STUDY OF BEAM-BASED ALIGNMENT FOR SHANGHAI SOFT X-RAY FEL FACILITY

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Abstract

In linear accelerators, dispersion and transverse wakefield from alignment errors will lead to a significant emittance growth. The performance of the Free Electron Laser (FEL) process imposes stringent demands on the transverse trajectory, dispersion and emittance of the electron beam. So finding an effective Beam-Based Alignment(BBA) procedure is crucial for the success of Shanghai X-Ray FEL facility. This paper presents the preliminary study of different BBA method performances in SXFEL Linac. In addition, a MATLAB based simulation including quadrupole misalignment, dipole field errors and beam position monitor errors have been used to predict the orbit and emittance growth along the beamline and the required corrector current. Comparison with other codes is also presented.

INTRUDUCTION

As a critical development step towards constructing a hard X-ray FEL in China, a soft X-ray FEL facility (SXFEL) was proposed and will be constructed to verify the cascaded HGHG scheme and carry out the research on key technologies for X-Ray FEL. The SXFEL facility will be working at 9 nm soft X-ray band which consists of a 130MeV photo cathode injector, a main linac accelerating the beam to an energy of 840MeV, an undulator section with two stages of HGHG scheme and a diagnostic beamline. The local energy spread is 0.1%-0.15%, the peak current is about 600A and the normalized emittance is 2 mm·mrad[1].

In FEL facilities, misalignments between Quadrupoles and Beam Position Monitors(BPM) cause an increase of the transverse beam size and emittance which turns into an increase of normalized emittance. To keep the normalized emittance due to misalignment below 2 mm·rad, the average Quad-BPM misalignment in the linac must be smaller than 100um.

The traditional optical alignment can no longer meet such strict requirements, but a lot of analytical and numerical studies have been done and proved that Beam-Based Alignment technology can simultaneously eliminate the misalignment and dispersion in linac and undulator section, which obviously will leads to a much smaller emittance growth and transverse beam size. With the method above, a software based on MATLAB has been designed and simulation results have been compared with other software.

BBA TECHNOLOGY OVERVIEW

Over past decade, a number of different realizations have been developed to measure the offset of magnetic center of quadrupole magnet[2][4]. Most techniques are based on a common approach, which is to change the quadrupole strength and measure the resulting deflection.

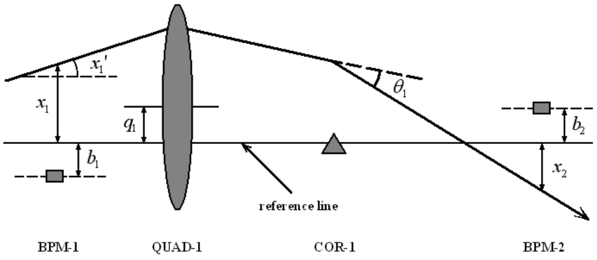

Figure 1: Common approach of BBA.

With respect to the reference line, m_i is the BPM reading at BPM-i. According to Linear optics theory (regardless wakefield effect and Quad-tilt), the transverse misalignment of upstream Quadrupole can be calculated using orbit response matrices, corrector values and inject parameters:

$$m_i = x_i - b_i = (x_i)_1 - b_i$$

$$x_i = R^{(B_1:i)} x_1 + \sum_{j}^{N_{Ci}} R^{(C_j:i)} c_j + \sum_{j}^{N_{Qi}} R^{(Q_j:i)} (I - R^{(Q_j)}) q_j \qquad (1)$$

Where b_i is BPM reading error due to off-axis between electronic center and geometric center. R is the 2×2 transport matrix form BPM-1 or corrector c_j or Q_j to BPM-i.

x_1 is initial incoming parameters, the unknown c_j the corrector strength and Q_j is Quadrupole misalignments, which are defined as:

$$x_1 = \begin{bmatrix} x_1 \\ x_1' \end{bmatrix};\ c_j = \begin{bmatrix} 0 \\ \theta_j \end{bmatrix};\ q_j = \begin{bmatrix} q_j \\ 0 \end{bmatrix} \qquad (2)$$

Further more, we can simultaneously correct both orbit and dispersion using so called "Dispersion Free Steering" method. The optimal settings are calculated using the orbit and dispersion response matrices, which are defined as the shift of the orbit or dispersion due to corrector strength change:

$$R_{i,j} = \frac{\Delta x_i}{\Delta \theta_j}\ ;\quad D_{i,j} = \frac{\Delta d_i}{\Delta \theta_j} \qquad (3)$$

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Where Δx_i and Δd_i is the change of the orbit and dispersion in the BPM-i, and $\Delta\theta_j$ is the change of the strength of corrector-j. The basic aim is to find a setting of $\Delta\theta_j$ which induces orbit and dispersion that minizes in a least squares sense the final orbit and dispersion:

$$(1-w^2)\|x_{meaus}+O\Delta\theta\|^2+w^2\|d_{meaus}+D\Delta\theta\|^2=\min \quad (4)$$

More details about the algorithm procedure and successful correction results can be found at [3].

