A DSP-BASED FAST ORBIT FEEDBACK SYSTEM FOR THE SYNCHROTRON LIGHT SOURCE DELTA

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Abstract

A DSP-based Fast Orbit Feedback (FOFB) system has been designed for the synchrotron light facility DELTA. DELTA consists of a 60 MeV linac, the ramped storage ring BoDo as full-energy injector and the 1.5 GeV storage ring Delta. BoDo and Delta have the same dipole, quadrupole and corrector magnet design, the same beam pipe design and the same BPM RF front-ends, therefore BoDo was used as a testbed for the newly developed FOFB hardware and software. Using the fast corrector magnet power supplies of BoDo, the FOFB could damp orbit perturbations up to 90 Hz. The envisaged future use of the FOFB for the Delta storage ring will require either the partial or full replacement of the present slow (1 Hz bandwidth) Delta corrector power supplies, or additional fast power supplies with dedicated FOFB corrector magnets. A first test of the FOFB in Delta for local orbit stabilisation at one beamline is in preparation. This paper presents the results of a successful test of the FOFB at BoDo, where it achieves a correction rate of 4 kHz for a global SVD-based feedback in both planes. The FOFB is based on the ”DeltaDSP” VMEbus DSP boards that are also used for the BoDo betatron tune feedback [1].

INTRODUCTION

In 2001/2002 a large part of the control system hardware of BoDo as well the beam diagnostics hardware for betatron tune and orbit measurements were replaced by a newly developed DSP-based system [2]. Motivations for this upgrade were the improvement of the overall reliability and performance of the injector in order to reduce storage ring filling times in excess of one hour, the simplification of operation and tuning of BoDo for the operators, but also the use of BoDo as a testbed for a future fast global orbit feedback in the storage ring.

The core of the new booster hardware consists of VMEbus DSP boards (“DeltaDSP”, see Figure1) with a generic architecture that was designed for a variety of different beam diagnostics and control tasks such as control of the ramped BoDo power supplies, beam loss measurement, fast global orbit feedback and tune measurement and feedback [3]. All BoDo DSP boards are connected in a ring-like structure by fibre-optics cables that use DeltaNet, a real-time network which was implemented in an FPGA (field programmable gate array) and which reflects a part of the internal memory of an ADSP-21062 “Sharc” DSP on each board periodically to the internal memories of the DSPs on all other boards with 160 MBaud and typical periods of some 10 μs. DeltaNet also distributes trigger signals and synchronises the board clocks of all DSP boards with less than 10 ns jitter, which provides global accelerator-wide synchronisation of monitor readings and magnet current changes. This architecture is ideally suited for a fast global orbit feedback with correction rates of several kHz. Since the corrector magnet power supplies of the storage ring have slow serial RS232 interfaces and a bandwidth in the order of 1 Hz, the use of the DeltaDSP boards for a fast orbit feedback was tested at the booster that has fast corrector magnet power supplies with a bandwidth in the kHz range. Booster and storage ring use the same corrector magnet design, same beam pipe design and the same Bergoz-type BPM RF front-ends, therefore a booster orbit feedback may be copied for the storage ring with little modifications. Furthermore, the booster was available for tests of feedback hardware and software during user operation of the storage ring except for refills of the ring a few times per day. This allowed faster development and tests of feedback software and hardware compared to feedback tests at the storage ring that would have required dedicated machine development shifts.

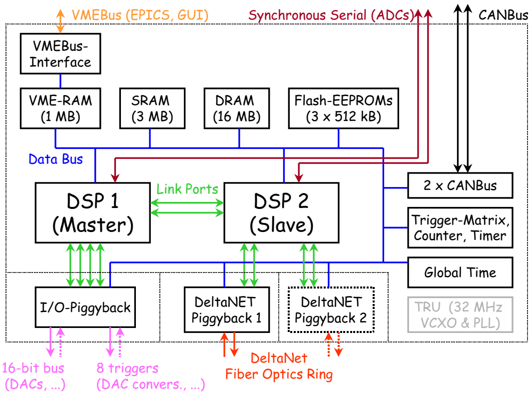

Figure 1: Architecture of the DeltaDSP VMEbus board.

FEEDBACK ARCHITECTURE

Beam Response Matrix

Figure 2 shows the layout of the booster with its 14 BPMs, 12 horizontal (“HK”) and 12 vertical (“VK”) corrector magnets coils that are integrated into the quadrupole magnets of the FODO lattice. During the feedback tests

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only 15 corrector power supplies were available for budget reasons, therefore all 12 HKs but only 3 VKs were available, and bandwidth tests were only made for the horizontal plane. However, it should be noted that the feedback software was designed for 12 correctors per plane with the possibility to disable unavailable correctors using a GUI. The latency of the feedback loop does not depend on the number of disabled correctors.

