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FOFB SYSTEM UPGRADE TO ZynqMP FPGA WITH FAST ORM MEASUREMENT

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Abstract

The FOFB processor has been ported from a Vertex 6 FPGA to a ZynqMP SoC (System on Chip) to provide additional resources to include the enhanced orbit diagnostics (EOD) system that has been designed to inject sinusoidal and pink noise through the feedback loop. The amplitude, duration, phase and frequency of sinusoidal, amplitude and duration of pink noise is user programmable.

INTRODUCTION

Fast orbit feedback (FOFB) systems are common in third and fourth generation storage ring light sources, usually needed to meet the tight stability requirements for the electron beam. However such a system has the potential to be far more than just a feedback system and can be used as a diagnostic to probe the linear properties of the storage ring. The first step in this direction requires that a user has the ability to control the fast power supplies, in our case to inject pink noise (via a PRBS generator) or a sinusoidal signal. This additional system, designed to run in parallel to the FOFB system, is called the Enhanced Orbit Diagnostic (EOD) system. the first clear benefit would be that such a system is capable of reducing the measurement time of the storage ring's corrector to position response matrix by a factor of 10, similar to methods used at DLS [1] and ALBA [2].

HARDWARE UPGRADE

The existing hardware used for the FPGA based FOFB system [3] did not have enough resources to implement the EOD system. The Trenz Electronics TE0808 system-on-module is selected to replace the legacy Xilinx Virtex 6 FPGA. This module is equipped with a Xilinx Zynq UltraScale+ XCZU9EG-1FFVC900E and 4 GByte on-module DDR4 RAM for the embedded 4 cores ARM Cortex-A53 CPUs. The FPGA portion of this chip is 7 times larger than the Vertex 6. An in-house designed motherboard PCB is used to host the FPGA module and drive an optical transmitter daughter board that sends out the correction data to the fast corrector power supplies. Figure 1 shows the hardware used for the FOFB and EOD system.

The simplified system architecture diagram is shown in the following Fig. 2. In the FOFB application, the processor receives the storage ring electron beam position data stream from the 98 BPMs and generates the correction data stream using an inverted BPM-Corrector response matrix. The correction data is use to drive the 84 corrector coils (42 horizontal and 42 vertical). While the EOD application

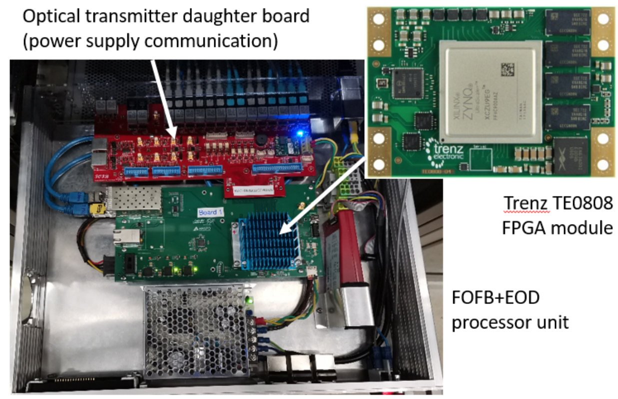

Figure 1: Updated hardware used to implement the FOFB and EOD systems.

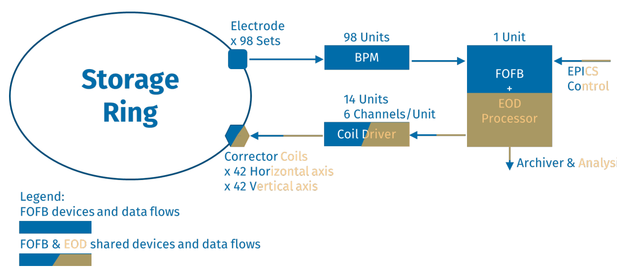

Figure 2: Simplified system architecture and data flows.

shares the same processor hardware with the FOFB system, it does not rely on the BPM data input but generates the sinusoidal/noise waves following the user's request. The EOD system can either run with or without the FOFB system.

A copy of the combined FOFB and EOD corrector data stream is sent to two virtualised PCs. The first is an EPICS IOCs that performs real-time spectral analysis on the data and another that archives the data. The corrector data is archived in the same way that we archive the position data using the DLS Fast Acquisition Data Archiver [4]. This is made possible by designing the system to transmit UDP data packets formatted in the same way as the Libera Grouping [5].

The ARM CPU cores will eventually be used to host an embedded EPICS IOCs using on-chip memory mapping to replace the current FPGA based EPICS Interface module. This means the registers of the FPGA portion are given memory locations in the CPU's memory space and can be written to and read from like any normal memory location.

