IMPLEMENTATION OF AN FPGA-BASED LOCAL FAST ORBIT FEEDBACK AT THE DELTA STORAGE RING

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Abstract

The beam orbit of the 1.5 GeV electron storage ring DELTA showed a variety of beam distortions with a pronounced frequency spectrum mostly caused by girder movements and ripples of the magnet power supplies. In order to enhance the orbit stability to at least 300 Hz bandwidth a global fast orbit feedback (FOFB) is under consideration. As a prototype an FPGA based local fast orbit feedback at a 10 kHz data acquisition rate has been developed. The digitized orbit data are distributed from I-Tech Libera and Bergoz MX-BPMs [1] to an FPGA board via a fibre interconnected network based on the Diamond Communication Controller [2]. The correction algorithm is written in VHDL and the corrections are applied with digital power supplies connected to the FPGA board through RS485 links. The first operational tests of the system achieved an effective damping of orbit distortions up to 350 Hz. The paper will give an overview on the layout of the FPGA-based local orbit feedback system, will report on the results of the measured uncorrected orbit distortions at DELTA and the stability enhancements that could be achieved by the local feedback system.

INTRODUCTION

The beam stability at the storage ring Delta is affected by low frequency distortions during the ramp of our booster BoDo and beam oscillations caused by mains power supplies generating distortions with the frequency of 50 Hz and its harmonics up to approx. 350 Hz. Furthermore girder movements at their resonance frequencies, excited by ground vibrations, lead to displacements of magnetic elements of the accelerator, particularly the quadrupoles and therefore detoriate the photon beam stability at the beam lines. In order to supply higher brilliance synchrotron radiation a global fast orbit feedback is under consideration in connection with the existing slow orbit feedback working at frequencies at about 0.1 Hz. For this reason a local fast orbit feedback in the vertical plane (see Fig. 1) has been developed to prove the feasibility of the planned feedback and to test designated methods and components.

LOCAL ORBIT BUMPS

The dependency between the corrector strength θ_j at the corrector j and the orbit z_i at position i can be described

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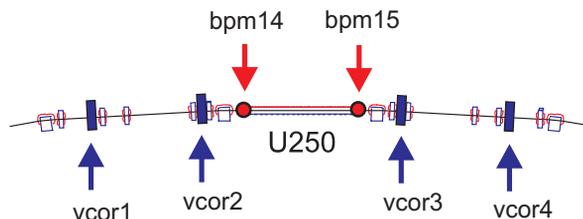* patryk.towalski@udo.edu

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Figure 1: Setup of the vertical fast local orbit feedback at DELTA consisting of an undulator (U250), two beam position monitors (BPMs) and four vertical correctors (vcor).

using the orbit response matrix $\boldsymbol{R}$:

$$R_{ij} = \frac{\partial z_i}{\partial \theta_j} \tag{1}$$

The calculation of the expected orbit $\vec{z}$ can be achieved by superposing the effects of all corrector θ_j:

$$\vec{z} = \boldsymbol{R}\,\vec{\theta}. \tag{2}$$

Using the technique of singular value decomposition (SVD) the calculation of a pseudoinverse is possible even if $\boldsymbol{R}$ is a singular matrix. The corrector strength θ_j for given orbit $\vec{z}$ is then directly derived from the pseudoinverse $\boldsymbol{R}^+$ of the response matrix $\boldsymbol{R}$ via:

$$\vec{\theta} = \boldsymbol{R}^+ \vec{z}. \tag{3}$$

The vector $\vec{z}$ represents the required orbit, the vector $\vec{\theta}$ represents the best approximation of the appropriate corrector strength to apply. Appropriate in the sense of being the best solution is achieved by the method of a least square fit. The superposition of two orbit bumps using four correctors allows for the adjustment of the orbit at bpm14 and 15. The bumps are created with the correctors vcor1 to vcor4 (see Fig. 1) mounted at appropriate positions [3].

A response matrix $\boldsymbol{R}$ for all of the 54 BPMs and four correctors was measured with beam. In a next step the pseudoinverse of $\boldsymbol{R}$ was used to calculate the corrector coefficients for the two orbit bumps using four correctors. Orbit bump induced crosstalk between bpm14 and bpm15, as well as the influence on the orbit outside the feedback section was less then 10 %, verified at 7 control BPMs.

