FPGA BASED FAST ORBIT FEEDBACK DATA ACQUISITION SYSTEM FOR ELECTRON AND HADRON STORAGE RINGS*

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Abstract

This paper presents a Field Programmable Gateway Array (FPGA) based, BMBF supported, development of a fast orbit feedback system for electron and hadron storage rings, in prospect of the upcoming Facility for Antiproton and Ion Research (FAIR) facility in Darmstadt. A short introduction into orbit correction is given, the developed feedback and data acquisition systems are presented and first results of in-situ measurements at electron and hadron accelerators are discussed.

INTRODUCTION

The requirement of a stabilized electron beam at DELTA storage ring led to the development of a Field Programmable Gateway Array (FPGA) based prototype local fast orbit feedback system in 2009, showing promising results [1]. To further develop this system, as well as to make it applicable to hadron machines, a BMBF funded collaboration between the Forschungszentrum Jülich (FZJ), the GSI Helmholtzzentrum für Schwerionenforschung GmbH (GSI) and Centre for synchrotron radiation of the TU-Dortmund (DELTA) was created. In case of the upcoming FAIR project an orbit feedback is one of the required components to reach the set beam stability goals. The Forschungszentrum Jülich (FZJ) is contributing the FAIRs High Energy Storage Ring (HESR). The HESR is going to contain an electron cooler, the cooling efficiency is proportional to the beams positional stability [2]. The FZJs operated synchrotron type hadron accelerator COSY, also containing and electron cooler, is utilized in this case for testing and measurements. One contribution of GSI to the FAIR project is the SIS18 synchrotron type accelerator. It will be used for as a booster for the upcoming SIS100 and SIS300 storage rings. In this case increased beam stability is expected to enhance reproducibility and booster performance.

FAST ORBIT FEEDBACK CONCEPTS

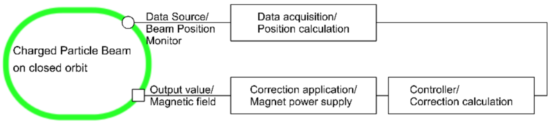

Figure 1: Orbit feedback control loop.

A fast orbit feedback is a control loop consisting of the beam position as input, a controller and a magnet field as output (see Fig. 1). Based on the accelerators magnetic lattice the correlation between beam position difference (Δb at the locations of Beam Position Monitors (BPM)) and magnetic corrector strength difference $\Delta\theta$ is well known. It is contained in the so called orbit response matrix A. By inverting this matrix (A^{-1}), in case of non square matrices via Singular Value Decomposition (SVD), a new magnetic configuration can be calculated for a set orbit:

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

For further discussion of this topic please see [3]. One advantage of this approach is its scalability. This means an arbitrary number of corrector values can also be calculated separately. A requirement of this approach is the availability of the complete Beam Position Monitor (BPM) data for calculation. As result a central control loop can be split into synchronized, distributed corrector stations. As stated, each corrector station requires an exchange of the recorded beam position, in this case via dedicated data network (see Fig. 2). This scalable implementation reduces single point data amount at the cost of the data and synchronisation network required.

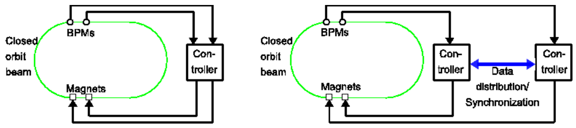

Figure 2: Central and distributed control loop.

Data Distribution

As interconnecting network layer a Small Form-factor Pluggable (SFP), glasfibre based custom network protocol, the Diamond Communication Controller (DCC) [4], was chosen. The protocol was developed at the Diamond Light Source for the Diamond, Libera based, fast orbit feedback. Hence it features accelerator feedback favourable properties: SFP is an industry standard for fast data connections. Connectors to many different standards are available. Due to its electromagnetic immunity, glasfibre as cable material was chosen. The protocol itself builds an expandable point-to-point network. The network flexibility gained thereby is

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of advantage in the case of DELTA, as the structure and/or hardware changes due to upgrades. Data distribution is split into synchronised time frames in which the position data is stationwise exchanged. Each station forwards, not yet received, position data to the connected stations until a complete distribution of the position data is accomplished.

