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AN MTCA.4 BASED POSITION FEEDBACK APPLICATION USING LASERINTERFEROMETERS

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Abstract

To perform experiments on the nanometer scale at high brilliant x-ray light sources, it is highly recommended to have the mechanical components of the experiment, like lenses, mirrors and samples, as stable as possible. Since these components need to move from nanometer up to millimeter range they cannot be stabilized by only using rigid structures. For that reason an active stabilization system with fast and precise sensors needs to be developed. Here a Laser-interferometer is used, which provides picometer resolution at several MHz sample rate. In this paper we will present a laboratory setup which consists of a 6-slot Micro Telecommunication Computing Architecture generation 4 (MTCA.4) crate with standard components such MicroTCA carrier hub (MCH), central processing unit (CPU), power supply (PS) and cooling unit (CU). The Interferometer application has been setup with Deutsches Elektronen-Synchrotron (DESY) advanced mezzanine card (DAMC-FMC20) data processing unit, DESY Field Programmable Gate Array (FPGA) mezzanine card (DFMC-UNIO) universal input and output extension and DESY rear transition module (DRTM-PZT4) piezo driver. The encoder signals given by the interferometer controller are processed within the FPGA and then forwarded to the piezo amplifier RTM-board. The signal processing application includes decoding the digital feedback signal, calculating the coordinate transform for specific experimental setups and closed-loop operation based on a proportional integral derivative (PID) controller. The first results of the laboratory setup are demonstrated and briefly discussed.

INTRODUCTION

During an experiment with a Laser beam, all components like focusing optics, mirrors and the sample must not move relatively to each other. To achieve that, the best way is to mount all the components as stiff as possible, which is not always a solution, since most of the components need to be moved due to alignment procedures and to scan the sample. In case of using an x-ray Laser beam, these motions have to be commanded remotely due to the hazardous radiation environment. In order to perform experiments on the nanometer scale, motors and sensors have to be capable of resolving sub-nanometer resolution. For this task piezo drives have become quite popular. They consist of a stack of piezo electric plates, which extent with respect to an applied voltage [1]. The force of this piezo stack is transmitted to a movable platform by a flexure guide to avoid mechanical backlash as well as friction. To measure the piezo's position, a Michelson-Laserinterferometer with a resolution of 1 pm and several MHz sample rate is commonly used. The idea of this device is to split a light source into two arms. Each of those light beams is reflected back toward the beamsplitter which then combines their amplitudes using the superposition principle. The resulting interference pattern that is not directed back toward the source is typically directed to some type of photoelectric detector or camera. For different applications of the interferometer, the two light paths can be with different lengths or incorporate optical elements or even materials under test. In the paper we would like to present experimental laboratory setup that consists of MTCA.4 based electronics, PicoScale Laserinterferometer from SmartAct and piezo motor P820.10 from PI with glued tiny optical mirror on it. The system has been established in Deutsches-Elektronen Synchrotron (DESY) as a part of research and development (R&D) program for the future planned Light Source upgrades such PETRA IV or FLASH2020+ experiments.

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SYSTEM OVERVIEW

The laboratory setup of position feedback application using Laserinterferometer consists of 6-slot MTCA.4 crate equipped with MCH, PS, CPU, CU, DAMC-FMC20 and DRTM-PZT4 components, a PicoScale Laserinterferometer and P820.10 piezo motor as it is shown in Fig. 1. The piezo

