BEAM ORBIT DIAGNOSTICS AND CONTROL IN CANDLE STORAGE RING

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Abstract

Stability requirements for the CANDLE light source are the consequence of a small electron beam size and a tolerable photon beam parameters. In a real machine, the components of the storage ring have static and dynamic imperfections, which cause disturbance of the electron beam and consequently photon beams parameters. In the present paper the basic approaches to the beam diagnostics, control and correction issues for the CANDLE facility are given. The algorithms, electronics and processing hardware are described.

PROCESSING HARDWARE DESCRIPTION

The basic approach to the diagnostic system for the CANDLE light source is based on the well-proven techniques adopted for many modern synchrotron radiation facilities. The system will be upgraded with the progress made in this field. The main function of the Storage Ring's Diagnostic System is to measure the main parameters of the beam in time and space domain, providing the necessary data for the feedback system and machine control [1]. Diagnostic tools of the facility will provide:

- Measurements of the beam current;
- Beam lifetime control;
- Beam position measurement;
- Beam profiles measurement;
- Aperture and halo measurements;
- Beam loss measurement;
- Instabilities control;
- Energy and energy spread measurements;
- Tune monitoring.

Beam current monitors, beam position monitors, scrapers and beam loss monitors, are necessary for realization of these tasks.

Beam Position Monitors

BPM Processing system can operate in the following modes:

- First Turn Mode

In a single (first) turn mode the BPMs measure the single short position of the injected beam by synchronizing the BPM processing signal with the injection kicker system. The four buttons of each single BPM are processed in parallel by 4 RF-IF converters. For the 0.03 *nC* injected bunch from the 2 *Hz* booster the bunch position will be detected with a single short position resolution of 1.5 *mm*.

- Turn-by-Turn Mode

In turn-by turn operation mode the signals from BPM buttons are stored in the IF processor memory for further data analysis and feedback by the Control system. In this mode the processor resolution at the level of 10.0 μm can be reached for the beam current larger than 5 *mA*. During the turn-by-turn BPM processing an effective measurement of the betatron oscillation phase and amplitude can be performed to determine lattice properties.

- Averaged Orbit Mode

This mode will be predominant providing highly resolved orbit information based on the averaging of the BPM readings over many turns. Averaging will take place on two time scales: a fast time scale for orbit feedback processing and a longer time scale for higher resolution monitoring. Averaging over 2000 orbits with orbit updates once every second will lead to 0.025 μm processing resolution.

CLOSED ORBIT STABILIZATION

The most critical issue that defines the stability of the electron beam in the storage ring is the quadrupole misalignment, which leads to the distortion of the central orbit. The most straightforward way to correct the orbit is the global correction of the disturbed closed orbit based on the BPM y_i readings of the beam positions around the ring. The close orbit correction is performed by means of powering correctors to steer the beam trajectory in BPM.

The orbit correction system for the CANDLE storage ring will be based on 80 BPMs, 64 corrector magnets and 64 corrector coils incorporated into sextupole magnets to stabilize the beam closed orbit. From 64 corrector magnets, 32 are of the combined functions type, 16 are vertical correctors and 16 are horizontal ones. Thus, from total 96 corrector magnets 48 will deal in horizontal plane and 48 in vertical plane. The location of the correctors and BPMs in a regular lattice is shown in Fig. 1.

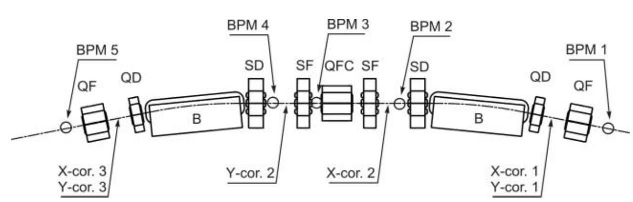

Figure 1: BPMs and correctors distribution per magnetic lattice.

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To correct the closed orbit, a global orbit feedback system will be adopted for the storage ring, which will minimize the orbit variations at all experiments at the same time. The control system converts voltage signals from beam position monitors into orbit position data by way of calibration factors, then a set of dipole kicks are calculated to adjust the orbit. The entire process takes place from a graphical interface connected to the control system.

To achieve this, an acquisition system consisting of digital signal processors (DSP) will be installed at each of the 16 sectors, which will acquire the reading from 5 beam position monitors. The obtained values may be selectively averaged over a number of turns of the machine. The values will be packed into a message and will be sent to a central crate equipped with a fast DSP, which performs the scaling of the input signals, calculates the position and current, as well as the fast Fourier transform, etc.

The direct orbit correction method using the response matrix R not always provide the adequate steering of the orbit as the response matrix is often close to singular, even when the number of BPMs is greater than the number of correctors. There is no unique inverse because there are combinations of corrector magnet strengths that produce zero or very small orbit shift in the BPMs [2, 3].

