MTCA.4-BASED BEAM LINE STABILIZATION APPLICATION

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Abstract

We want to summarize the beam line stabilization application with MTCA.4 electronics. Presented solution is based on the compact 2U MTCA.4 crate integrating sensor and actuator cards. The optical beam position sensor is based on quadrant Si PIN photodiode connected to low cost AMC based FMC carrier equipped with ADC card. The optical beam position correction is done using picomotorized stages equipped with active piezo elements and high voltage RTM piezo driver. The data processing and digital feedback units are implemented using Spartan 6 FPGA. The control algorithm has been optimized for low latency and high precision computations. The control electronics performance has been tested using single beam line test stand consisted of commercial laser diode drivers, supported optics and motorized stages. The first results are demonstrated and future possible applications are briefly discussed.

INTRODUCTION

In accelerator facilities, especially free-electron lasers (FEL), the use of mode locked lasers is one of the common approach, e.g. for electro-optical diagnostics (EOD), as photo-cathode lasers, seeding, Beam Arrival and Beam Position Monitors (BAM, BPM) or pump-probe experiments.

The repetition rate of the laser oscillator train pulses is typically a sub-harmonic of the main RF synchronization signal. At European X-Ray Free Electron Laser (XFEL) the main reference signal is at 1.3 GHz while the lasers run in a range between 54 MHz and 216 MHz. In order to synchronize the laser to the accelerator reference a piezo element within a laser cavity is applied [1]. The accelerator reference signal must be also distributed over different places of the machine. The main approach is to encode the reference timing information in the very precise rate of the optical pulse trains using master laser oscillator (MLO). The MLO optical signal is next transmitted to different accelerator locations (e.g. RF Gun, main linac or long undulator sections) using fiber laser connections. The fiber lasers needs to be actively stabilized using piezo stretcher in a fibre due to temperature drifts and microphonics [2].

The common part for the laser oscillator based applications is a need of delivering their output pulses to different experiments. The beam transmission lines can have different type of optics and different length. The long beam lines can be also affected be external environment disturbances. The traditional way for the beam line tuning and alignment is to manually rotate the vertical and horizontal position of the mirror optics to get the beam to the center of the detector. In order to automate alignment process and make it robust to any external disturbance source the MTCA.4 based beam line stabilization application is proposed. The MTCA.4 hardware architecture offers compact solutions for sensor, controller and actuator cards design together with fully integrated crate composed of cooling units, redundant power modules, MicroTCA Carrier Hub (MCH) and central processing unit (CPU) with hosted SSD discs.

BEAM LINE STABILIZATION APPLICATION TEST SETUP

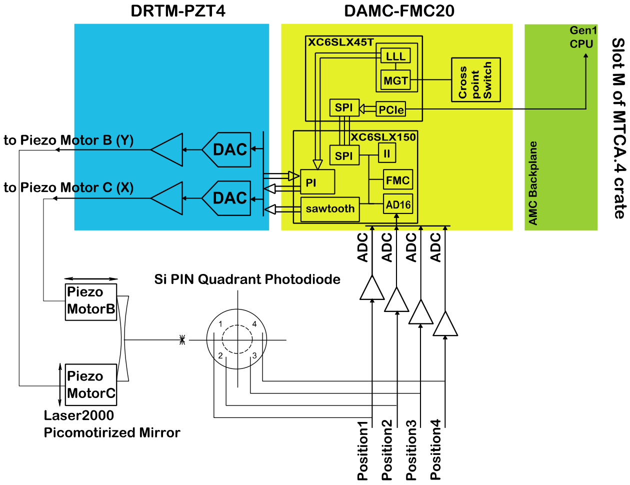

Figure 1: The block diagram of beam line stabilization test setup.

The beam line stabilization application test setup is composed of THORLAB laser diode driver, manual and piezo motorized mirror stages, optical position sensor (Si PIN), FMC-AD16 (sensor), DAMC-FMC20 (data processor and controller) and DRTM-PZT4 (actuator) modules (see Figure 1). The laser diode driver is used to generate the beam light. The mirror sections are used to position the beam to the center of the detector. The quadrant Si PIN photodiode is used as optical position sensor. The typical quadrants detectors have two or four distinct photosensitive elements separated by a minuscule gap. A light spot illuminating just one element only produces photocurrent in that element. When the spot is translated across the surface of the detector, the energy becomes distributed between adjacent elements. The ratio between the photocurrent outputs from these elements determines the relative position of the spot on the surface. The photocurrents are translated to DC voltages using trans-impedance amplifiers and next delivered to the FMC-AD16 sensor card. The Fast Mezzanine Card (FMC) module is equipped with 16-channel ADC (first 4 channels used) allowing data acquisition up to 100 kSPS. The horizontal and vertical positions of the beam are calculated inside 150 Spartan 6 FPGA and then applied for a digital feedback con-

