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BEAM POSITION FEEDBACK SYSTEM SUPPORTED BY KARABO AT EUROPEAN XFEL

V. Bondar*, W. Ehsan, M. Beg, M. Bergemann, C. Carinan, R. Costa, F. Dall'Antonia, C. Danilevski, S.G. Esenov, R. Fabbri, H. Fangohr[1], G. Flucke, D. Fullà Marsà, A. Galler, G. Giovanetti, D. Göries, J. Grünert, S. Hauf, D. Hickin, T. Jarosiewicz, E. Kamil, Y. Kirienko,

A. Klimovskaia, T. Kluyver, D. Mamchyk, T. Michelat, I. Mohacsi, A. Parenti, D. Rueck, H. Santos, R. Schaffer, A. Silenzi, C. Youngman, J. Zhu, P. Zalden, S. Brockhauser[2]

European XFEL GmbH, Holzkoppel 4, 22869, Schenefeld, Germany

[1]also at University of Sauthampton, SO17, 1BJ, Southampton, United Kingdom

[2]also at Biological Research Center of the Hungarian Academy of Sciences, Szeged, Hungary and at University of Szeged, Arpad ter 2, 6701 Szeged, Hungary

Abstract

The *XrayFeed* device of Karabo [1, 2] is designed to provide spatial X-ray beam stability in terms of drift compensation utilizing different diagnostic components at the European XFEL (EuXFEL). Our feedback systems proved to be indispensable in cutting-edge pump-probe experiments at EuXFEL.

The feedback mechanism is based on a closed loop PID control algorithm [3] to steer the beam position measured by the so-called *diagnostic devices* to the desired centred position via defined actuator adjusting the alignment of X-ray optical elements, in our case a flat X-ray mirror system.

Several *diagnostic devices* and actuators can be selected according to the specific experimental area where a beam position feedback is needed. In this contribution, we analyze the improvement of pointing stability of X-rays using different diagnostic devices as an input source for our feedback system. Different types of photon diagnostic devices such as gas-based X-ray monitors [4], quadrant detectors based on avalanche photo diodes [5] and optical cameras imaging the X-ray footprint on scintillator screens have been evaluated in our pointing stability studies.

INTRODUCTION

At the European X-ray Free Electron Laser (EuXFEL) facility there are currently three X-ray optical beam lines which provide soft and hard X-ray photons to six instruments. In order to control both the hardware components of the beamline and the data acquisition from the instruments, EuXFEL has developed in-house a control system, Karabo. Hardware devices and system services are represented in this control system as Karabo software devices, and are distributed among various control hosts, thus making Karabo a distributed control system. The Karabo design is event-driven, offering subscription to remote signals to avoid polling for parameter updates. Devices communicate via a central message broker using language (C++ and Python) agnostic remote procedure calls (RPC) [6, 7]. Here, we focus on the design and usage of one such device, called *XrayFeed*. Its aim is to continuously stabilize the beam position in experiments, removing the need for direct user manipulation to ensure beam stability.

The idea of feedback control is to make a setup that ensures that any deviation of a measured parameter (beam position) from the set point (desired position) will be corrected, thus providing stability (e.g. beam position in a given plane). It is implemented using the PID (Proportional-Integral-Derivative) mechanism.

The *XrayFeed* software device (see Fig. 1) can be used in conditions where external disturbances to the positions of mirrors under control are not predictable and when the PID mechanism satisfies positional accuracy requirements [3]. The proposed device is robust for PID tuning process as well as for PID controller operation. The device allows different actuators and different diagnostic devices to be involved in the feedback control schema and monitoring of the real time behavior of the system under PID control. By so-called diagnostic detector we mean a diagnostic device whose output can be used as a 'measured' signal in feedback control loops. *XrayFeed* has a flexible implementation allowing choice of diagnostic device for feedback control and characterization and optimization of the feedback solution used. In this paper we describe the design of *XrayFeed* software device and present results of its application for precise position feedback control in the flat X-ray mirror system using different actuators and diagnostic devices.

BEAM POSITION FEEDBACK SETUP

Block diagram of *XrayFeed* device implementing PID algorithm is illustrated in Fig. 2. Actual beam position in a plane normal to the beam is measured by a diagnostic device (*Px* signal on diagram) and is inputted into the PID controller whose aim is to minimize beam position displacement error *e(t)*. This error is processed according to the Proportional-Integral-Derivative algorithm using PID gains determined during a tuning process. Resulting PID signal is set in the actuator device as an input voltage *u(t)*.