ORBIT DISTORTIONS

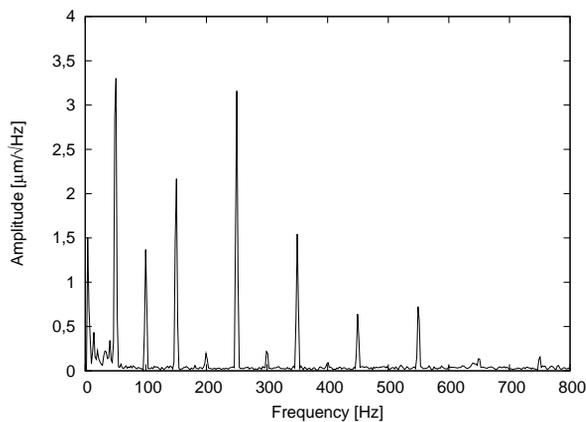To identify the typical orbit distortions, a frequency spectrum was created from decimated turn-by-turn data

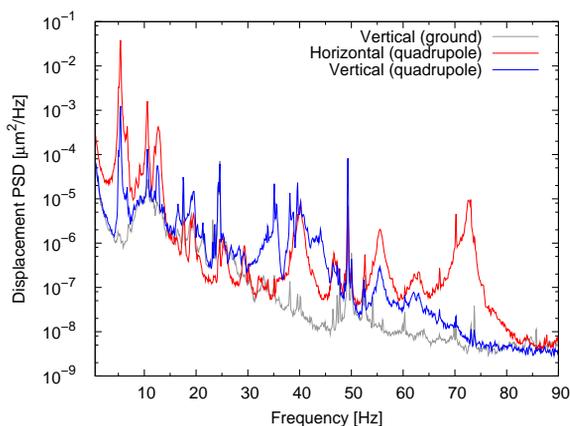Figure 2: Spectral rms orbit deviation versus frequency.

Figure 3: Displacement PSD horizontal and vertical on a quadrupol and vertical on the ground.

taken by an I-Tech Libera electronic [4] installed at bpm14. The experimental results are shown in Fig. 2. Apart from distinctive distortions at 50 Hz and its harmonics, caused by the mains power supplies, low frequency perturbations in the range of 5 Hz have been observed.

Girder oscillation has been measured using geophones [5] during regular beam operation to identify the source of these low frequencies. One geophone capable to measure in three dimensions was attached to a quadrupole, a second one (measuring in one dimension) was mountend vertically on the floor. The geophones create a voltage proportional to the speed of their movement. This voltage was amplified and then recorded using a "LeCroy WaveSurfe 454" oscilloscope at a sampling frequency of 500 Hz.

MATLAB [6] was used to calculate the spectral power density (PSD), to apply a Hamming window function and to convert the velocity data to real displacement. Figure 3 shows the experimental results. Excitation frequencies of 5.3 Hz, 10.6 Hz and 12.5 Hz are caused by girder resonances. These oscillations lead to a time dependent transverse misalignment of the quadrupoles [7], influencing the orbit.
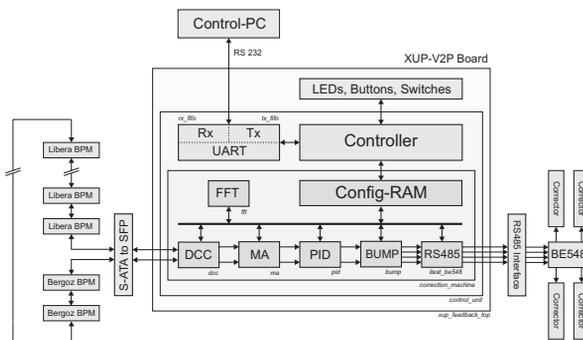
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Figure 4: Block diagramm of the correction system of the local fast orbit feedback implemented in VHDL.

IMPLEMENTATION OF THE LOCAL FAST ORBIT FEEDBACK SYSTEM

The fast local orbit correction has been implemented as a classic control loop. Each element of the loop can influence the control dynamics by delay or bandwidth.

The orbit position has been measured at bpm14 and 15 with I-Tech Libera Electron [4] BPMs, equipped with the Diamond Communication Controller allowing to distribute the fast orbit position data over a glas-fibre network at a rate of 10 kHz.[1] The BPMs digital filters have a latency time of about 300 μs at a bandwidth of 2 kHz.

The data processing takes place on the Xilinx XUP-Virtex-II Pro Development Board [8], available through the Xilinx University Program. It is, similar to the I-Tech Liberas, equipped with a Virtex-II Pro FPGA. The correction system was implemented using the hardware description language VHDL. It is controllable using a connected standard-PC. The data processing is done in modules, which can be seen in Fig. 4.

