Recent Developments in Control Software for Optical Synchronization Applications at DESY

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Abstract—Proper operation of FELs such as the Free-Electron Laser in Hamburg (FLASH) and the European X-Ray Free-Electron Laser (XFEL), which is currently under construction in Hamburg at DESY, requires many specific subsystems to be synchronized with a precision exceeding 10 femtoseconds. Those components are often separated by several hundred meters or even kilometers, in case of the European XFEL. Such distances mean that it is extremely difficult to use only conventional RF signal distribution in coaxial cables for synchronization because of high losses and phase drifts. Electromagnetic interference is also an issue. Therefore, a laser-based synchronization scheme can be employed in parallel. In this paper, the signals are transmitted via length-stabilized optical fibers. Such architecture is currently being used at FLASH and will also be the main means of synchronization at the European XFEL. The hardware for such a synchronization system consists of many optical elements such as commercial lasers and self-built free-space and fiber optic setups. However, a significant part of it is also the electronics responsible for control, diagnostics and signal processing as well as high-level servers and front-end software running on those devices. Currently, the VME standard is used throughout FLASH as the basis for the control system digital hardware. For the European XFEL, however, an architecture with a high level of reliability and availability is required as well as one with higher data acquisition and processing rates. Because of that, the Micro Telecommunications Computing Architecture (µTCA) had been chosen. It is a fairly new standard and it provides significantly better performance and employs modern technological solutions making it more suitable than the older VME architecture. The paper presents the latest improvements in the control software for the optical synchronization system based on the VME standard. Servers for phase-locking the lasers as well as controlling the fiber link stabilization units are described in detail. Plans for migration to the new infrastructure are also outlined.

Index Terms—Optical synchronization system, DESY, FLASH, European XFEL, VME, control systems, µTCA

I. INTRODUCTION

THE sub-10 femtosecond requirements [1] for the synchronization of elements at FLASH and XFEL demand all the various elements of the system to work well on their own but also in cooperation with each other. That means that the optical setups have to be well arranged, e.g. with monitoring purposes and various measures of automation, and provide reliable operation. However, a well-designed software architecture is mandatory to monitor and control them.

In this paper, the authors first briefly describe the basic block used in all the applications which is a proportional-integral-derivative (PID) regulator implemented in a Texas Instruments Digital Signal Processor (DSP) [2]. Then, they focus on the more advanced features of the phase-locking software for lasers and link stabilization units such as automatic switching between reference signals, error recovery routines, automatic signal discovery, and tuning. Exception handling procedures and future development plans are also described.

The optical synchronization scheme is important for other subsystems of machine control, including the Low-Level RF system (LLRF). A bridge between those two elements is the so-called beam-based feedback, in which the information about beam position and its arrival time can be used to more precisely tune the accelerating cavities of the machine. The beam information is provided by specialized hardware [3] running under control of servers such as the Bunch Arrival Time Monitor (BAM) one. It, however, needs access to information included in the servers controlling the Master Laser Oscillator (MLO) and the fiber links providing stable laser pulses at remote points in the tunnel, including the BAMs. Thus, the control software for optical synchronization is required to run in a stable and correct way and is relied upon by other control components crucial to the proper operation of the machine. In addition, the European XFEL will primarily depend on the optical synchronization scheme because of large distances between system elements.

II. VME-BASED HARDWARE PLATFORM FOR CONTROL PURPOSES

The control system hardware infrastructure of Free-Electron Laser in Hamburg (FLASH) is currently based on the VME standard. A typical VME crate used for optical synchronization applications, as depicted in Fig. 1, consists of several boards: a CPU module, where the servers are run (a); a storage blade (b); a timing card, which distributes trigger and clock signals to other boards (c); an analog-to-digital (ADC) card (d); a digital-to-analog (DAC) module (e) and a digital signal processing (DSP) blade (f). The three latter boards form the basis for the feedback loop which is used wherever active control of system elements is required.