SVD Correction

The singular value decomposition method (SVD) applied for the response matrix *R* solves the problem. SVD is based on the theorem [4] according to which any matrix whose number of rows *m* is greater than or equal to its number of columns *n*, can be written as the product of an $m \times n$ column matrix *U*, an $n \times n$ diagonal matrix *S* with positive or zero elements σ_i (singular values of the matrix), and the transpose of an $n \times n$ orthogonal matrix V: $R = U \times S \times V$. The inverse of response matrix is then given by:

$$R^{-1} = VS^{-1}U^{T} = \sum_i \vec{v}_i \frac{1}{\sigma_i} \vec{u}_i^{\,T} \qquad (1)$$

If any σ_i is zero or very small then R^{-1} is infinite or very large (singular). Even a small measured orbit associated with BPM noise would then generate undesirable large changes in correctors. The problem is avoided by deleting all the terms in response matrix with small σ_i thus correcting real orbit trajectory with reasonable magnet strengths and filtering out the BPM noise effectively. This method provides the steering of the closed orbit at the level below 100 μm rms.

A GUI using MATLAB tools was coded, which displays response matrix, inverse response matrix, results of the SVD analysis. The BPMs and correctors used in the algorithm can be selected at the window menu from the corresponding lists of 80 horizontal and vertical BPMs and 48 horizontal and 48 vertical correctors. (Fig. 2-5).

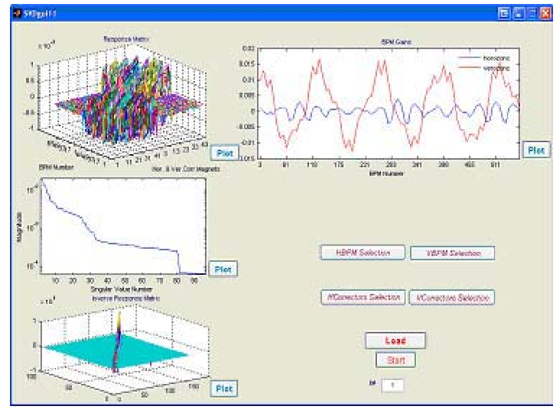

Figure 2: GUI using MATLAB Accelerator Toolbox for global orbit feedback.

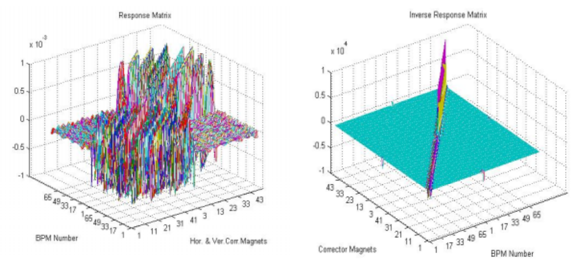

Figure 3: Response (left) and the inverse (right) matrixes of the CANDLE storage ring.

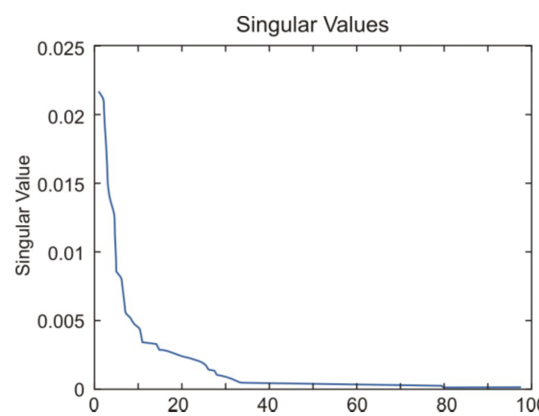

Figure 4: Singular values of the response matrix.

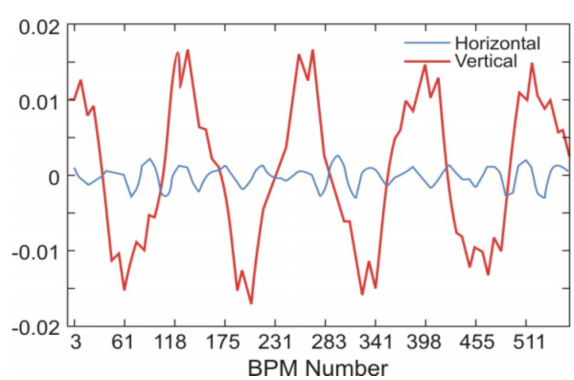

Figure 5: BPM gains after first turn.