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troller input. DAMC-FMC20 card has been used for the FMC module carrier hosting, data processing and controller design. The modified PID controller structure has been proposed to handle saw tooth like piezo driving excitation. The FMC carrier module communicates with outside world using PCIe interface over 45 Spartan 6 FPGA, supported PCIe device drivers and Matlab command line tools. The digital controller output is sent to actuator DRTM-PZT4 piezo driver (2 channels used) module. The piezo driver is mainly used to drive both piezo motors of Laser 2000 picomotorized mirror stages with voltages of 0÷80 V. The analogue power amplifier bandwidth has been limited to 50 kHz in order to not excite the piezo elements resonances. Several on-board diagnostics are available for the Rear Transition Module (RTM) i.e. to monitor piezo driver output voltage, current delivered to the piezo capacitance load or high voltage power supply lines ripples [3].

FPGA IMPLEMENTATION

The position of the light spot with respect to the centre of the quadrant detector can be calculated with the following formulas:

$$X = \frac{(1+4)-(2+3)}{\Sigma}, \qquad (1)$$

$$Y = \frac{(1+2)-(4+3)}{\Sigma}. \qquad (2)$$

The X, Y parts stands for the horizontal and vertical positions of the beam. The numerator components correspond to the photocurrent produced in each segment. The denominator part of the equation is a sum of all four segments to cancel out the effects of light level variations.

Data Processing Block

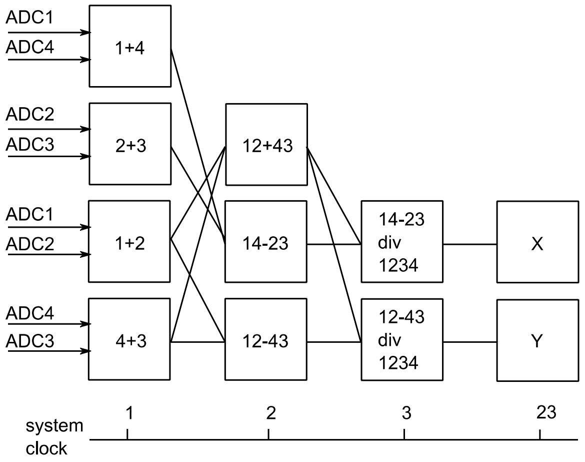

Figure 2: The block diagram of data processing unit.

The block diagram of the computation and its latency is shown in Figure 2. The DSP48 blocks have been used to calculate the current beam position. To optimize the computation latency the common blocks for both positions are calculated the same time i.e. numerator and denominator sections of Eq. 1 and 2. The division block has been implemented using Radix2 algorithm. The error computation of division block is shown in Figure 3. The several built-in FPGA block have been used to monitor the crucial block of all the computations. The FPGA logic utilization is summarized in Table 1.

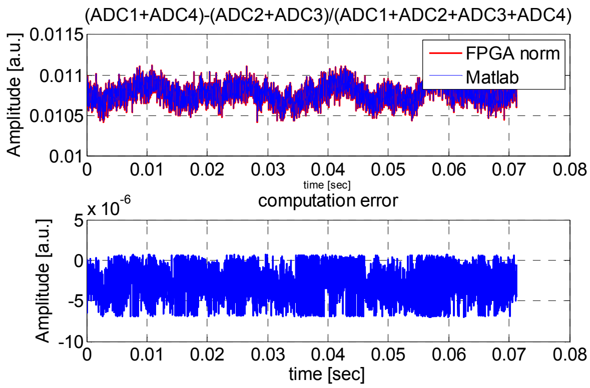

Figure 3: The computation error estimation for applied division block.

Table 1: The FPGA Logic Utilization

Resource	Usage
DSP48	6
LUTs	7828
BRAMs	8

Digital Controller Design

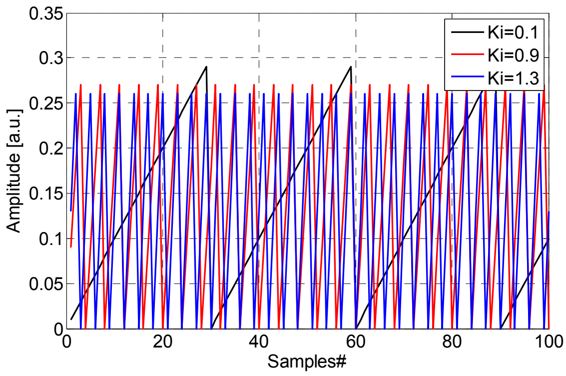

Figure 4: The modified PID control response to different integral gain values.