The position data sent to the network from bpm14 and bpm15 (see Fig. 1) is received from the Diamond Communication Controller [DCC in Figure 4] in a first step. During a settable time window (60 μs in our case) received position data is passed to a moving average filter/low pass filter [MA]. In this way the dc-part and therefore the interference with the existing slow orbit correction is eliminated. Calculation of the correction values is done by a standard proportional, integral and derivative controller [PID]. The D-fraction is set to zero to minimize the influence of data noise. In a next step the desired orbit is converted into corrector currents using equation (3) to create a superposition of the two four corrector bumps [BUMP]. The new desired current values are converted into a serial data stream [RS485] and are distributed via the RS485 interface to the corrector magnet power supplies. The time for correction calculation on the board is approximately 0.2 μs and therefore negligible.

The power supplies BE548 from the company iTest are

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[1]Future plans include the connection of existing analog Bergoz BPMs into the fast orbit posititon data network. For reference please see G. Schuenemann [1].
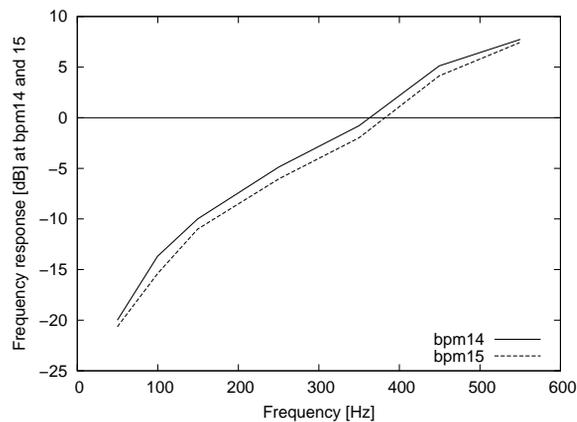
Figure 5: Frequency response at bpm14 and 15.

Figure 6: Integrated rms ampl. with feedback on and off.

used as four-quadrant power supplies (±24 V, ±10 A). They are connected to the four corrector magnets vcor1 to vcor4 (see Fig. 1 and 4). The minimum time delay after reception of new desired values is 40 µs. The additional delay to reach steady state depends on the desired current variation and the coils inductance. In our case 5 A can be applied in approx. 220 µs. This corresponds to a slew rate of 20833 kA/s.

The magnetic field of the corrector magnets varying in time induces eddy currents in the vacuum chamber. The frequency response was measured using an inductance coil inside the chamber. The vacuum chamber cut-off frequency (-3 dB) was estimated to 1.7 kHz.

The minimum latency for the control loop is about 400 µs resulting in a controller resonance frequency of about 1.25 kHz. Assuming oscillations with a current change of 5 A the total delay increases to 620 µs causing a shift of the resonance frequency of the control loop to 800 Hz.

Increasing this resonance frequency and thereby increasing the attainable cut-off frequency is in principle possible by further reducing the delay.

RESULTS

The frequency response being the ratio of distortion amplitudes with and without orbit feedback was measured with beam at bpm14 and 15. The experimental results are shown in Fig. 5. The amplitude ratios have been determined at strong distortion frequencies only, intermediate values have been interpolated linearly. The cut-off frequency at bpm14 turned out to be 355 Hz, bpm15 has a cut-off frequency of 370 Hz. A total damping of -20 dB at a frequency of 50 Hz has been obtained with the controller.

Figure 6 shows the integrated rms amplitude with and without orbit feedback obtained at bpm14 (averaging over multiple spectra). Due to strong intensity fluctuation of the girder movements in the lower frequency range the integrated rms amplitude would be spoiled by this random ef-
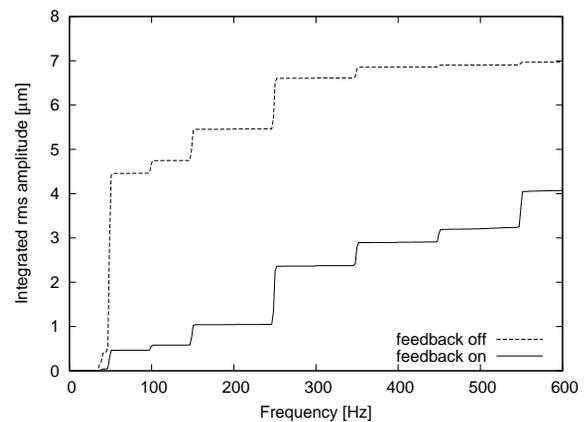
fect. To avoid this, frequencies below 40 Hz were removed from the spectrum.

In summary a substantial overall reduction of the orbit distortions below 350 Hz has been achieved in a first approach. Based on this results a future global orbit feedback will be designed and installed at the DELTA storage ring in the near future.

ACKNOWLEDGMENTS

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