PHOTON BEAM DIAGNOSTICS

After the closed orbit steering, the dynamical change and control of the closed orbit will be based on the photon beam position stabilization. To control the vertical stability of the electron beam at the source point (changes in position Δy and angle $\Delta y'$), two photon position monitors spaced by the distance Δd will incorporate in each beamline. From the simple geometrical considerations, the vertical position Δy and angle $\Delta y'$ changes of the electron beam trajectory defined from the vertical displacements of the photon beam y_{p1} and y_{p2} , measured at the positions of d_1 and d_2 along the beamline. If the precision associated with the photon measurement is δ_p then the precisions of the position δ_y and angle $\delta_{y'}$ detections of the electron orbit are:

$$\delta_{y'} = \sqrt{2}\delta_p / \Delta d;\ \delta_y = \delta_p \sqrt{\left(d_1^2 + d_2^2\right)} / \Delta d \qquad (2)$$

The photon BPMs usually have the resolution of the order of few microns. Two photon BPMs with $1\mu m$ resolution spaced at the distance of 15 and 25 *m* from the electron source, will then detect the position and angular change of the electron beam with the accuracy of $3\mu m$ in position and 0.16 μrad in divergence.

The diagnostic beamline will be used also for the beam profile measurements. The most direct way to obtain information about the transverse profile is to produce a direct image [5]. The direct image of the electron source is produced in X-ray region by the compound refractive lens (CRL). The refractive and absorption properties of such a lens are best suited for the photon energy between 8 and 30 keV.

The radiation from the bending magnet passes the Double Crystal Monochromator that produces a highly monochromatic beam at photon energy of 10 keV. The beam is focused on both directions by the CRL into the image plane. The source-to-lens and lens-to-image distances are equal to $2f$ (with f the focal length of the lens), and therefore the image has the same size as the source. The scintillation counter behind the pinhole is detecting the transmitted radiation.

The focal length for a compound lens with N elements is given by $F = R/2N\cdot\delta$, with R radius of curvature and δ refractive index decrement. For the aluminium lens (δ=$5.46 \cdot 10^{-6}$) with $500\mu m$ curvature, five series of multiple lenses will provide the focal length of 7.7 *m*. This corresponds to source-to-lens and lens-to-image distance of 15.4 *m* ($2f$), when the focusing of the primary source produces a direct image of the photon source.

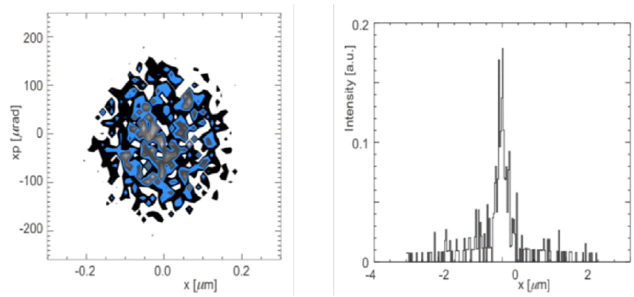

Figure 6: Photon beam phase pattern (left) and intensity profile (right) produced by electron beam after focusing by CRL (10 keV).

Resolution of the method is defined by the rms opening angle of the photon source that for the bending source in the region of the critical photon energy X-ray can be presented as

$$\sigma_\psi \approx \frac{2}{\gamma}\left(0.324 - 0.172\frac{\Delta\varepsilon}{\varepsilon_c}\right) \qquad (3),$$

with critical photon energy $\Delta\varepsilon/\varepsilon_c << 1$ and ε_c = 7.9 keV for dipole source. Diffraction limited source size corresponding to the angle σ_ψ is approximately given by $\sigma_r = \lambda/4\pi\sigma_\psi$ with λ the photon wavelength. Thus, the diffraction limited source size and divergence at 10 keV of the emitted photon in bending magnet are $\sigma_r = 0.1\mu m$ and $\sigma_\psi = 0.1$mrad respectively. Fig.6 shows an image after the focusing of the 10 keV photon beam by the compound refraction lens located at the distance of 15.2*m* from the source and the screen. The image profile of the photon beam has the Gaussian shape with the rms spread less than $1\mu m$ that defines the minimum expected resolution of the detector.

REFERENCES

[1] V. Tsakanov et. al, CANDLE Design Report, ASLS-CANDLE R-02-001, 2002.

[2] J. A. Safranek, Beam-based Accelerator Modeling and Control, 9th Beam Instrumentation Workshop, Cambridge, AIP Conf. Proc. 2000 (546), p.23.

[3] Y. Chung, G. Decker and K. Evans, Proc. US Particle Accel. Conf., 1993, p.2263.

[4] J. C. Nash, Compact Numerical Methods for Computers, (linear algebra and function minimization), New York, 1979.

[5] A. Hofmann, Diagnostics with Synchrotron Radiation, CAS, Grenoble, CERN98-04, August, 1998.

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