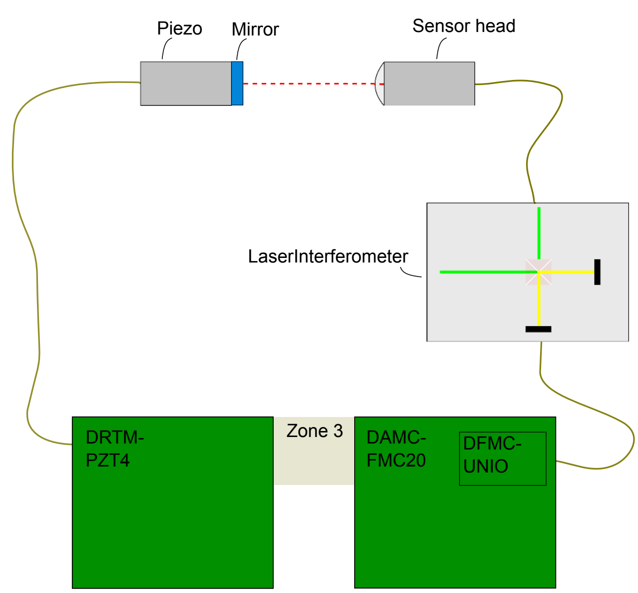

Figure 1: The block diagram of position feedback application using Laserinterferometer and MTCA.4 based electronics. The MTCA.4 crate with standard components is omitted for the clarification.

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motor is fixed with tiny mirror close to the Laserinterferometer sensor head. The decoded output of the Laserinterferometer is connected to the DFMC-UNIO extension card using a differential to single ended converters equipped with voltage level shifters. The DAMC-FMC20 carrier is used to encode Laserinterferometer signals and farther data processing. The control signals are send to the DRTM-PZT4 module over Zone 3 connector in order to drive digital-to-analog converters (DACs) and analog power amplifiers. The power amplifiers are connected to the piezos using on-board relay switches. The DAMC-FMC20 card communicates with CPU using Peripheral Component Interconnect Express (PCIe) interface over the crosspoint switch (CPS) device located on the MCH unit. The MCH also provides CPU connectivity over Gigabit Ethernet medium (GbE).

Firmware Implementation

The Laserinterferometer firmware consists of board and application layers. The board layer is responsible for an on-board peripherals configuration as well as PCIe communication with CPU. The application layer is composed of DFMC-UNIO, DRTM-PZT4 modules including proportional integral derivative (PID) controller, the Laserinterferometer (LINT) and data acquisition (DAQ) blocks. The DFMC-UNIO block is responsible for setting a specified voltage level (5 V or 3.3 V), direction as well as activation of the IO buffers (input or output and its enable). The DRTM-PZT4 block is providing a serial-peripheral interface (SPI) to control on-board DACs and analog-to-digital converters (ADCs). Additionally, the inter-integrated circuit (I^2C) interface is given for the flexible board configuration (relay switches, external or internal input drive signal selection, DAC output and ADC input voltage range, unipolar or bipolar operation of the power amplifier). The LINT module allows aquadb encoding, vertical and horizontal beam positions calculation. The six coefficients are given as an input to the LINT block in order to allows flexible calibration for different experiments. The idea of aquadb encoder it to sense rising and falling edges of both a and b decoder signals and increase the output counter with a direction given by the phase lag between a and b. The DAQ module is connected one side to monitor a crucial LINT and PID controller parameters. The monitored data are stored inside Static Random Accessible Memory (SRAM) and read by direct memory access (DMA) interface provided by PCIe. The arbiter (ARB) block is included for flexible access of SRAM content by both DMA and DAQ components. The internal interface (II) block is used for flexible mapping of the board and application registers on the PCIe address space memory. The serial (Ser) block is used to communicate between hosted Field Programmable Gate Arrays (FPGAs). The detailed block diagram of the implemented firmware components is depicted in Fig. 2.