The ADC module consists of eight AD9240 analog-to-digital converters with a 14-bit resolution which can support a sampling rate of up to 10 Msamples/s. The analog characteristics, such as signal level range or input impedance, can be adjusted separately for each channel using on-board jumpers. The eight digital-to-analog converters on the DAC card are THS5671 devices. Their resolution is also 14 bits and they can provide voltages of up to ±/6.3 V. However, in the DSP configuration discussed in this paper, only two of the
channels of the DAC module are available. The DSP chip is a Texas Instruments TMS320C6701 floating-point digital signal processor operating at 164 MHz. It is equipped with a Host Port Interface (HPI) which allows external hosts to access all the memory of the DSP over the VME bus. This feature is extremely important as it allows the higher-level Distributed Object Oriented Control System (DOOCS) [4] servers to easily read and write properties included in the firmware, such as regulator gains, and present them to the system operators. The ADC and DAC boards are clocked with a 1 MHz signal provided by the timing module, making it synchronized to other elements of the control system. The same module also provides a 10 Hz trigger signal synchronized to FLASH operation which is crucial when it comes to data acquisition timing and its processing.

III. CUSTOMIZABLE DSP-BASED PID REGULATOR

The core of the servers used for optical synchronization applications described in this paper is the DSP firmware implementing a customizable proportional-integral-derivative (PID) regulator. Since the ADC board provides eight inputs and the DAC board is able to drive two outputs, the DSP firmware is designed in such a way that two independent devices can be controlled using one DSP board. This allows each device to take advantage of up to four inputs and one output. For example, two different lasers, each with four different reference signals, can be phase-locked this way. In addition, each of the signal paths for each of the reference signals can have different values of the P, I, and D gains as well as the set-point (SP) and the cut-off frequency for a low pass infinite impulse response filter, also implemented in the DSP firmware. This structure is presented in Fig. 2. The MUX in the figure represents the selection of signal source and the parameters for each of the reference signals while the CTRL module includes the filtering stage and the PID regulator.

IV. SERVER FOR LASER PHASE-LOCKING

This server is used to synchronize a laser’s repetition rate to a reference signal coming either from an RF source such as the Master Oscillator (MO) or another laser such as the Master Laser Oscillator (MLO). In both cases, the controlled and the reference signals are converted to RF signals and sent to a phase detector [5]. Its output is then fed into the PID regulator which, ultimately, drives a piezo element which changes the length of the laser cavity, adjusting its repetition rate (see Fig. 3). This fairly standard way of phase-locking the lasers [6] is enhanced in the current implementation of the server by additional functionality. First, it has to be mentioned that in most of the setups more than one reference signal is used. There is one at the fundamental repetition rate of the laser and one or more at higher harmonic frequencies, depending on what signals are available. A common frequency is 1.3 GHz available from the MO, although 9.1 GHz is also used, for example in case of the laser system used for pump-probe experiments. The fundamental frequency is required to ensure a unique phase-lock relation between the laser and the accelerator while the higher harmonics help achieve a tighter lock since the sensitivity of the phase detectors is larger.

The server allows the reference signals used in the control loop to be manually selected, providing moreover even two sets of PID gains for each of the inputs. This can be used by the operators depending on the outcome they desire. For example, a more relaxed gain settings can be used for locking the laser initially and then a more strict set of parameters can be selected to optimize the lock. Furthermore, an automatic
switching procedure can be initiated, where the operator defines the sequence in which the laser is phase-locked to specific reference signals (from the fundamental frequency to the higher harmonics) and, upon successfully locking to one of them, moves to the next one. The server also provides monitoring and automatic control of the piezo driver voltage, making sure that it is always kept within a defined range. This functionality is described in more detail below. The operator panel for the MLO is presented in Fig. 4.

