

# GLOBAL ORBIT FEEDBACK SYSTEM FOR THE SLS STORAGE RING

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## Abstract

Experiments at the SLS (Swiss Light Source) require a highly stabilized photon beam spot with high brilliance. In order to achieve this goal orbit oscillations due to ground motion amplified by girder resonances have to be reduced. The beam motion has to be kept below  $1 \mu\text{m}$  at the insertion devices. A fast closed orbit feedback will be implemented to suppress these oscillations over a frequency range of up to 100 Hz. Digital signal processors will read the digitized beam positions and apply the data to a feedback algorithm using Singular Value Decomposition (SVD) and PID controller algorithms. The computing power of the global orbit feedback system is distributed around the storage ring and therefore requires data exchange of beam positions from one sector to another with high speed. Theoretical studies on the feedback loop have shown that a sampling rate of 4 kS/sec is needed. The proposed layout of the global orbit feedback system will be presented.

## 1 INTRODUCTION

The SLS (Swiss Light Source) is a third generation light source designed to deliver high brilliance synchrotron radiation. To achieve this challenging goal the orbit of the electron beam has to be stabilized to a tenth of the beam sigma at the locations of the insertion devices which corresponds to  $1 \mu\text{m}$  tolerance in the vertical plane [1]. The orbit stability is determined by the ground motion spectrum, mechanical vibrations caused by the accelerator environment (traffic, machinery, pumps etc.), by the girder response to those excitations and by the orbit response. Measurements of the ground motion spectrum at the location of SLS have shown that the seismic activities are well below 100 Hz and 100 nm amplitude [2]. Simulations have been carried out that those excitations lead to orbit oscillations up to  $15 \mu\text{m}$  (rms) in the vertical plane at the location of the experiments [3]. In order to reach the demanded orbit stabilization high requirements are imposed to several subsystems. Firstly, the beam positioning system has to provide sub-micron position data. Secondly, the tolerable granularity of the corrector power supplies with a maximum kick of 1 mrad has to be better than 15 ppm in amplitude and thirdly, the feedback system has to suppress beam oscillations with at least -20 dB up to frequencies of 90 Hz. The concept for the SLS orbit feedback system is outlined in this paper. The digital BPM system is described in [4]. The theoretical basis of orbit corrections has to be discussed briefly since it has a direct consequence on the implementation of the feedback

layout. The integration of this sub-control system in the overall accelerator control system (EPICS) is presented as well.

## 2 FAST ORBIT FEEDBACK

Based on a lattice inherent well known correlation between beam position monitors and correctors (orbit response matrix), the new settings of the corrector magnets can be calculated on-line by fast processors. Two different approaches to reduce the beam oscillations at the insertion devices exist:

- individual feedback systems at each insertion devices minimize the orbit variations locally.
- a global feedback system minimizes the beam oscillations at all experiments simultaneously.

The drawback of the first approach is that a possible crosstalk between the individual feedback systems could lead to a situation where the orbit is difficult to control. Therefore, a global orbit feedback system has been chosen for the SLS storage ring.

### 2.1 Theoretical Concepts

A total number of 72 beam position monitors (BPM) and 72 corrector magnets per plane will be installed in the SLS storage ring. Correctors for  $(x, y)$  will be placed at the same location as the BPM. The storage ring is divided into 12 identical sectors resulting in 6 correctors for each plane and 6 BPM per sector. The layout of one sector is shown in Fig. 1. In the following, only one plane is described. Based on

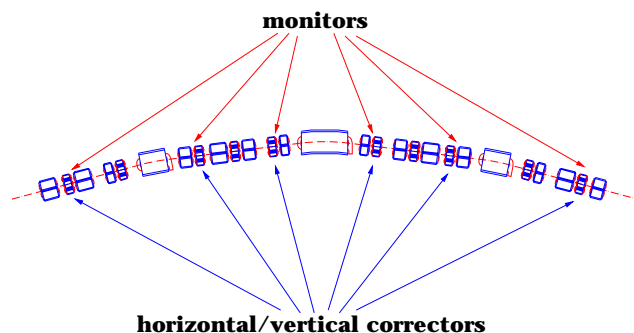


Figure 1: Layout of one of the twelve sectors of the SLS storage ring. Correctors for each plane and beam position monitors are installed at the same location.

a linear optics model for the machine or on real measurements, a correlation matrix  $\mathbf{A}$  (orbit response matrix) can be defined which maps the corrector magnet settings on the beam position monitor readings. For implementation of a feedback algorithm the monitor readings  $\Delta b$  have to be multiplied by the inverse correlation matrix  $\mathbf{A}^{-1}$  in order to get the corresponding corrector settings  $\Delta\theta$ .

$$\Delta\theta = \mathbf{A}^{-1} \cdot \Delta b$$

The Singular Value Decomposition algorithm (SVD) is used to invert the  $72 \times 72$  correlation matrix  $\mathbf{A}$ . The result is a matrix where only the diagonal and their adjacent coefficients have significant values. The structure of  $\mathbf{A}^{-1}$  is visualized in Fig. 2a where it is divided into 12 blocks to represent the 12 sectors. Details can be found in [1]. The