FEEDBACK STRUCTURE

Based on each accelerators properties, a total of three feedback designs were developed:

DELTA Feedback Structure

The planned DELTA feedback structure is a mapping of the distributed structure (see Fig. 3). It was chosen for numerous technical and structural reasons, the main being the 3 different type commercial BPMs at the DELTA storage ring (analog Bergoz MX [6], digital Libera Electron and follow-up model Libera Brilliance [7]) which had to be integrated into the feedback loop. This is accomplished by integrating the required data network components on both the Libera electronics and the custom made controllers called the Extender 3000 (to which the Bergoz MX-BPMs are attached). The data is collected by correction calculation controllers, based on the Extender 3000 hardware platform, which then drive the corrector magnets power supplies.

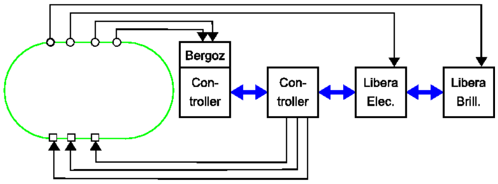

Figure 3: Distributed feedback design for DELTA.

Planned COSY Feedback Structure

As COSY is used as a platform for the HESR development, a local fast orbit feedback around the existing electron cooler is planned. The suitably amplified BPM signal is processed to digital position data. This is then transferred using the DCC to the Extender 3000 type corrector stations which calculate and apply the required correction. The position electronics used are commercial, digital, Libera Hadron BPMs [7]. As local feedback, it consists of two BPMs and two corrector stations driving a total of four corrector magnets (see Fig. 4).

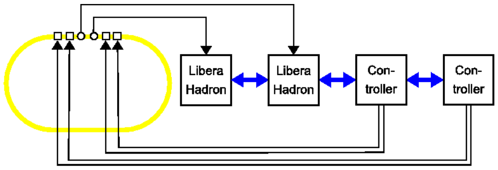

Figure 4: Planned local orbit feedback for the COSY accelerator using two Hadron BPM and two, Extender 3000 type, corrector stations.

Planned SIS18 Feedback Structure

Figure 5 depicts the planned SIS18 fast orbit feedback. The structure is similar to the COSY feedback, in this case the feedback is planned to be a global fast orbit feedback during ramping. As the SIS18 magnetic lattice changes during ramping, a time dependant orbit response matrix has to be implemented for the orbit correction. All of the twelve BPMs, Libera Hadron type, is going to be utilized for data acquisition. A total of twenty-six corrector magnets is available at the SIS18 storage ring. Due to the changes in the control system/hardware structure for the upcoming FAIR project, the number of required corrector stations is not yet set. This uncertainty is compensated fully by the flexibility of the design.

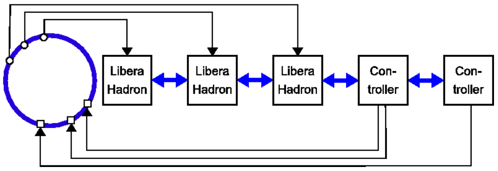

Figure 5: Planned orbit feedback for the SIS18 accelerator.

THE BPM-EXTENDER 3000 SYSTEM

The Extender 3000 system was developed as a hardware platform for the different feedback applications. The main features are an FPGA-based mainboard and a custom ADC-board for Bergoz connectivity. Figure 6 shows an overview of the connectors and the internal structure. Due to the re-programmability of the FPGA the platform can be utilized as simple data collectors, BPM connectors, corrector stations or other custom applications. An IP-core based software design flow ensures short development times by re-using software components.