SIMULATION ON SXFEL LINAC

Soruces of the emittance growth and misalignment in the LINAC of FEL facilities has already well-studied[2][6]. Usually it consists of field errors and stray magnet fields in the beam line as well as dispersion created upstream of the BPM, for instance, misalignment of Quadrupole, Dipole, Accelerator modules and even BPMs themselves. The Errors and launch parameters used in simulation are shown in Table 1.

Table 1: SXFEL linac Simulation Parameters

Parameter	Δx, Δy/μm（+/−）	Δθ/μrad（+/−）
DIPOLE	150	10
QUAD	150	10
ACC.MODULE	100	--
BPM	150	--
Launching error	100	150

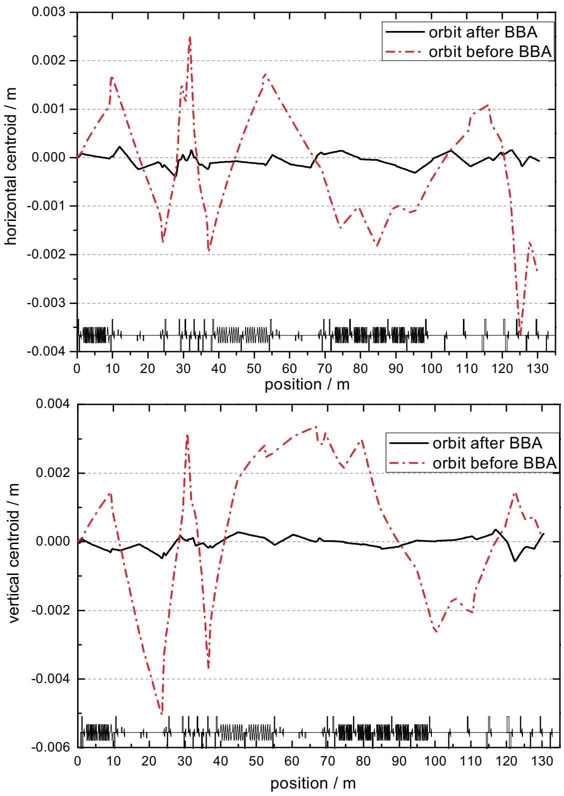

Figure 2: Comparison of orbit before and after correction.

SXFEL linac BBA simulations have been done using Elegant [7] as shown in Figure 2. After applying magnet errors and launch parameters in Table 1, we can get the correct result with Global correction method. As one can see in Figure 2, the deviation can be very large. When the electron beam travels across chicanes, the deviation will be notable increase due to the magnet effects, so these errors must be controlled in a reasonable region during BBA procedure.

In simulation results one can see that after 1st correction, the transverse orbit deviation is decline from 10^{-3}m to 10^{-4}m. Meanwhile the Smoothness of orbit and RMS orbit deviation can meet design requirement for SXFEL linac. Naturally, the impact of these errors on orbit kick and dispersion generation depend on the actual operating conditions of the accelerator, so the orbit must be measured and controlled frequently.

Further more, transverse wakefield effects caused by structure misalignment in accelerate modules is also an important factor which should be considered, as it can lead to a significant emittance growth[8]. By doing simulations, the emittance growth before and after correction are shown in Figure 3. As one can see, after BBA the final emittance growth can be controlled within 5%, and in vertical plane the correct result is much better.