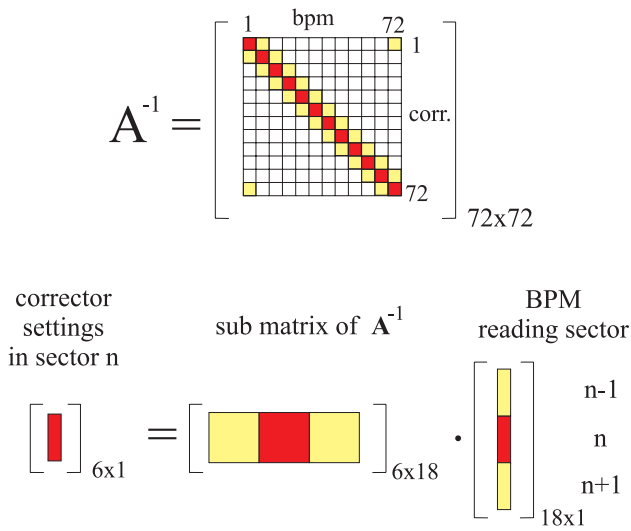


Figure 2: Schematic of the inverse correlation matrix which maps the beam position monitor readings onto the corrector settings.

shape of this inverse matrix has a strong influence on the layout of the global orbit feedback system. In order to set the correctors in sector  $n$ , beam position monitor readings from sector  $n-1$  to  $n+1$  are required. Although the scheme is global, it should be stressed that only information from the sector itself and from the two adjacent sectors are necessary. If beam position monitors fail or the numbers of correctors are reduced more and more coefficients in the inverse matrix are different from zero. Therefore, BPM readings from four or more adjacent sectors are required. In any case, the  $72 \times 72$  dimensional matrix multiplication reduces to localized sub-matrix multiplications (Fig. 2b). The new corrector settings are the input to a PID feedback algorithm. Simulations have shown that the global orbit feedback has to operate at a sampling rate of 4 kS/sec in order to get the required noise suppression of -20 dB within the bandwidth up to 100 Hz.

## 2.2 Implementation

Based on the specialized shape of the inverse correlation matrix and the moderate update rate it is favorable to spread the computing power which is needed to calculate the corrections. A dedicated processor, called "SVD engine", applies the SVD algorithm to the correlation matrix  $\mathbf{A}$ . This calculation has to be carried out only if the monitor-corrector set changes or the correlation matrix is updated. Fast digital signal processor stations will be installed in each sector around the storage ring. They take over the frequent on-line matrix multiplications at a rate of 4 kHz. The global orbit feedback system is integrated in the digital beam position monitoring system which already uses digital signal processors to calculate the  $x$  and  $y$  position from the four digitized BPM pick-up signals VA,...VD. The WS2162 DSP board (Wiese Signalverarbeitung) with two SHARC 21062 processors and 2 MB on-board shared S-RAM has been chosen to perform this task. All software is written in assembler in order to minimize the time delay in the feedback loop. The layout of the board together with the whole chain of data processing is shown in Fig. 3. All SHARC memory of both DSPs and the on-board S-RAM is fully memory mapped on the VME bus. For details about the RF front end and digital down converters (DDC) see [4]. The data from the 6 DDC boards are passed in parallel to the DSP board via separate SHARC links operating at 40 MB/sec. One DSP is dedicated to calculate the beam positions of 6 BPMs based on the raw signals VA, ... VD. It applies scaling and offset corrections to the beam position data. The whole  $(x,y)$  block is transferred to the second on-board DSP through the on-board SHARC multiprocessor bus and in parallel to the on-board SRAM memory. The DSP 2 transmits the beam positions of its own sector to the adjacent sectors and receives the beam positions from those by starting a DMA process. For this purpose two bi-directional fiber optic piggy packs WS9003 (Wiese Signalverarbeitung) are plugged onto the DSP main board and use four SHARC link ports. Two fiber optic cables (transmit and receive) to the DSP stations in the next sectors connect the distributed digital signal processors forming a separate ring network. The fiber optic links operate at full link port speed which is at 40 MB/sec. The block transmission of 48 Bytes ( $6 \times 32$  bit  $x$  and  $6 \times 32$  bit  $y$  position data) to the adjacent sectors is therefore less than 2  $\mu$ s since uni-directional point-to-point transmission is used which avoids packing overhead and data collisions. All twelve DSPs around the ring transmit and receive the beam position data simultaneously by using the SHARC's separate DMA channels. Four microseconds after starting the DMA process the  $x,y$  data of 18 BPM stations are in the internal memory of DSP 2 which can start the sub-matrix multiplication shown in Fig. 2b. In case that position information from the four adjacent sectors is required the DSP can pass the received BPM data to the next sector by the same DMA mechanism. The calculated corrector magnet changes  $\Delta\theta$  are fed into a PID feedback algorithm. The new