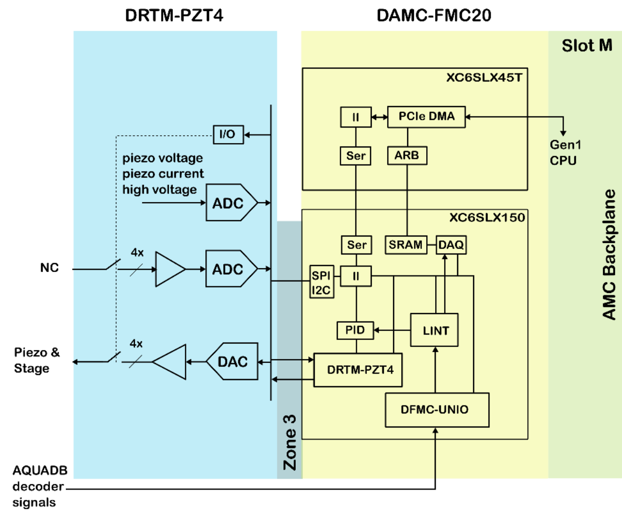

Figure 2: The block diagram of implemented Laserinterferometer firmware.

EXPERIMENTAL RESULTS

The Laserinterferometer system has been installed at FS-PETRA laboratory and used for several days of measurements. The P820.10 linear piezo motor from PI of capacitance of 367 nF has been connected to the Vector Signal Analyzer (VSA) and characterized with an amplitude and phase response. The obtain transfer function is shown in Fig. 3. As a next step the piezo linear motor has been as-

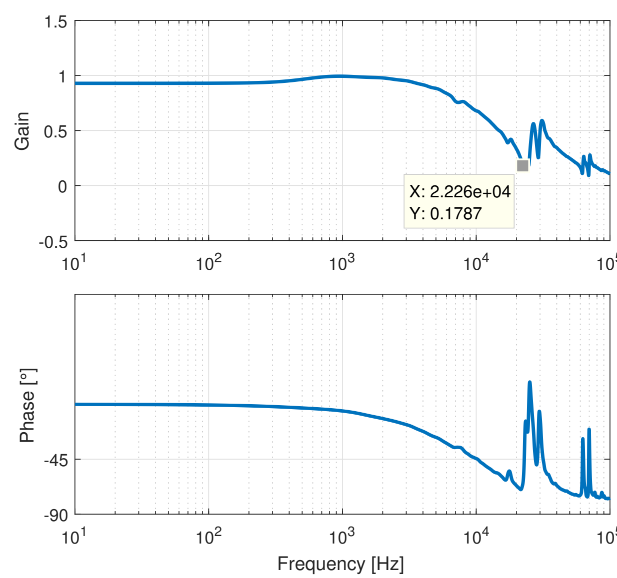

Figure 3: The P820.10 piezo linear motor response to the random chirp signal of order of 100 mV_{rms} and frequency range between 10 Hz and 100 kHz.

sembled on the optical table together with a sensor head and connected to the DRTM-PZT4 electronics. The piezo driver output voltage range has been programmed to perform forward and backward scans. During the process the Laser-

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interferometer response has been recorded as it is depicted in Fig. 4. The PID controller has been reduced to PI parts

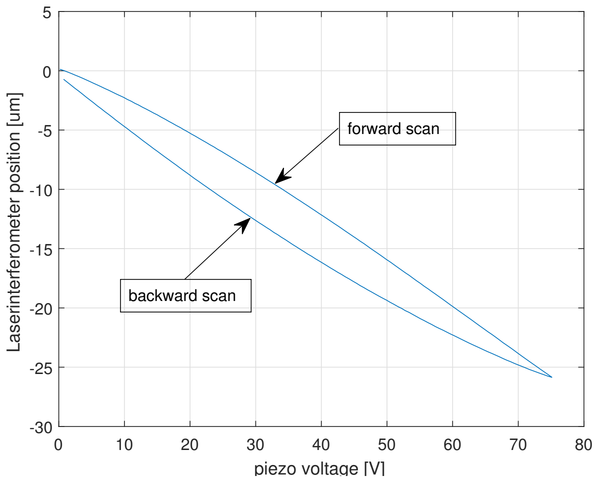

Figure 4: The Laserinterferometer response to the DC bias applied to the piezo linear motor with fixed mirror. The forward and backward scans range has been set correspondingly from 0 to 74 V and from 74 to 0 V.

only due to the fact the derivative part had no significant impact to the Laserinterferometer response. The initial offset of the beam position has been corrected using integral part of the PID controller as it is shown in Fig. 5. Finally, the optical table has been equipped with DC current motor for the low frequency vibrations generation. The proportional controller gain has been adjusted in order to dump the induced vibrations [2] as it is shown in Fig. 6.

