THE PETRA III FAST ORBIT FEEDBACK SYSTEM

J. Klute, H.T. Duhme, K. Balewski, H. Tiessen, F. Wierzcholek, DESY, Hamburg, Germany

Abstract

Orbit stability is a crucial and import issue of 3rd generation light sources. Ambient mechanical and electrical noise cause rather large orbit distortions which have to be counteracted by an orbit feedback. Extensive studies of the orbit distortions in PETRA III have shown that the frequencies of the ambient noise lie within a frequency range from about 0.01Hz to 100Hz. In this paper we describe the main components, their properties and the layout of PETRA III's orbit feedback. Furthermore experimental results on short and long term stability will be presented. It will be shown that the required orbit stability of ±0.5 µm in the vertical plane can be maintained over 50 h.

PRINCIPLE SYSTEM LAYOUT

The PETRA III instrumentation electronics is concentrated in buildings that are located around the 2.3 km wide circumference and referred to as the cardinal points. These buildings are connected with the main control building by high bandwidth optical fiber and coaxial cabling. Hence, in order to install a Fast Orbit Feedback system for PETRA, it is obvious to use a star like cabling structure, with which the position data will be sent to a central processing unit. This unit consists of a single printed circuit board carrying an FPGA that performs all real time calculations for the FOFB System. The generated digital output streams are sent back to the instrumentation buildings where they are received by digital power amplifiers that are finally feeding air coil correctors. The number of BPMs is 226 and each of them provides horizontal and vertical position data. To correct the distortion there are 40 horizontal and 40 vertical air coils. The orbit response matrix R is determined by synchronous detection of pilot signals that were previously sent to the correctors. The inverse response matrix R^{-1} is then calculated by using Singular Value Decomposition (SVD) that solves and reduces for the 80 most important and independent singular values. The “loop” is finally closed by the same amount of PI controllers.

DESCRIPTION OF THE FOFB MAIN COMPONENTS

Beam Position Monitors

PETRA III is equipped with seven different types of button monitors that are installed in various chamber profiles. Commercial RF button feedthroughs are used as pickups for the BPM blocks. Most of the buttons have a diameter of 11mm. A detailed description of the mechanical layout and output level calculations can be found in [1], [2].

Beam Position Detector Electronics

The beam position measurement is based on commercially available Libera Brilliance devices [5]. Their Ethernet link is used for slow orbit correction, the machine protection system and for diagnostic purposes. The device has extra outputs providing real-time beam position data streams that are designed to be used with Fast Orbit Feedback systems. The output stream can be configured to contain packets of position data that are synchronous to the machines revolution frequency. The bandwidth of the position signal at this point is about 39 kHz and the resolution is not worse than 50µm rms. In order to achieve the required resolution and stability, the BPM electronics is installed in air-conditioned huts that are inside the instrumentation buildings [3].

The Signal Combiner Module (SCM)

This module is an in-house developed device that allows merging of position data streams from up to 14 Libera devices into a single optical fiber that is connected to the main processing unit. A second optical fiber is used to receive machine timing signals that are the input for the Libera clock splitter modules. Because the BPM electronics is installed in a total of 24 distributed racks, the same number of signal combiners is required.

The Main Processing Unit (MPU)

is located in one of three racks that are installed near the PETRA III control room. The remaining two racks contain the optical fiber transceivers for all position signals and the optical fiber transmitters to send the output stream to the locally placed corrector drivers and finally the transceivers to control the corrector drivers remotely. The received position input streams are connected to the MPU board via standard RJ45 cables. All necessary signal processing that will be described later in this paper, is performed by a single ALTERA Stratix II FPGA. The MPU board is USB connected to its server computer that is a rack mounted PC which is linked to the PETRA III control system.

The Digital Power Amplifier (DPA)

The driver amplifier for corrector coils works as a regulated current source that is build-up with a digital controlled H-bridge that is composed of four power MOSFETs. The in-house developed device is an FPGA based circuit board that receives a serial data stream from the MPU. The digital signal processing consists of the PI current controller and a 3rd order delta sigma modulator. [4] The PI controller can be parameterized in order to operate with different correctors and chamber types. Due to the digital design of this amplifier it is very compact with low thermal power losses. The maximum output current is 20A, the frequency range is DC to 1 kHz with a resolution of 18 bit.

The Corrector Coils

Due to different chamber profiles, three types of correctors are used. All of them are air coil dipoles with 40+40 windings. The maximum deflection is about 45µrad. The transfer characteristic for magnetic fields traversing a 4 mm stainless steel chamber has a 3dB cut-off at 715 Hz. Above, the decay is -20dB/decade. Special care was taken in selecting an adequate cable between a DPA and its corrector coil. In order to minimize for crosstalk and power losses, a coaxial cable design with a 30 mm^2 conductor has been chosen.

SIGNAL PROCESSING STRUCTURE

By decomposition of the orbit response matrix: $R = U\ \Sigma\ V^T$, singular values are produced as sorted numbers on the diagonal of Σ. In order to obtain R^{-1}, the inversion of the less dominant very small singular values is critical and they should be omitted if possible.

