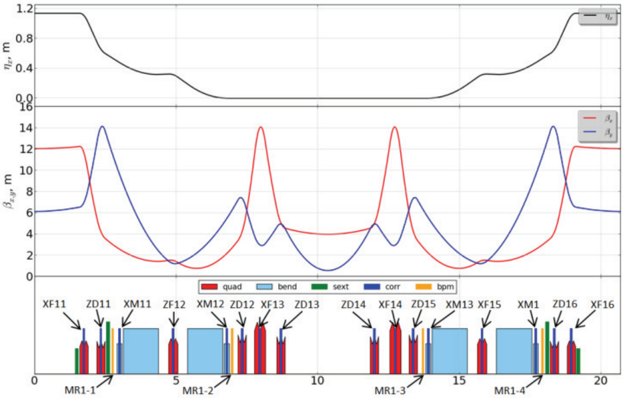

Figure 1: Optics functions and layout of magnets elements.

For conversion of angle to current we used simple expression:

$$\alpha = \frac{K_{conv} \cdot I_{coil} \cdot L_{elem}}{E}$$

where E – energy in MeV, α - angle in rad, L_{elem} – length of element in m, I_{coil} – current of corrector coil in A, K_{conv} – conversion coefficient equal to 4.62 MeV/(A·m) for correctors combined with dipole magnets and 0.9 MeV/(A·m) for correctors combined with quadrupoles.

New electron beam reference orbit measurement system is based on the electron beam position processor Libera Brilliance units developed by Instrumentation Technologies, Slovenia. 24 Libera Brilliance processors are used to process the signals from BPMs.

SOFTWARE OVERVIEW

Electronics upgrade of closed orbit correction system required development of new software. To minimize time of software debugging on the real facility we simulated the magnet alignment errors on the virtual model of the Siberia-2 using OCELOT. As a basis of the correction

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algorithm we have chosen singular value decomposition (SVD). OCELOT is cross-platform tool based on Python. As the host-machine for OCELOT we chose server of the new reference orbit measurement system.

Architecture of new software was chosen in such way to minimize time to switch from virtual to real model, Fig.2.

BPM Interface

The Libera Brilliance unit runs on embedded Linux OS (armel). In the first stage, EPICS IOC provides the control and data readout to the control system. EPICS IOC (is used as IO server) and EDM screens (is used as graphical user interface) are controlled under Ubuntu Linux operation system. Closed orbit correction (COC) module can obtain data from real BPMs via a module based on pyEpics and from virtual BPMs via a simple python module.

Corrector Interface

Power supplies of correctors are controlled by real-time controls system NAMU [5]. For third party codes there is possibility to control facility parameters via SQL database. Thus COC module controls correctors of real facility via SQL database and via a python module of virtual model.

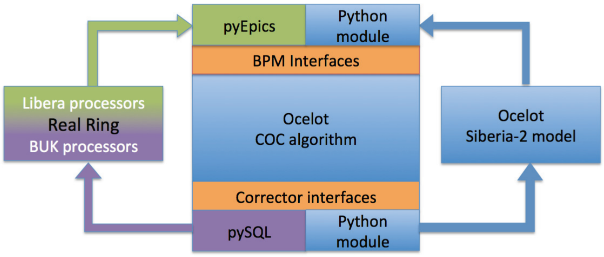

Figure 2: Block-scheme of orbit correction program.

SIMULATION OF CLOSED ORBIT CORRECTION

Using an approach described above the simulation of the magnet alignment errors was carried out, which induced COD. Dipole correctors in vertical and horizontal plane are used for correction of orbit distortion. A dipole corrector installed on the azimuth s_0 of a storage ring with kick θ induces new closed orbit relatively to the reference orbit:

$$y(s) = \frac{\theta\sqrt{\beta(s_0)\beta(s)}}{2\sin(\pi\nu)}\cos\left(|\varphi(s) - \varphi(s_0)| - \pi\nu\right)$$

where $\beta(s_0)$ – β-function on the azimuth of a dipole corrector, $\varphi(s)$ – betatron phase, ν – betatron tune. Using principle of superposition we can write orbit changes for N correctors kick θ_i at s_i.

$$y(s) = \frac{\sqrt{\beta(s)}}{2\sin(\pi\nu)}\sum_{i=0}^{N-1}\theta_i\sqrt{\beta(s_i)}\cos\left(|\varphi(s) - \varphi(s_i)| - \pi\nu\right)$$

Easy to see that in order to compensate orbit distortion at the BPM positions we need to solve system of equations, this in matrix form is:

$$\vec{y} = R\vec{\theta}$$

where $\vec{y} = [y_0, \dots, y_{K-1}]$ – inverse orbit shifts at the BPM positions, K – number of BPMs, $\vec{\theta} = [\theta_0, \dots, \theta_{N-1}]$ – angles of correctors, N – number of correctors, R – response matrix. SVD algorithm is used to solve this question. Elements of response matrix, as easy to derive from above expression, are:

$$R_{i,j} = \frac{\sqrt{\beta_i\beta_j}}{2\sin(\pi\nu)}\cos\left(|\psi_i - \psi_i| - \pi\nu\right)$$

where $j = 0, \dots, K-1$ – BPM number, $i = 0, \dots, N-1$ – corrector number.

Response matrix may be calculated as was described above or may be measured. On Fig.3 is shown ideal response matrix of Sibera-2.