A. Calibration and Automatic Coarse Tuning

Before any phase-locking of the lasers can take place, the particular setup needs to be calibrated in order to properly calculate the timing jitter of the phase-locked laser. This is done by measuring the sensitivity of the phase detector by observing the beat frequency it produces when the repetition rates of the target laser and reference signal are not equal. By calculating this frequency, as well as taking an average of the captured slopes of the signal, taking into account the sampling frequency of the DSP, it is possible to obtain a calibration coefficient ($K\phi$) expressed in mV/deg of the mixing frequency (Fig. 5). When this coefficient is known, all the signal variations in the voltage domain observed when the laser is phase-locked can be translated into the time domain giving a measure of the quality of the lock. This allows the operator to fine-tune the parameters of the regulation in order to improve its quality.

The DAC output voltage, in the range of +/- 6.3 V, is not enough to drive the piezo element inside the laser cavity. An additional piezo driver is required which will convert it to an acceptable level, that is 0 - 100 V in case of laser systems. This means that it is possible to lose the phase-lock if the phase difference between the target laser and the reference signal drifts beyond this limit. A slow coarse tuning with a much larger range but a smaller accuracy is required in this case. There are currently two coarse tuning schemes applied to the lasers used at FLASH that are phase-locked using the software described in this paper. One is based on temperature control and the other uses stepper motors. The former tuning is employed in the commercial SESAM-based Origami laser, serving as MLO, where the SP of the internal temperature stabilization scheme can be modified [7]. In the latter case, one of the laser’s cavity mirrors is additionally mounted on a motorized translation stage. Both tuning methods can be set to execute automatically as soon as modifiable thresholds for piezo voltage are crossed. In most of the cases the acceptable range of the piezo voltage is around half of the total range. For the MLO it is set between 20 V and 75 V. The tuning scheme choice does not require any changes in the compiled code. Switching from one type to another is a matter of changing several parameters in the configuration file of the server which makes it very easy to install the software for new laser locations as well as modify the servers if the lasers in already supported locations change.

The operators can monitor all the crucial parameters of the tuning system, including the piezo voltage, the motor position, and the temperature SP. They can also modify the thresholds for which the automatic tuning takes place as well as the maximum and minimum motor position or temperature SP. On top of that, manual tuning is also provided which is particularly useful when the laser is left unlocked for a significant period of time and drifts far away beyond the range of the piezo. Manual tuning allows the operators to move the laser back into piezo range and phase-lock it using the DSP-based PID regulator. Due to limited sampling rate of the DSP of around 200 kHz, however, this procedure is not automated since it is possible to phase-lock the laser to an aliased higher frequency. While this is usually not the case if the laser is unlocked for shorter periods of time and the detuning is not that large, when setting up a new laser this has to be taken into account and an oscilloscope should be used during commissioning of a newly installed laser to confirm the ADC readings.

B. Two-piezo Tuning Setup

A slightly different type of tuning is employed in a Venteon oscillator used for the pump-probe experiments [8]. There are two coarse tuning stages available there. Between the small-range, fast piezo driven by the PID regulation and the long-range motor tuning, a second, slower piezo is installed. The first one can compensate for timing drifts in the range of around 25 fs while the second one extends the range that can be covered without driving the motor by another 150 fs.
The second piezo voltage is held at a constant level until the first one crosses defined thresholds. Then, the voltage level is changed accordingly with a modifiable step size. This step can be calculated in a way that the first piezo voltage drops right into the middle of its range making the necessary tuning actions as limited in number as possible. Also, when the larger-ranged piezo crosses its threshold and the motor eventually needs to be moved, the voltage level is modified to again keep the regulation piezo as close to the range center as possible. The operators can use the panel shown in Fig. 6 to set all the necessary regulation parameters.