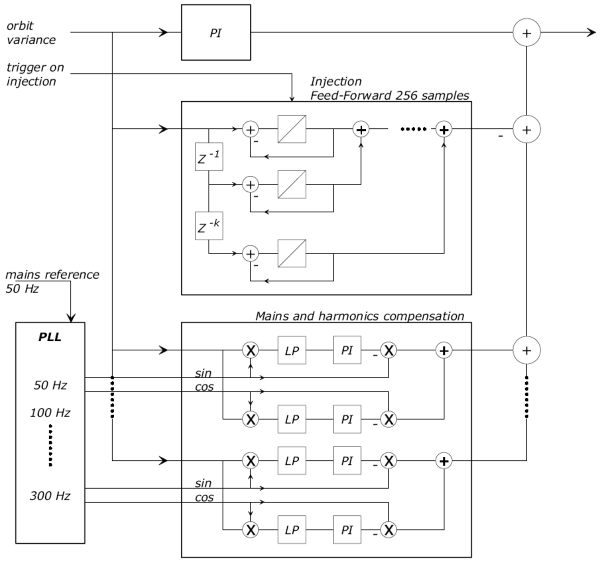

Figure 1: Signal flow for one of the 80 processing channels.

Signal processing takes place in 80 identical channels. Figure 1 shows one of them in more detail. The input stream is processed in parallel by three different functional blocks. The PI regulator at the top is used for normal feedback operation. The second block shows the implementation of a feed forward mechanism. Orbit deflections, caused by injection can be significantly reduced by learning the systems response in the time domain. Successive external injection triggers are used to enable a set of integrators to adapt to the shape of the orbit deflections. Feed forward applies the adapted and negated shape during injection. The number of integrators is 256 per channel. The last processing block describes the very important requirement of compensating orbit influences that are synchronous to mains frequency and its harmonics. For this purpose a set of mains synchronous reference frequencies are generated via PLL technique. (50, 100, 150, 250, 300, 600 Hz) Each reference is generated as a pair of orthogonal signals that are used for synchronous detection of orbit distortions. The compensation is achieved by subtraction of both detected components.

Dynamic Closed Loop Characteristics

The systems closed loop response due to beam orbit perturbations is described by the model shown in Figure 2. The transfer characteristic is defined by the four blocks stated in the backwards flowing signal path. Its propagation delay is a very harmful component, which is demonstrated in Figure 3. The two graphs are the result of an analytical calculation for different signal delays. Higher frequency orbit perturbations may be amplified, leading in degrading the systems performance. The FOFB system has a delay time of about 130 µs.

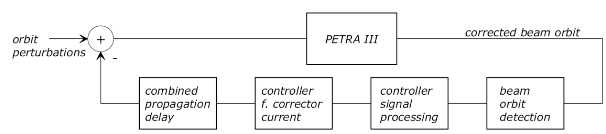

Figure 2: Model for closed loop response calculation.

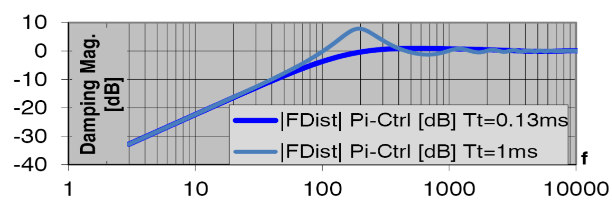

Figure 3: Analytic closed loop response, calculated for two different reaction times due to signal propagation.

THE FOFB OPERATION PERFORMANCE

A measurement of the PSD for vertical orbit distortions is shown in Figure 5. The blue graph displays the PSD when FOFB is off. A big and diffuse distributed part can be observed in the range between 3 and 10 Hz and at 30 Hz. This is consistent to measurements of quadrupole supports that have resonances in the same frequency area. The PSD also shows big components of mains frequency and its harmonics. Regarding the integrated PSD displayed below, the contribution of 50, 100 and 600 Hz takes nearly 2/3 of the total summation! The red graph shows how the FOFB reduces orbit distortions. As supposed the damping in the lower frequency region achieves 40dB. Above 200 Hz, a slight increase of distortions can be observed. The graphs of the integrated PSDs, measured when FOFB is on or off, crosses each other at 600 Hz. The value of the transverse integrated PSD, taken from 1 kHz down to 30 mHz is 4.5 times less in the vertical and 10 times less in the horizontal plane when the FOFB is running.