PERFORMANCE

The system is currently under test and has been operating according to its design parameters as listed in Table 1. Spec-

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tral analysis has confirmed the efficacy of the pink noise generator (using a PRBS generator) and sinusoidal generator with a frequency stability of 0.005 Hz (one standard deviation). The system is capable of driving seven fast correctors simultaneously with the sinusoidal wave pattern and can be run with or without the FOFB system.

Table 1: EOD system capabilities and performance. The three values indicate Min / Max / Resolution.

Parameter	Value
Amplitude resolution	0.5 mA (PSU resolution)
PRBS Duration	0.1 s / 10 s / 0.001 s
PRBS Amp Max	1.0 A
Sin Duration	0.1 s / 10 s / 0.001 s
Sin Amp Max	1.0 A
Sin Amp Accuracy (std)	0.5%
Sin Freq	1.0 Hz / 10 kHz / 0.001 Hz
Sin Freq Accuracy (std)	0.005 Hz
Sin Phase	0 deg / 360 deg / 1 deg
Sin Delay	0 s / 10 s / 0.001 s

Data Acquisition

One deficiency in the design is that there is no mechanism for synchronising the corrector and position data. After sending the command to the EOD to start the drive signal (noise or sinusoid) the system time is logged and later used to retrieve the position data from the position data archiver. For the most part this is sufficient and can repeatably retrieve data that with an accuracy of approximately ± 1 ms as shown in Fig. 3. There are future plans add extend the EOD to stitch both the position and corrector data together to be sent to the fast data archiver.

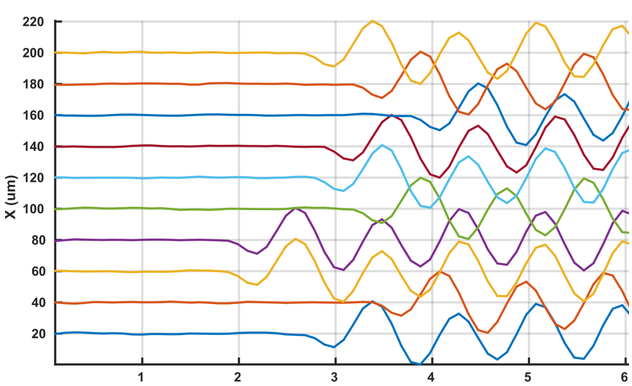

Figure 3: Synchronisation between different data sets collected separately. Data has been band-passed at the drive frequency.

Data Processing to Extract Close Orbits

The extracted data is bandpassed at the oscillation frequency to determine the window around which to perform the closed orbit pattern analysis, checked for gaps in the data (lost packets not archived) and analysed using the NAFF algorithm [6] to determine the precise frequency. The closed orbit pattern for a given corrector is extracted following the method in reference [2] for parallel measurements.

Initial measurements and orbit response matrices have been generated with an oscillation frequency around 170 Hz and at 1170 Hz, and a combination of fast correctors in serial and parallel fashion. A typical orbit response matrix (ORM) measurement using slow correctors takes 400 seconds. In serial fashion with a one second duration (and dead time of 0.5 seconds) the ORM measurement takes 140 seconds. With seven correctors in parallel this is further reduced to 25 seconds. Even at the higher frequency above 1 kHz the closed orbit pattern for a given corrector can be extracted.

One of the difficulties with the extraction of the closed orbit is the π ambiguity of the overall closed orbit. The method applied in this analysis is to use a model to determine the correct phase in order to stitch together a “typical” ORM that is comparable to one measured with slow correctors.

In the following example seven horizontal and seven vertical correctors were driven simultaneously all at different frequencies ranging between 1100 Hz and 1200 Hz. Figure 4 shows the spectral analysis of the horizontal position data with a frequency separation of 10 Hz is enough to distinguish individual corrector closed orbits. Figure 5 shows a sample of some of the closed orbits extracted using the current method. For a one second duration/window we found that precisely determining the frequency to approximately 0.1 Hz important, hence the step to precisely identify the frequency from the data. Normally measured frequency is exactly at the expected frequency, however if the measurements are done with the FOFB system there will be a frequency shift that is also frequency dependent.