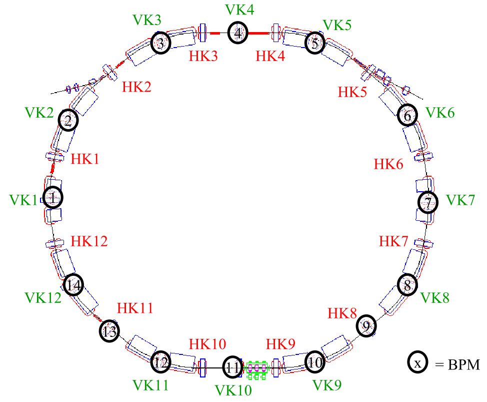

Figure 2: Locations of BPMs, horizontal (“HK”) and vertical (“VK”) corrector magnets in BoDo.

The BoDo orbit feedback uses the SVD (singular value decomposition) method. Figure 3 shows the theoretical beam response matrices and the SVD-inverted matrices for the case where all correctors and all BPMs are used. 12 of the 14 BPMs are located in vertically focussing quadrupole magnets (“QDs”) and only BPM9 and BPM13 in horizontally focussing quadrupoles (“QFs”). Therefore the horizontal SVD-inverse is not well-conditioned, and a non-zero cutoff value was used to remove the smallest eigenvalues and to guarantee robust feedback performance. A Tcl/Tk GUI allows to adjust the theoretical quadrupole focussing strengths for the optics model and to choose the SVD cutoff values. By pressing a button, the resulting beam optics, response matrices, eigenvalues and SVD inverse are calculated and displayed as 2D or 3D-plots. The SVD inverse is then downloaded to the DSP boards using data files that are also loaded after reboots of the VME crates.

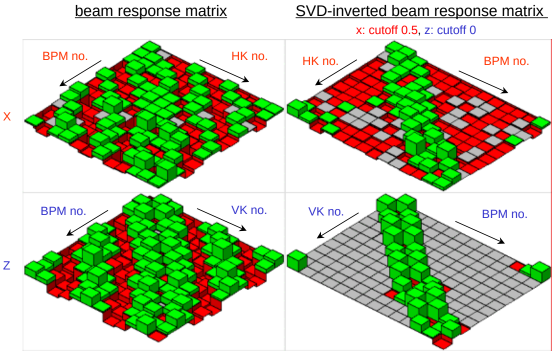

Figure 3: BoDo beam response matrices, calculated from an optics model, and SVD-inverted matrices for horizontal (x) and vertical (z) plane, with a non-zero eigenvalue cutoff for the horizontal plane.

Hardware Architecture

The data flow of the BoDo orbit feedback loop is shown in Figure 4. External ADC boards for the 14 BPMs are connected to the “bo-steerer” DSP board in a daisy-chained fashion using two 10 MBaud serial buses with 7 ADCs per bus. It should be noted that BPM ADCs as well as the DACs for the correctors can be connected to all DSP boards in any order, since DeltaNet distributes all BPM data globally to all DeltaDSP boards in the network. Two DSP boards of BoDo control analog corrector magnet power supplies using external DAC boards that have direct fast (16 MByte/s) interfaces to the DSPs. These DSP boards use the respective rows of the SVD-inverse and one PID controller per corrector to calculate the corrector magnet currents. Orbit corrections are performed at a rate of 4 kHz. ADC conversion triggers and corrector current changes are synchronised via DeltaNet, with less than 10 ns jitter between two DeltaDSP boards while the feedback is running.

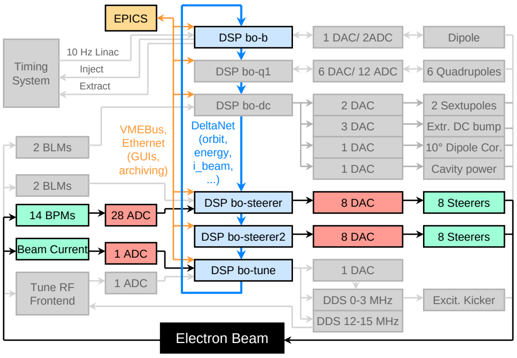

Figure 4: Structure and data flow of the global BoDo orbit feedback system. Shaded dark boxes represent hardware and devices that are not used for the orbit feedback, e.g. components of tune feedback system.

MEASUREMENTS

Figure 5 shows the horizontal orbit of BoDo during a ramp from 60 to 1500 MeV with the orbit feedback switched off (thin lines), and with the feedback switched on some 100 ms after injection (thick lines). The feedback reduces the orbit perturbations significantly. The orbit cannot be corrected perfectly because there are more BPMs than correctors. BoDo and Delta are connected to the same RF generator, and its frequency is optimised for an ideal Delta orbit. The positive offset of all BPMs in Figure5 shows that the booster circumference is too small for this frequency, which forces the beam onto a dispersion orbit. The slight deterioration of the orbit after t=6.25s is caused by an extraction orbit bump that uses dedicated coils in dipole magnets. This bump was not switched off during the feedback tests.