DISCUSSION AND FUTURE PLANS

The position feedback application using Laserinterferometer has been successfully demonstrated for the experimental setup established in laboratory conditions. The piezo motor resonance frequency and a travel range have been estimated to be 22 kHz and more then 20 um, respectively. The strong impact of the piezo hysteresis effect has been observed for the Laserinterferometer response to the piezo DC bias voltage. The MTCA.4 based position feedback controller has been able to reduce the induced mechanical vibrations by a factor of 5. The presented solution is planned to be extended with more advanced feedback algorithms and finally applied for a new beam line experiments.

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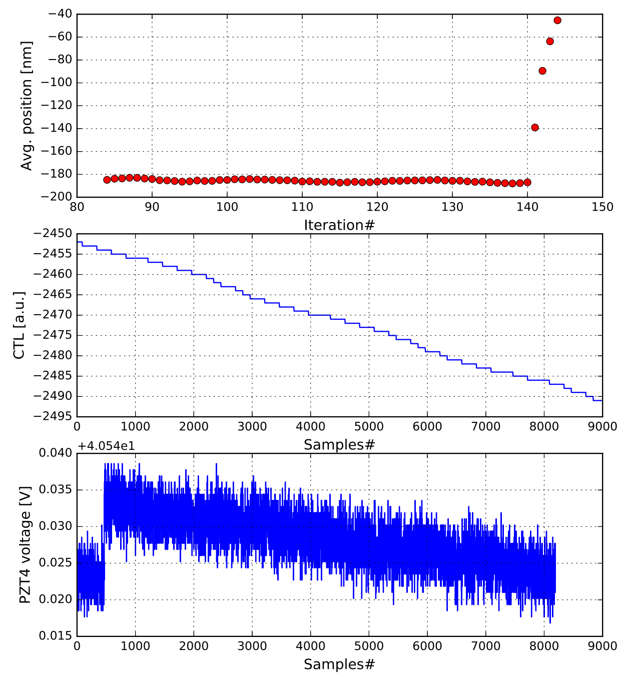

Figure 5: The mean value of the beam position is shown on the top plot. The controller output is given on the middle plot. The piezo driver output voltage is presented on the bottom plot. The integral gain has been tuned to 50e3.

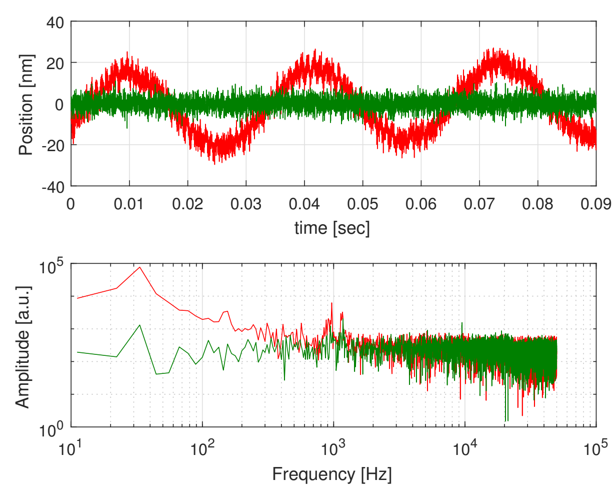

Figure 6: The time domain data of the beam position with and without active piezo feedback applied is shown on the top plot. The Fast Fourier Transform (FFT) of the beam position is depicted on the bottom plot. The proportional gain has been set to 100e4.