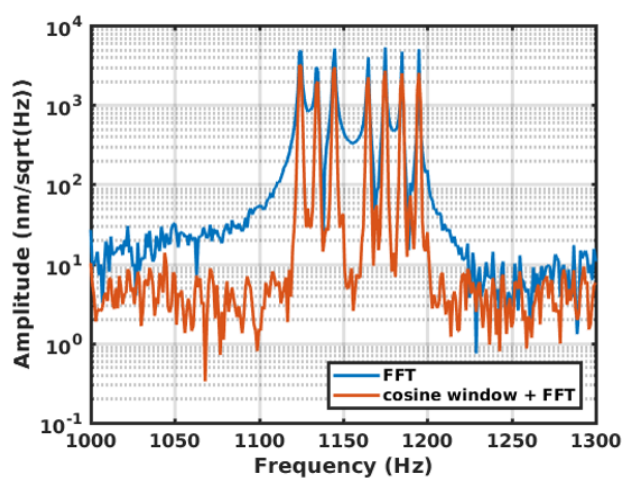

Figure 4: Spectrum of the horizontal position with seven correctors driven simultaneously.

Comparison between Fast and Slow ORM

A simple test was used to determine if the ORM's measured using the new faster method is comparable to our existing slower method. Two ORMs, fast and slow, were

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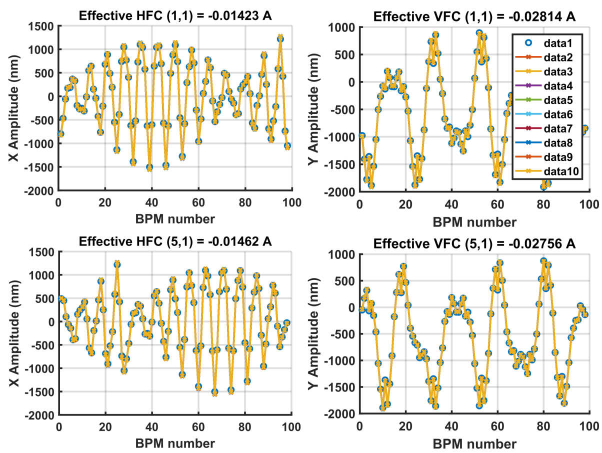

Figure 5: Sample of the closed orbit patterns extracted from the position data. Circles represent expected closed orbits based on a simulated model. The 9 separate data sets indicate repeatable results.

measured before and after changes to quadrupoles in the storage ring. Using the ORMs and the LOCO method (implemented in the Matlab Middle Layer toolbox) we attempt to infer what the changes were in the storage ring. Figure 6 shows the results of such a comparison. The fast ORM in this initial test was measured using a serial fashion with an oscillation frequency of 1173 Hz. The current methods using slow correctors can pin point the changes with an error of less than 10% while the fast method shows poor results. The faster method still produces a reasonable result however is not as accurate. It is possible measuring at higher frequencies introduced other effects and work to improve these measurements are progressing.

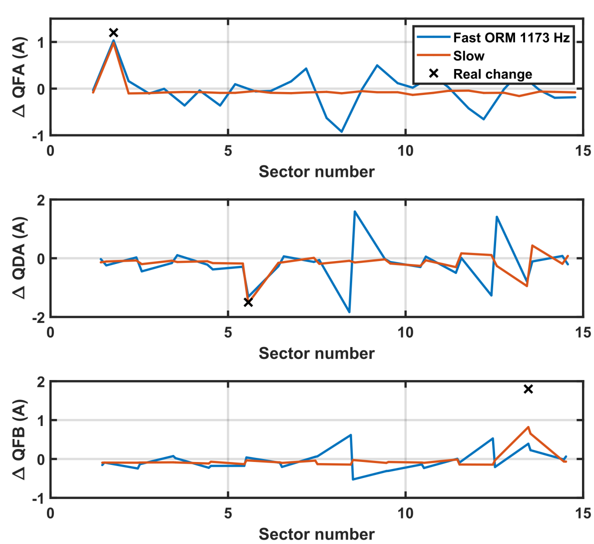

Figure 6: LOCO extracted changes to the quadrupoles using ORMs measured in a serial fashion using fast vs slow methods. Typical QFA, QDA and QFB settings are 139 A, 82 A and 120 A.

CONCLUSION

The FPGA platform for the FOFB system has been upgraded from a Vertex 6 to a Zynq Ultra-Scale+ and the additional resources has been used to develop the EOD system that can inject pink noise or sinusoidal signal into the signal sent to the fast power supplies. The system has been successfully commissioned and the initial analysis of the ORM's measured using the new EOD system shows promising results. However further work is still required to ensure that it is as good or better than our existing methods. Future developments on the hardware will be to implement a better method of synchronising the data acquisition and to make use of the ARM CPU cores for an embeded EPICS IOC.

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