C. Automatic Reference Signal Switching

In order to minimize the timing jitter of the laser, phase-locking to higher frequency reference signals is performed. As a tradeoff for better short-term performance, the lock is getting less stable with greater frequencies. To make sure that the best possible lock for particular conditions is found, an automatic reference signal switching mechanism has been proposed and implemented in the server. As presented in Fig. 7, the operator sets the mixing frequencies for all the inputs, which are defined by the phase detector hardware that is actually installed, in ascending order and then uses the functionality to calculate the calibration coefficients \((K_\phi, \text{see section IV-A})\) for each of the mixers. The next step is setting the timing jitter thresholds for which switching is done. In the presented example, taken from the pump-probe laser, when the 108 MHz lock produces timing jitter of less than 1000 fs, a switch happens and the 1.3 GHz reference is used starting from the next ADC sample. Dropping below 20 fs causes the server to switch to a yet higher frequency of 9.1 GHz. As there are no higher frequency reference signals available the next threshold is set to -1 fs, which obviously cannot be crossed. If the lock deteriorates and the timing jitter gets higher than the reset threshold the whole procedure starts over from the lowest mixing frequency. The reset can also be triggered manually.

Locking to a low frequency reference signal adjusts the repetition rate of the server in a good-enough way that a signal with no beat frequency at the higher frequency phase detector output appears. However, a phase mismatch may be observed if the reference signals are not synchronized to one another. This can be seen in the figures above, where the laser is locked to 108 MHz (ADC0, Fig. 8) but the output of the 1.3 GHz phase detector is not zero (ADC1, Fig. 9), indicating a phase difference between this reference and the controlled signal.

When switching, it is important to make sure that the DAC output, and in turn the piezo voltage, changes as smoothly as possible. If the higher frequency reference PID is allowed to
take over the control with an error signal proportional to the phase difference and a SP of zero, a point of significant discontinuity can be introduced. In order to avoid such jumps, a mean value of the ADC reading is calculated, which corresponds to the DC offset of the phase detector output, and introduced as the new SP of the target PID regulator (Fig. 10). The previous SP level is stored. Also, the integrator value at the moment both these conditions are met, the switching instant will not introduce large jumps in the DAC output [9]. Afterwards, the SP of the current PID regulation is restored in incremental steps (Fig. 11), smoothly transitioning to the desired phase difference level, which is usually zero.

V. SERVER FOR PHASE-LOCKING THE FIBER LINK STABILIZATION UNITS

The fiber link stabilization units are used for distribution of laser pulses of the MLO to remote locations along the FLASH tunnel with a desired precision. Their purpose is to minimize the timing jitter of the pulses at the link end, aided by the control software. Relative timing changes can be measured using a balanced optical cross-correlator (OXC) installed inside the stabilization unit. The full optical setup of the OXC is out of scope of this paper, but the principle of operation will be shortly presented [10]. The laser pulse train from the reference source (MLO) is split up into two parts. One of them is directly sent to the OXC arm and the other one is transmitted down the link. At the end of the fiber a small fraction of the light is reflected with a 90 deg. rotation of linear polarization and returns to the OXC arm. The cross-correlation of the reference and reflected pulse trains takes place in the periodically poled potassium titanyl phosphate (PPKTP) crystal, which requires perpendicular polarization states for the second-harmonic generation (SHG) process and occurs when pulses overlap temporally. The signal generated by the SHG process in the PPKTP is transmitted into the first detector of the balanced receiver. The second SHG process is required to find the timing relation between the pulse trains in a balanced, i.e. amplitude-independent, scheme. Therefore, the fundamental pulses are reflected and pass the PPKTP crystal the second time. Due to a different group velocity for light with perpendicular states of polarization, a delay is introduced between the fundamental pulses, which results in a small temporal shift of both generated second-harmonic signals. Because of this, the balanced receiver produces a bipolar signal with a steep slope around the zero-crossing. This, in turn, provides a very precise measurement for the relative timing of the fundamental pulses as the SHG process, and hence the produced output voltage of the detector, is very sensitive to the overlap of the pulses in the crystal. The floor level can be observed when pulses do not overlap. The valid timing information is available only when the OXC is set in the dynamic region, near the zero-crossing where the sensitivity is highest. The OXC characteristic can be seen in the lower left graph of the operator panel in Fig. 12.