* valerii.bondar@xfel.eu

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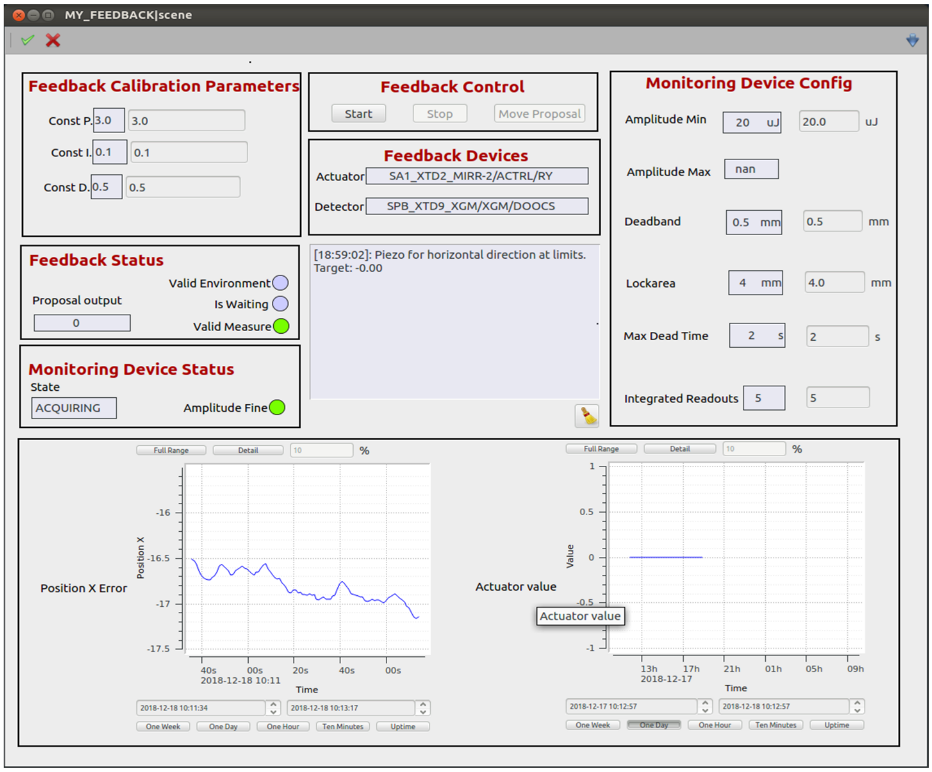

Figure 1: Karabo Graphical User Interface Dialog window of *XrayFeed* device.

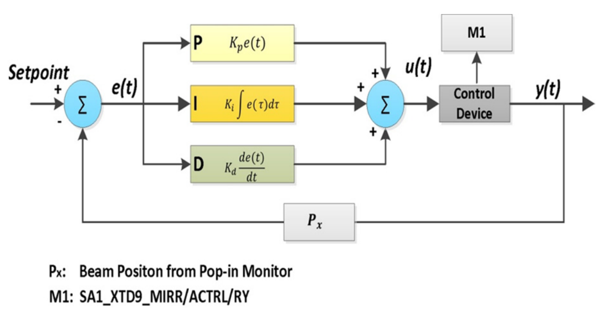

Figure 2: Diagram of PID controller in a feedback loop with Intensity Position Monitor (IPM) and Mirror (M1).

A number of beam position monitoring hardware systems have been successfully used:

- X-Ray Gas Monitor (XGM)
- Pop-in imager
- Intensity and Position Monitor (IPM)

XrayFeed is required to guarantee beam position stability despite possible external disturbances, therefore all monitoring systems must provide stable control process with required response times and should cause no overshoots and wind-ups.

Integration in Karabo

Figure 3 shows location layouts for devices that take part in the described feedback control within the EuXFEL photon optics tunnels and instrument beam lines.

To enable integration of XGM data into Karabo a software Karabo device was developed.