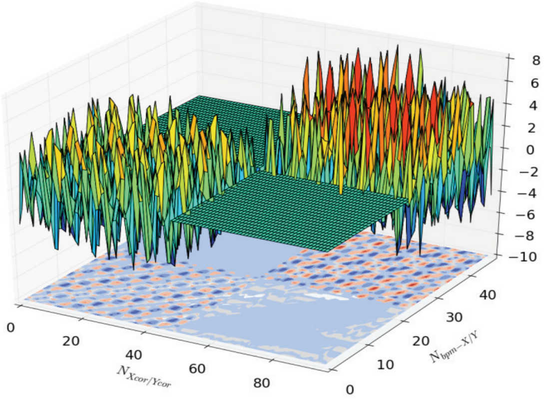

Figure 3: Response matrix of the Siberia-2 model.

On left axis correctors' number is shown. 48 horizontal correctors situated at the beginning of the axis then 48 vertical ones. On right axis numbers of BPMs are shown, 24 horizontal BPMs at the beginning of the axis and then 24 vertical BPMs.

One example of closed orbit correction of Siberia-2 virtual model is shown on Fig.4.

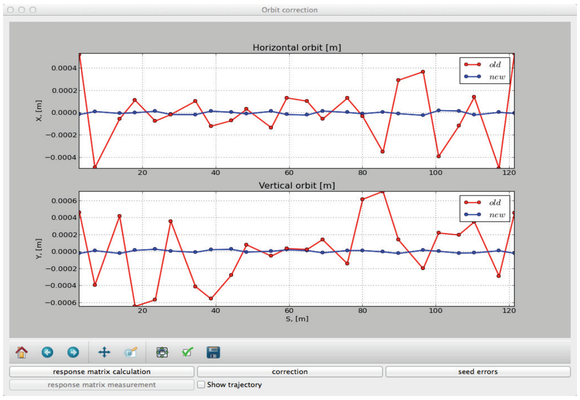

Figure 4: Example closed orbit correction of the model and screenshot of GUI.

FIRST OPERATIONAL RESULTS OF THE ORBIT CORRECTION SYSTEM

After debagging of the simulation codes on the virtual model we transferred Ocelot with these new modules to the control room of Siberia-2. Short time was needed for writing and debagging of interface modules for hardware connection. Partly it was made without spending of operational time of the facility and partly requires some operational time. Thus it took us couple of hours for commissioning of new closed orbit correction system. First results are shown on Fig.5. Here we used ideal response matrix of the Siberia-2.

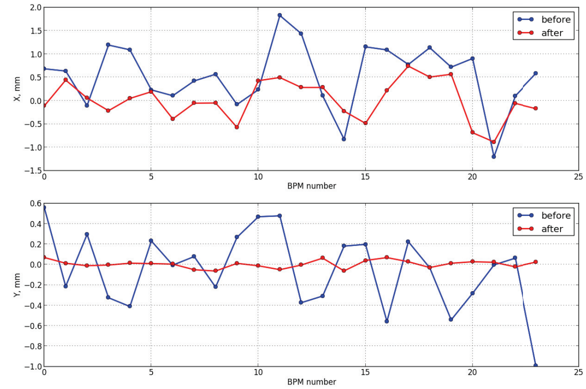

Figure 5: Orbit correction of real facility on the 2.5 GeV.

RMS of the beam centres and BPM positions are listed in Table 2.

Table 2: RMS of the Beam Centres Before and After Correction

	Before correction	After correction
σ_x, µm	880	420
σ_z, µm	380	38

As we can see the orbit correction is very efficient in the vertical plane. Orbit RMS is about 40 µm after correction. For horizontal plane situation is worse because of:

- Magnet alignment errors are bigger in horizontal plane then in vertical.
- Calibration of BPM position in horizontal plane is made with less accuracy.
- Irregular spacing in betatron phase and lack of BPMs in horizontal plane.
- Difference between calculated and operational revolution frequency 2.41519 and 2.41504 MHz, respectively.

Taking into account these factors currents of some correctors for orbit correction in horizontal plane must be more than 13 A when maximum possible current is 5 A.

REAL RESPONSE MATRIX MEASUREMENTS

Response matrix was also measured by the software on injection energy and full energy. Result of measurements of response matrix on injection energy is presented on Fig. 6. Orbit corrections using measured and calculated response matrix are very similar.

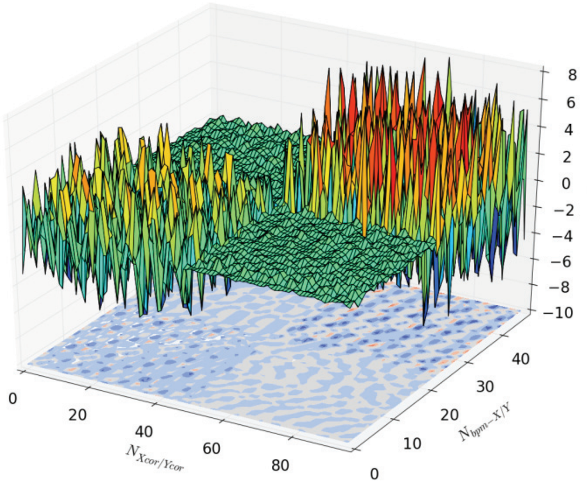

Figure 6: Measured response matrix on the injection energy 450 MeV.

CONCLUSION

Developing of closed correction system was shown that using Ocelot helps to minimize time of new control system commissioning.

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