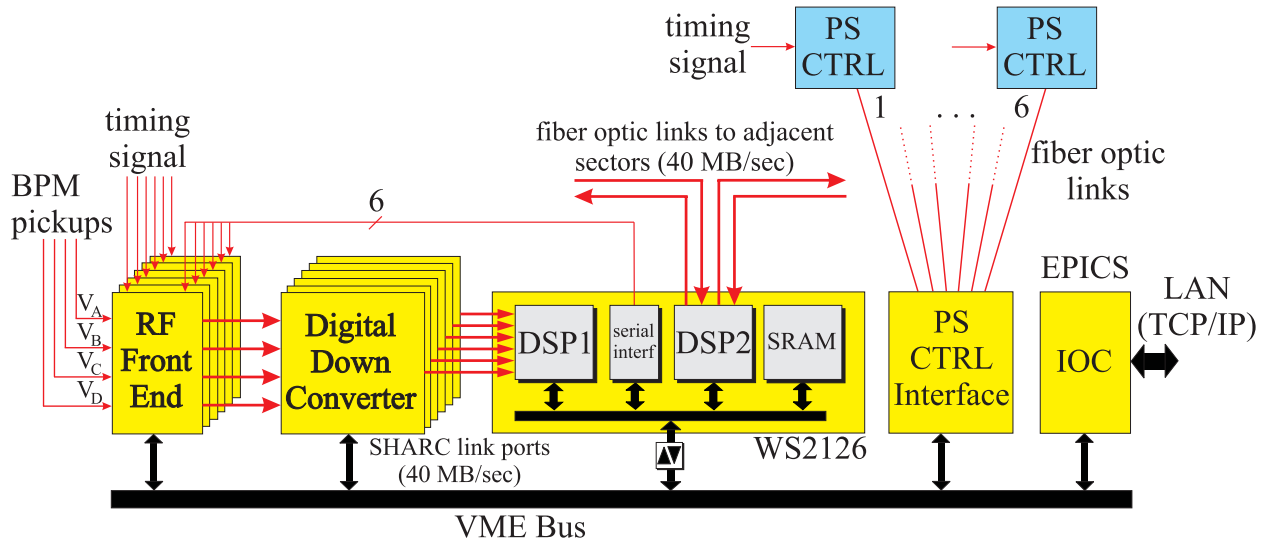


Figure 3: Hardware layout of the beam position monitoring and global orbit feedback system in one sector of the SLS storage ring.

magnet settings are written to registers of the power supply interface card via VME bus. It is a VME carrier board with three in-house developed industry packs. Each module serializes the data and transmit it to two digital power supply controllers over 5 MHz fiber optic links [5]. Additional to the beam position calculation, the DSP 1 hosts a second feedback system which is the RF gain control of the RF front end. After passing the  $x, y$  positions to DSP2 it tunes the digital down converter to the pilot signal [4] via VME bus and sets the gains of the RF front ends. Those new settings are transmitted over another in-house developed serial piggy pack interface which is plugged onto the DSP board and can be accessed through the SHARC multiprocessor bus. The gain control is on a time scale of seconds and is therefore not time critical. In order to avoid wait states in the global orbit feedback processing DSP 1 must not access the VME bus and SHARC multiprocessor bus before DSP 2 has transmitted the corrector magnet settings to the power supply controller interface. Therefore, attention has to be paid to the internal timing of the DSPs. The overall timing of the processing chain is controlled by the SLS timing system. It applies a timing signal to the DDC and to the digital power supply controller. The DSPs generate an interrupt whenever data is written to the link ports. The new corrector settings are transferred to the power supply controllers where a second delayed trigger signal indicates the validity of the data. By that mechanism, synchronization of the applied corrector settings is guaranteed. The global orbit feedback system is integrated in the EPICS control system. A PowerPC Input Output Controller (IOC, Motorola MV2306) running vxWorks 5.3 provides the interface to the EPICS local area network. All parameters like scaling factors, offset corrections, inverse sub-matrix coefficients as well as the raw button values and beam positions are accessible through EPICS. Therefore, a separate

position monitoring system (POMS, [4]) which detects mechanical drifts of the individual BPM stations can easily update the offset corrections by making an EPICS channel access (CA). The SVD engine also distributes and downloads the necessary sub-matrix coefficients to the individual DSP stations through CA.

### 3 CONCLUSION

The global orbit feedback system for the SLS storage ring is an integral part of the digital BPM electronics. The shape of the inverse correlation matrix which maps the beam position monitor readings on the corrector magnet settings allows a decentralized structure of the computing power. A dedicated bi-directional point-to-point fiber optic network around the storage ring provides fast information exchange only where it is necessary. This reduces the time delay in the feedback loop but provides enough flexibility to increase the distribution of beam positions if necessary.

### 4 REFERENCES

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