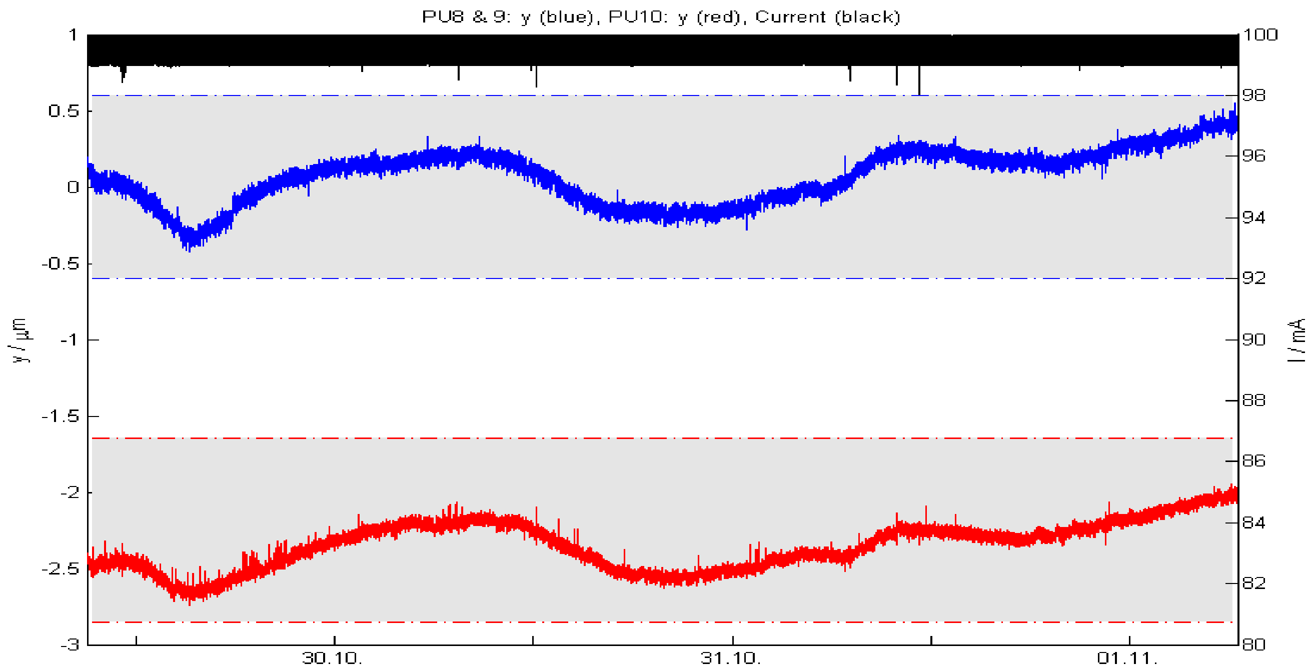

Figure 4: Vertical Long Term Stability at different undulator positions. 2010-10-29 to 2010-11-01.

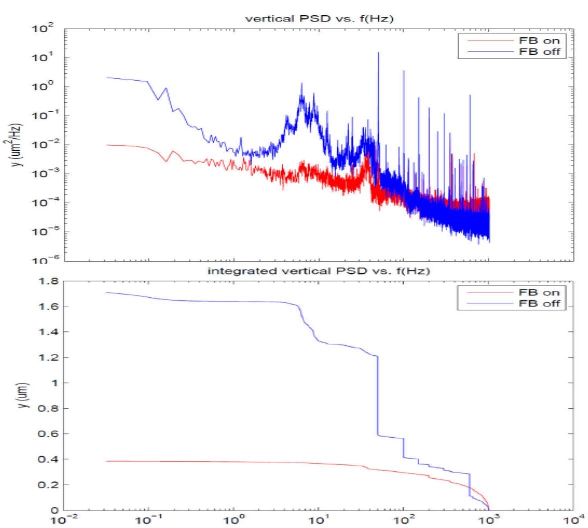

Figure 5: On top the vertical PSD, and below the SQRT of its integral, taken when FOFB is off and on.

Long Term Stability

The operating experience with the FOFB system indicates that beam orbit drifts can be compensated over more than 60 hours. The FOFB correctors are working down to DC and they are strong enough to stabilize the orbit over hours. Cumulated DC components in the air coils can be easily released by the stronger corrector magnets because these two magnet types are assembled close together. Relaxation can be done while the FOFB is running. A second method, that has also successfully tested, works by reverse calculating a virtual orbit from the FOFB air coil currents. This orbit can then be fed to the orbit correction system to compensate for DC currents in the air coil correctors. At start-up the "golden orbit" that is provided by the machines orbit correction system is passed to the FOFB as a reference. While the FOFB is running, this reference orbit can be modified for adjustment purposes. Long term stability is depicted in Figure 4. PETRA is running in top up at 100 mA. The graphs are showing the vertical orbit stability at two different IDs that can be kept within ±0.5 µm during more than 60 hours of operation.

REFERENCES

[1] K. Wittenburg et al., "The Beam Diagnostic Instrumentation Of PETRA III", BIW'08, Lake Tahoe California, MOVTC06.

[2] G. Kube and M. Werner, "Signal Level Calculation For The PETRA III Beam Position Monitor System", DIPAC'07, Venice, Italy

[3] I. Kroupchenkov et al., "Experience With The Commissioning Of The Libera Brilliance BPM Electronics At PETRA III", DIPAC'09, Basel, Switzerland, TUPD03

[4] D. Milovanovic, M. Savic, and M. Nikolic, "A Third Order Sigma-Delta Modulator", Dept. of Electron., Nis Univ., Serbia.

[5] Instrumentation Technologies, Slovenia, http://www.i-tech.si/