A. Link Calibration and Fast and Slow Control

The control algorithm implemented in the software needs to compensate for link length changes introduced by temperature drifts and mechanical stresses, e.g. introduced by vacuum pumps inside the accelerator tunnel, to keep the OXC in the dynamic range and provide valid information about link timing. A PID controller, similar to that used for laser phase-locking, has been introduced for this purpose. Its input is the OXC signal and it drives a fast piezo-stretcher installed in the link stabilization unit to compensate for the detected length change in the range of 15 ps. The piezo-stretcher is used to fine-tune the link.

However, the drifts of the links exceed this value, so an additional motorized delay stage has been introduced into the laser pulse path. The motor is controlled by another software module which not only provides slow tuning of the link length, but also several new features not available previously.

The first one is automatic OXC signal finding routine. When a new link is set up or after a longer shutdown, the dynamic range of OXC has to be found. This procedure was done manually by connecting the OXC signal to an oscilloscope in the laboratory and driving the motor delay stage in order to find the correct position. The new server is able to follow this routine automatically with a single click of a button. First, the OXC floor level is determined by moving the motor by large steps and reading the OXC signal value. Then, the motor is moved to a position where the OXC signal had been present the last time a lock had been found. If the last position is unknown the motor is driven to the middle of the available range. The software drives the motor with steps significantly smaller than the OXC pulse width, scanning for the OXC signal. If the signal is not found in proximity of the initial position, the program exceeds the range and repeats the procedure. If the link is in shutdown for a short time the signal is found very fast. In case of first scanning after setting up a new link or a long shutdown period, the routine can take up to 30 minutes. This limitation comes mainly from the communication delay between the server and an industrial controller driving the motor. Nevertheless, this procedure provides an automatic way of finding the OXC dynamic region without having to physically access the...
hardware.

B. DAC Calibration

Another feature introduced into the server is determining the coefficient translating changes of the PID output (DAC voltage) to changes of link timing. The idea is to scan the whole DAC range, from -6.3 V to 6.3 V, by driving the delay stage motor. If the regulation loop stays closed and the motor is moving, the delay introduced by the motor is immediately compensated for by changing the DAC voltage. The number of steps made by the motor during scanning can be easily recalculated into distance, which then can be expressed as time. It allows to determine what timing change at the end of the link is introduced by a specific voltage change on the DAC output. In case of the test setup used during software development for one of the links available at DESY, the value of this coefficient was calculated at $K_{dac2ps} = 1.24 \text{ ps/V}$. This value is used during coarse tuning and for the fast calibration routine which are the next two features described below.

C. OXC Calibration

In order to find the OXC calibration coefficient ($Cc_{oxc}$), the slope of the OXC dynamic range needs to be found. Previously, this was done using a Matlab script by scanning the motor delay stage near the zero-crossing point which had to be found manually. Then, the received data was linearly approximated and the coefficient was determined. The same algorithm was transferred into the server. The main disadvantage of this approach is a very long time of execution because of the communication delay between the server and an industrial controller driving the motor. Therefore, drifts and other instabilities have significant influence on the received result. Moreover, scanning can only be done when the link is not in use, because the PID lock is opened and the link is not stabilized while the motor is moving. Furthermore, the absolute timing at the link end changes, which causes, for example, the overlap with the electron bunch in a BAM to be lost or changes the timing relation of a synchronized laser. Therefore, a new approach for fast calibration has been proposed and implemented.

Fast calibration is performed by the DSP firmware running the PID regulation, but is triggered from the middle-layer server. A sinusoidal excitation of controllable amplitude is superimposed on the last DAC output as shown in the top left graph in Fig. 13.