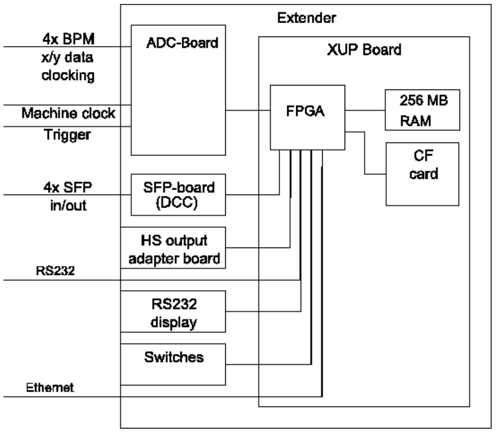

Figure 6: Extender Hardware structure.

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CURRENT STATUS

In case of DELTA, the fast data acquisition part of the feedback system is installed and operational. In the course of a reliability test the system is (up to now) operating for twelve month without failures. After finishing commissioning tests, the necessary corrector hardware (corrector stations/power supply controllers, power supplies, fast corrector magnets) are currently being installed. To test the hadron data acquisition, a mobile "hadron measurement system" has been developed, resembling the structure of the future systems. Figure 7 depicts the installation of the system at the SIS18. Measurements using this system were conducted at the SIS18 and the COSY storage ring.

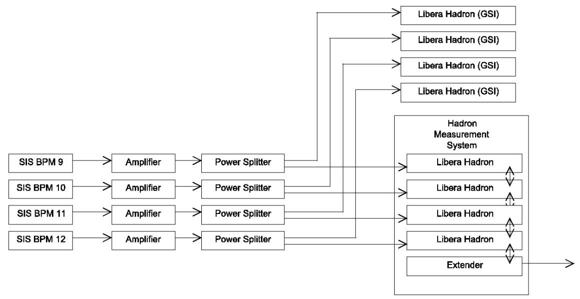

Figure 7: SIS18 measurement structure with hadron measurement system. For comparison the BPM signal is split for recordings using the GSI native system. System is also used for COSY measurements.

DAQ MEASUREMENTS

DELTA

Successful initial measurements were already conducted during the testing of the fast local orbit feedback, which is based on the same components. These measurements were confirmed during the commissioning phase of the global orbit feedback data acquisition system.

SIS18 & COSY

After development of the hadron measurement system, the goal was to commission it at COSY and SIS18 for first measurements as well as reliability testing. It was deployed to COSY for first on-beam tests. Position data of the beam was taken, analysis of this data showed non-beam induced position changes, hinting to a software problem. This problem was resolved during measurements taken at the SIS18 during an Uranium 73+ session at different energies and intensities. The measurements then fully corresponded to the native SIS18 beam position readout. Figure 8 shows the an overlay of beam positions during different ramps at BPM10 in horizontal direction at an energy of 300 MeV. The positional variance between each ramping was found to be in the order of measurement uncertainty. As a result the possible gain of a feedback to this cause is limited. A spectrum analysis showed the major position distortion to be in the low frequency range, which can be counteracted by a feedback. The fully operational measurement system was then installed at COSY, where position data was taken during different beam modes. The emphasis on these measurements was the testing of the bunch recognition software part, which was developed primarily for SIS18 [5]. First analysis of the data showed a good recognition ratio even for not well-shaped bunch patterns (barrier bucket scheme). Analysis of the positional stability is still ongoing, first simulations of feedback influence on the beam position yielded promising results.

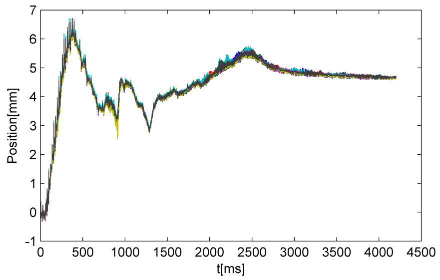

Figure 8: Overlay of positions during ramping at SIS18 BPM10 (horizontal).

CONCLUSION

The approach of a transferring feedback expertise from an electron to hadron machines proved successful in the area of data acquisition. The deployed fast position measurement at DELTA has showed the expected reliability and performance. Measurements using the representative hadron measurement system further specified the application range of the feedback at the SIS18 and COSY, as well as showing future research areas for feedback related topics.

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