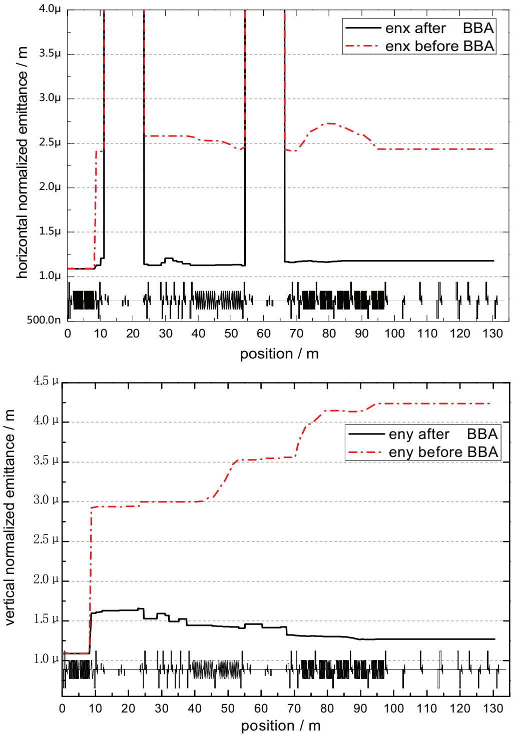

Figure 3: Comparison of emittance growth before and after correction.

CONTROL SOFTWARE DESIGN AND DEVELOPMENT

To assist the design and measurement, an automated control software based on MATLAB has been designed with interfaces to EPICS. This software aims to connecting BBA methods and bottom devices, so we can seem it as a middle level application.

After setting launch parameters and using the BBA method above, the final offset could be determined. The flow diagram of the simulation code is shown in Figure 4.

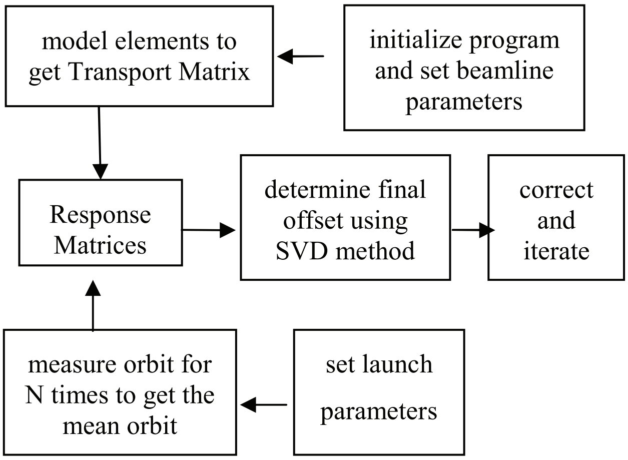

Figure 4: Flow diagram of the control program.

The response matrices are calculated from the quadrupole currents and the estimated energy along the machine. In this case, energy uncertainties such as magnets field errors and calibration errors are not take into account in this preliminary study.

After applying magnet errors and launch parameters in Table 1, we can get the correct result with Global correction method within the Matlab application. The correction results are shown in Figure 5.

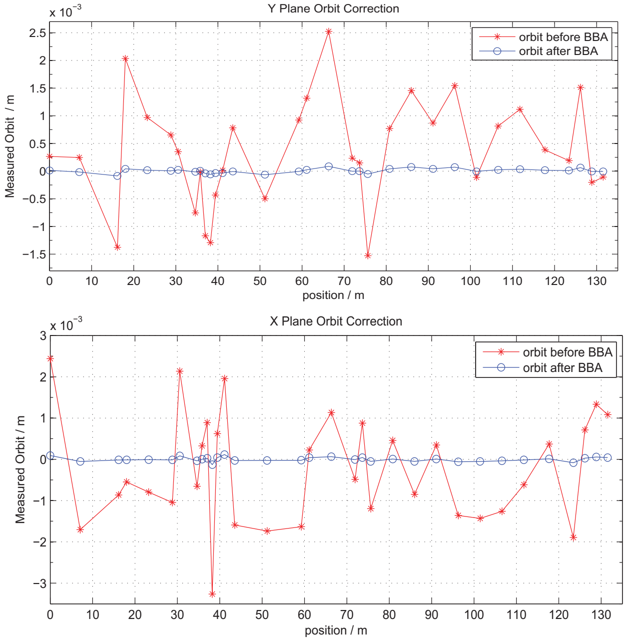

Figure 5: Simulation results from MATLAB BBA codes.

CONCLUSIONS

Preliminary design and simulations of the SXFEL Beam-based Alignment procedure have been presented in this paper, including brief introductions to main linac alignment method, beam dynamics simulations with nominal parameters, and orbit sensitivity studies. Simulations show SXFEL linac beam qualities are well within the capabilities of Beam-based Alignment technology. Further study is on the way to optimize and properly implement this technology into the SXFEL facility.

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