The excitation response is the OXC characteristic near the zero-crossing point (see bottom left graph in Fig. 13) which allows the $Cc_{oxc}$ to be calculated. The $K_{dac2ps}$ coefficient is required here in order to translate the DAC voltage to time units. After the fast calibration, the PID resumes its usual operation. The biggest advantage of this approach is the amount of time it takes to do the whole calibration. In the current implementation, the sinusoidal excitation consists of 2048 points and the DSP processing rate is 200 kHz, which leads to 10.24 ms. For such a short period of time, link drifts are too small to have a noticeable impact on the obtained data. Therefore, the received values are constant and do not fluctuate between measurements as was the case with the slow calibration. Moreover, the fast calibration can be done periodically, even during machine operation, between the electron macropulses at a 10 Hz rate. Therefore, the timing relation of the reference pulse train and the end-stations in presence of the electron bunches is not disturbed by the calibration routine.

D. Automatic Coarse Tuning

The automatic coarse tuning of the link timing is in principle the same as in the laser phase-locking scheme. The delay stage motor needs to be driven in order to compensate for the timing drifts that are beyond the range of the piezo-stretcher. What is different are three versions of the correction algorithm. In the simplest one the routine is finished just after the piezo-driver falls back within the limits set by the operator, which triggered the motor movement in the first place. The more advanced correction routine introduces hysteresis into the calculation. The piezo voltage limits are shrunk by the hysteresis factor ($H_f$) which may vary from 0 to 0.9. In this case, the end of correction happens when the piezo is in the range calculated by the formula $(1-H_f) \times V_{piezo\_max} < V_{piezo} < (1-H_f) \times V_{piezo\_max}$. Here, the motor is also moved by a constant number of steps defined by the operator. The most advanced algorithm employs the $K_{dac2ps}$ coefficient. It allows the software to calculate the exact number of step which the motor needs to be moved by to put the piezo voltage back into the desired limits. This makes the correction algorithm much faster because the bottle neck in the system is communication between the server and the motor. In this case the server only has to generate a single command for the delay stage motor which significantly decreases the time of the correction routine. Not only is this type of coarse tuning the fastest one, it also limits the number of times the motor needs to be moved, extending its lifetime.

VI. EXCEPTION HANDLING

Many of the devices that are being supervised by the servers described in this paper are relied on by other systems that require certain operation conditions to be met. Additionally,
the hardware that is controlled has physical limits which should not be exceeded because of possible damage. This mostly applies to the stepper motors and piezo elements. In cases when those requirements are not met, appropriate actions need to be taken to make sure that no harm will be done to the rest of the machine as well as to inform the operators of possible problems so that it is easy to identify and solve them. This means that the exceptions need to be handled in software as far as control of the devices is concerned as well as in the operator panels where easy-to-read indicators and warning messages should appear. The latter action is very important since not all exceptions can be handled by software and expert intervention is necessary, for example when a laser loses its mode-lock or when the injector laser timing changes by an amount which cannot be compensated for with the installed delay stage.

In the setups discussed in this paper there are two major common sources of exceptions that need to be handled by both servers.

A. Error Connecting to Hardware

In order to monitor and control properties such as the piezo voltage or the motor position, the software needs to connect to low-level servers or industrial controllers, that are responsible for communication with the hardware. An example of such a piece of software is the DSP server interacting with the PID regulator on the DSP chip. If those front-end servers fail, be it because of hardware communication issues or simply because they are stopped manually, the middle-layer servers do not have a way to obtain data such as ADC readouts or DAC output values. It is then impossible to determine the value of the piezo voltage the DSP regulator provides and so the control of this voltage may not take place. Similarly, the inability to connect to the motor driving server makes the coarse tuning unavailable. In both cases the coarse tuning functionality is disabled by the server and an indicator in the panel tells the operator that the status of the front-end servers is invalid.