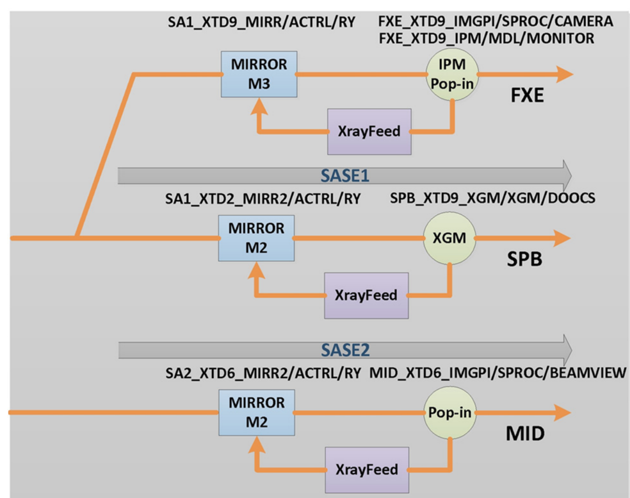

Figure 3: Block diagram of acuators and diagnostic devices taking part in feedback setups. Setups of three instrument lines are shown – SPB, FXE and MID.

Imagers are integrated in Karabo as separate devices. Imager properties and functionality can be accessed by users during run-time. Images acquired as well as corresponding image data can be saved via DAQ system to hdf5 files allowing offline quality control. For the feedback control the image acquiring frequency was found to be satisfactory at 10 Hz with image size 1640x1240 pixels and 16 bit resolution.

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TUNING RESULTS

To determine optimal *P*, *I*, *D* gains with each diagnostic device in a control loop the following manual tuning procedure was performed in steps:

- Firstly, the optimal actuator working region has to be found: output range in voltages, output deadband, lock area, etc. Then, the optimal frequency at which PID output signals can be sent to actuator has to be evaluated
- By increasing P gain magnitude, with I and D set to zero, the moment when PID output starts oscillating around the desired reference position or a position shifted with respect to the desired position is found
- With P gain set to ½ P found previously I gain is increased until there is no offset between oscillation average and desired position. If at the begin of this step there is no offset already and control output oscillates around desired value then I gain is left zero
- With P and I set to values found previously D gain is increased until the beam position approaches the desired position within minimal time but with control process still being stable and with minimal overshoots.

Imager as Feedback Diagnostic Device at FXE experiment

Pop-in monitors are imagers with large horizontal beam offset which are used for beam finding and alignment. To compute the beam position image processing is used. The pop-in imager (located in XTD9 photon optics tunnel) is used as the diagnostic device in FXE instrument line feedback setup with piezo actuator of mirror M3 (located in XTD9 photon optics tunnel) as actuator (see FXE part on Fig. 3). In this setup, voltage applied to RY (y-axis rotation) piezo actuator is the controlled value, beam position along *x*-axis in a plane normal to beam as measured by imager device is the target value, and the set point is the new target value for the feedback.

After PID gains were determined during the manual tuning process, following steps described above, the accuracy and stability of control process position correction was tested by displacing (changing RY) beam from the desired position and monitoring position recovery driven by the PID algorithm back.

Figure 4 shows an example of the progress of the beam position in time without and with feedback control. It can be seen that applying feedback control improves systems performance with respect to stability and response type.

X-Ray Gas Monitor (XGM) as Feedback Diagnostic Device at SPB Experiment

EuXFEL runs in burst mode with 10 Hz repetition rate of the bursts and rates between ~10 kHz and 4.5 MHz within the burst. The XGM setup provides non-invasive single-shot pulse energy measurements, average beam position monitoring and pulse resolved measurements [4]. While monitoring pulse energy and beam position the XGM is able to resolve separate photon pulses at MHz rates. Diagnostic device monitors beam position in plane normal to the beam position with accuracy +/- 10 µm within a range +/- 1 mm. In this setup the feedback is designed to compensate only the slow drifts as detected by the average beam position within a burst. It therefore averages out the unpredictable fast jitters, providing moving average.

The SPB instrument line XGM (located in XTD9 photon optics tunnel) feedback was used as the diagnostic device with piezo actuator of mirror M2 (located in XTD2 photon optics tunnel) as actuator (see SPB part of Fig. 3). Before manual PID tuning, the optimal operational region was found for XGM. Stability of tuned PID feedback was checked by displacing mirror M2 with following beam position return to initial point. With same settings of the piezo actuator as in case of the pop-in monitor setup, applying feedback control improved the correction of beam position back to the initial position when compared to correction done without feedback. Setting times to required beam position where similar to the ones observed in case of pop-in monitor feedback setup (right plot on Fig. 4)