In order to stabilize the beam position to the center of photodiode detector modified PID controller structure has been designed. Since the piezo motor position can be change using like saw tooth excitation the integral part of the controller has been equipped with automatic clear option whenever user defined threshold is reached. Since the bandwidth of the controller strongly depends on the integral gain values, the controller time response can be efficiently tuned to the different application requirements. The simulation of the controller response is shown in Figure 4. The controller block has been also setup with custom table mode of operation using internal BRAM block memory of FPGA device. The user can easily define the direction, amplitude, frequency and number of pulses of generated driving piezo shape. This option can be efficiently used to allow user predefined conditions setup for the initial beam position.

EXPERIMENTAL RESULTS

The experimental test setup has been equipped with 30 cm long beam line packed into beam absorption material box. The Si PIN photodiode detector has been biased with voltage of 5 V using low noise laboratory power supply. The MTCA.4 control electronics have been packed inside 2U, 6 slots start kit crate from Power Bridge.

The both piezo motor scans have been performed using custom table mode of controller operation in order to check the system response and setup the initial conditions for the beam (see Figure 5).

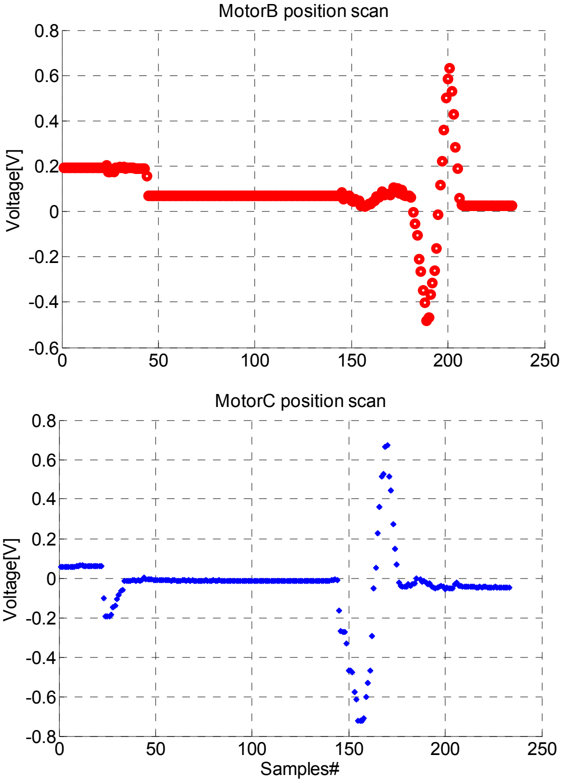

Figure 5: The horizontal and vertical piezo motors response to custom table mode of controller operation.

Finally the digital feedback loop controller have been activated and its performance in presence of external disturbance source (using none-piezo mirror manual tuning) has been measured as show in Figure 6.

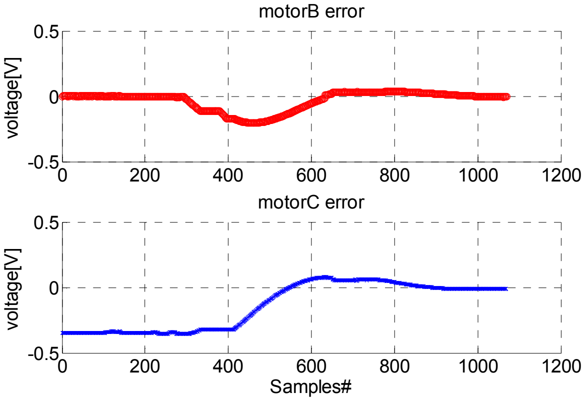

Figure 6: The automatic beam line alignment using MTCA.4 control electronics.

CONCLUSIONS AND FUTURE PLANS

The proposed solution has been successfully tested using experimental test beam line. The artificial error has been automatically corrected by both position feedback controllers. The beam line stabilization application has been demonstrated using MTCA.4 hardware architecture and available DESY hardware portfolio [4]. The system can be efficiently used for large scale machine diagnostics as well as laser synchronization, distribution subsystems whenever the need of automatic optics alignment plays a crucial role. What is more the European Molecular Biology Laboratory (EMBL) in Hamburg and supported laser optics industry partners keep outstanding interest for such applications usage and even their permanent deployment.

REFERENCES

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