B. Coarse Tuning Failure

It is possible that the tuning feature will not do what it should, that is the piezo voltage level will not be brought back within the desired limits. This is a very unlikely situation but may happen if the motor is unresponsive, if some connections along the way fail or even if the piezo voltage jumps by a significant amount that is beyond recovery. In order to prevent driving the motor indefinitely, or temperature-tuning of the Origami laser, which can be even more harmful, only three tuning attempts take place. If those attempts do not cause the piezo voltage to come back into the threshold limits, the PID feedback loop is opened and the automatic tuning is disabled. This means that the phase-lock is lost, which is indicated in the operator panel, but usually in those cases the lock is already not there or is in a very unstable condition so it is safe to disable the regulation. An alternative, where the control loop acts on undefined signals driving the piezo in an unspecified way is unacceptable.

VII. Future Development of the Optical Synchronization Software

Although a lot of progress has been done over the last year, the optical synchronization software development faces new challenges and still presents much room for improvement as far as new functionality is concerned. Also, the emergence of the µTCA standard [11]–[13] as the replacement of VME, especially in physics applications [14], [15], means that adaptation of software needs to take place.

A. Laser-to-Laser Phase-locking Control

It has been proposed to use the cross-correlator to lock a laser to a reference light source. This is similar to the approach used in the link phase-locking scheme, only there the same light source is used as both inputs – one in the forward direction and the other one reflected from the link end. The details of the optical setup are beyond the scope of this paper but can be found in other publications [16]. In case of two light sources, the signal is less stable and the optical alignment is more difficult. Consequently, the regulation gains need to be tuned with more care. Also, the switching between the phase detector reference signal and the OXC reference signal is more complicated because of the temporal characteristic of the latter signal. More accuracy in the switching procedure parameters is required. This feature is currently under development and first tests in laboratory conditions have been completed.

B. Migration to µTCA Infrastructure

The VME architecture is quickly becoming obsolete as the speed of the computation blades as well as the reliability and availability of the crates and modules becomes less satisfactory to be used in advanced control environments. Migration of the existing control system to run on a modern µTCA infrastructure is the next big challenge in front of the optical synchronization system. Some parts of the existing control systems at FLASH, for example the LLRF system, have already migrated to the new architecture with success during test runs [17]. The middle-layer servers described in this paper are platform-independent and can run on any hardware structure that supports DOOCS. On the other hand, the low-level servers as well as the entirety of firmware of reprogrammable devices (FPGAs, DSPs, etc.) will be rewritten and redesigned to fully use the advantages of modern, fast hardware.

VIII. Conclusions

Last year resulted in a significant improvement of the software in control of the optical synchronization system at DESY. Several outdated servers got replaced with newer versions and many features have been added. This paper focused on two examples of the improved servers, both based on the redesigned, customizable, DSP-based PID regulator. The DSP firmware works now with a processing rate of up to 250 kHz which is an improvement of three times over the previous implementation [2].
Most of the new features in the laser locking software and the link locking software were implemented in order to make those procedures less prone to human error with many of the activities previously done by the operators now automated. Options such as signal discovery for link locking or switching between different reference signals for laser locking do with a remote single press of a button what earlier had to be done manually with an oscilloscope in the actual laboratory. This is especially important for devices that are placed in locations where access is forbidden or at least unwelcome. For example, the MLO and the link boxes located in the synchronization hutch are highly sensitive to vibrations and temperature changes, which are obviously introduced with people walking around them. Now, with the automated procedures, in many cases, there is no need to physically be present near the equipment. Furthermore, with the redesigned operator panels, it is much easier to recognize possible errors in the system due to indicators that are driven by exception handling routines implemented in the software. The presented high-level software solutions are hardware-independent and the code is portable to any architecture able to support DOOCS used at DESY. Therefore tests of the software can be thoroughly performed at FLASH and later seamlessly moved to operate in the European XFEL environment.

The next big step for the optical synchronization is migration to a modern µTCA infrastructure. However, the middle layer servers, described in this paper, are architecture-independent and will be able to work on top of the new firmware and front-end software which are also under development. A step up in the computational power capabilities as well as data transfer and acquisition speeds will result in an increased performance of the optical synchronization system in terms of maximizing stability of crucial components such as fiber link units and MLOs.

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REFERENCES