Intensity and Position Monitor (IPM) as FeedBack Diagnostic Device

The device allows ADC conversion at rates 2 GS/s (12 bit), burst of 120 pulses at 1.1 MHz Repetition rate, single pulse resolved readout and firmware-based peak integration. The IPM (located in FXE instruments area) was used as feedback diagnostic device with piezo actuator of mirror M3 (located in XTD9 photon optics tunnel) as actuator (see FXE part on Fig. 3). It has to be noted that since IPM is located in FXE instruments area it cannot be used continuously. Unlike XGM and pop-in imager detectors IPM can be used in feedback loop only when FXE hutch is searched. The same settings were applied to the piezo actuator as in case of setups with imager and XGM as diagnostic devices. After manual PID tuning in steps as described above, the PID feedback stability was checked by displacing mirror M3 and following the return of the beam position to initial point. When compared to correction of beam position without feedback using XRayFeed improved setting stability with setting times similar to the ones observed in pop-in and XGM feedback setups (see right part of Fig. 4)

CONCLUSION

We have developed feedback software device, *XrayFeed*, to provide spatial X-ray beam stability in terms of drift compensation for flat X-ray mirror system. Robustness of the feedback software solution allowed us to use different types of diagnostic devices according to the specific experimental area where a beam position feedback is needed. Our solution provides robust and reliable control with performance characteristics like reaction time and stability with respect to external disturbances which are difficult to achieve when done manually.

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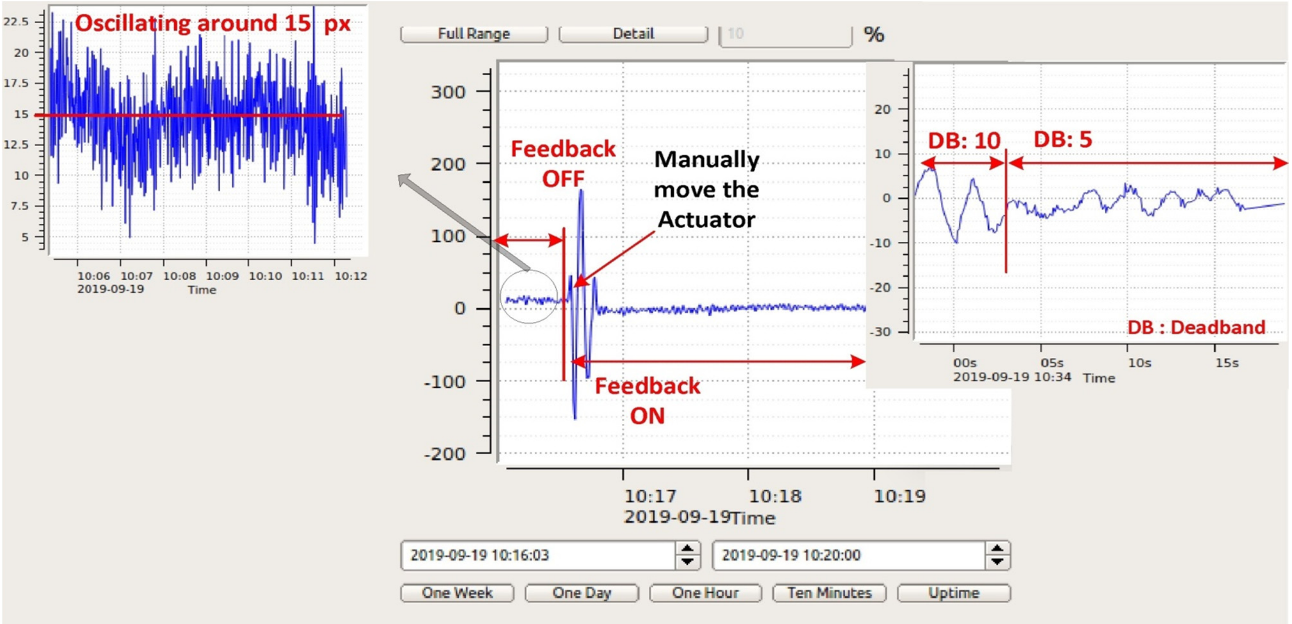

Figure 4: PID algorithm tuning results with pop-in imager used as a diagnostic device. Beam positions along *x*-direction in a plane normal to the beam is shown changing with time (plot in the middle), all positions are in pixels. System behavior in time without (left plot) and with (right plot) feedback control is shown. Beam stabilization with two different output deadband magnitudes set to *XrayFeed* PID control (right plot).

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