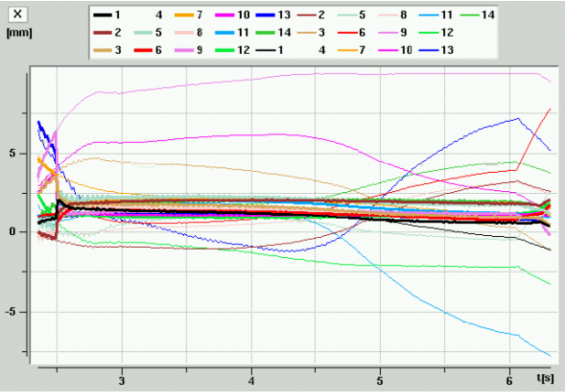

Figure 5: Plot of the horizontal BoDo orbit in [mm] as a function of time at the 14 BPMs during a booster ramp from 60 MeV (t=2.1 s) to 1500 MeV (t=6.45s), without orbit feedback (thin lines) and with the feedback switched on at t=2.5 s (thick lines).

Frequency Response

Figure 6 shows the amplitudes of a horizontal orbit perturbation generated by a corrector that was not used by the feedback, with feedback on and off. The PID controller gains that were used for the test resulted in damping of orbit oscillations up to 90 Hz, with moderate orbit excitations above this frequency. The feedback achieves damping factors of 16 for 10 Hz and 2.5 for 50 Hz orbit perturbations.

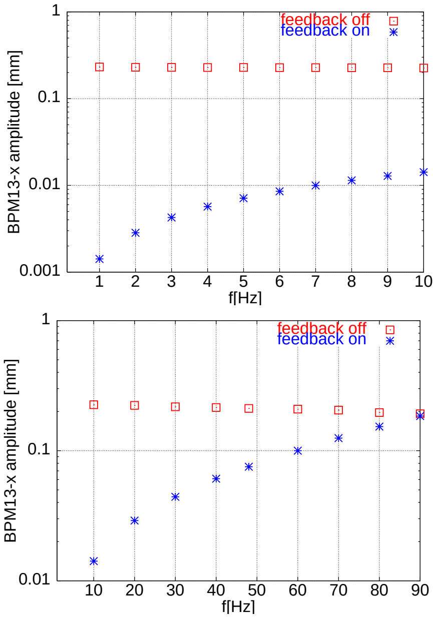

Figure 6: FFT amplitudes of horizontal orbit perturbations at BPM13, with orbit feedback switched on and with orbit feedback switched off. The orbit perturbations were generated by current modulation of a corrector that was not used for the feedback, with modulation frequencies between 1 and 10 Hz (upper plot) and between 10 and 90 Hz (lower plot).

CONCLUSIONS AND PERSPECTIVES

A fast global orbit feedback was designed and successfully tested at the booster synchrotron BoDo, where it corrects the orbit during energy ramps at a rate of 4 kHz. The feedback can damp orbit perturbations of up to 90 Hz in the horizontal plane. Due to its generic hardware and software architecture and the similarity of booster and storage ring, the feedback hardware and software can be used for a global orbit feedback in the storage ring with little modifications. While the booster DSP software is not optimised for fast orbit correction and has a latency of about 510 μs from ADC conversion until corrector magnet DAC update (using pipelined operations that require two 4 kHz cycles), the estimated delays in Table 1 show that optimised software may achieve a latency of less than 200 μs and thus correction rates of 4-5 kHz for a global feedback in the storage ring consisting of 8 DSP boards, 64 BPMs, 32 vertical and 32 horizontal correctors. The reduced latency should allow the damping of orbit perturbations significantly above 100 Hz, especially when dedicated corrector magnets are used. First tests with a fast feedback at one storage ring beamline have already been performed successfully [4].

Table 1: Estimated worst-case delays in the digital processing chain for a future fast global SVD orbit feedback at Delta that consists of 8 DeltaDSP boards, 64 BPMs, and 32 correctors per plane.

Delay[μs]	**Task**
25	BPM ADC conversion and readout
8	Copy BPM data to DeltaNet Tx buffer
38	Wait for access to DeltaNet
4	Send package onto fibre optics
13	BPM data received by all DSP boards
70	Calculate and set new DAC values
6	DAC settling time
164	**Overall delay from ADCs to DACs**

REFERENCES

[1] B. Keil et al., “The DSP-based Betatron Tune Feedback of the Ramped 1.5 GeV Electron Storage Ring BoDo”, EPAC04, Lucerne, July 2004.

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[4] N. Zebralla, diploma thesis, University of Dortmund, Physics Department, 2004, to be published.