ISBN: 978-3-95450-237-0 ISSN: 2673-5512 doi:10.18429/JACoW-PCaPAC2022-THP13

CONTROL AND TIMING SYSTEM OF A SYNCHROTRON X-RAY CHOPPER FOR TIME RESOLVED EXPERIMENTS

U. Ristau, V. Palnati, J. Meyer, D. Jahn, S. Fiedler
European Molecular Biology Laboratory, EMBL, Hamburg, Germany

Abstract

A mechanical X-ray chopper for the Small Angle Scattering (SAXS) beamline P12 operated by the EMBL Hamburg Unit at the PETRA III synchrotron on the DESY campus has been developed. In this paper we will describe how control and timing for time resolved experiments have been implemented.

INTRODUCTION

In the time resolved SAXS experiments carried out at P12, the structural changes of proteins in solution are studied. The scattering of the sample is recorded with a fast area detector as a function of time after a reaction has been triggered. As the samples are sensitive to radiation damage, it is desirable to minimize the exposure to the X-ray beam between two frames. This is achieved with the chopper that can be adjusted to variable duty cycles.

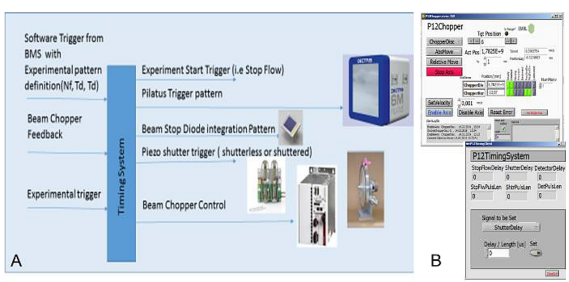

Figure 1: (A) Schematics of instruments to be synchronized for an experiment. (B) Clients for the timing control of the experiment and of the chopper [1].

Also pump and probe measurements can be carried out with chopper systems where the sample is probed with a short X-ray pulse after a laser excitation [2]. For such experiments several systems or processes must be synchronized like storage ring bunch pattern, sample injection, excitation laser pulse, intensity monitor signal, shutter opening, detector trigger, and the chopper revolution frequency that must be kept very constant (Fig. 1A). The solution chosen for the timing and synchronization system is based on EtherCAT electronics [3]. Servers and clients are integrated into the TINE control system [4] with LabView [5] (Fig. 1B) and TwinCAT [6].

CHOPPER DESIGN & IMPLEMENTATION

Different designs for X-ray beam choppers used at synchrotrons have been suggested ranging from the milli- to the sub-microsecond range (see for example [2, 7]).

Our beam chopper design (Figs. 2A, 2B) is based on a rotating disk that has a 10-fold symmetry cut-out pattern with stepped slots of different length in angular direction (Fig. 2C). When the disk is rotating the beam is chopped as a function of the length of the slots. The chopper can be translated laterally so that the X-ray beam can be transmitted at positions with different slot lengths. In this manner variable duty cycles can be adjusted. The chopper can also generate short X-ray pulses. For this, a narrow slot at the outer diameter of the disk is used. The pulse length can be varied by adjusting the angular velocity.

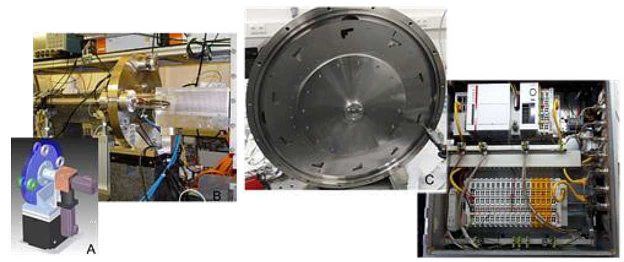

Figure 2: (A) Mechanical design of the chopper, (B) Photograph of installation at P12 beamline, (C) Photograph of the chopper disk, (D) Fieldbus electronics for chopper control.

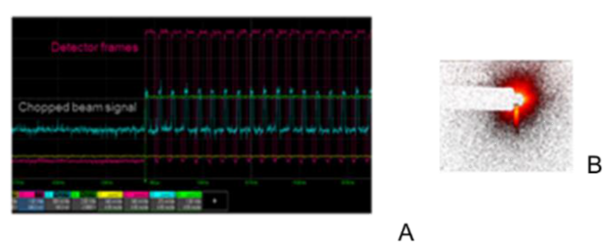

Figure 3: (A) Chopped beam signal at 750 fps measured with an intensity monitor at the detector with ¼ duty cycle. (B) Residual parasitic scattering pattern in the SAXS region of the chopped beam at 750 Hz.

Examples of the system in operation are depicted in Fig. 3. The chopper can run with a beam chopping frequency of up to 1500 Hz. A frequency stability of $<10^{-5}$ can be achieved and the jitter is below 2 µs. The shortest X-ray pulse that can be produced is 10 µs.

CHOPPER CONTROLS

The TINE Control system is used as transport layer at the EMBL Hamburg beamlines at PETRA III [1, 8–10]. All server and client communication are based on the TINE protocol. The TINE CDI (Common Device Interface) [11] has

ISBN: 978-3-95450-237-0 ISSN: 2673-5512 doi:10.18429/JACoW-PCaPAC2022-THP13

a plugin for ADS (Automation Device Specification) communication with TwinCAT. ADS is the TwinCAT internal communication protocol to link IOs, NC (numeric control) and the PLC tasks. TwinCAT and TINE servers are both running embedded on a DIN-Rail PC. The communication between the real time PLC and the control system is executed as fast local loopback data traffic. The TwinCAT real time software PLC is executed on the real time kernel of the Intel PC. The TwinCAT real time Operating System (OS) and the Window OS share the PC hardware resources. 80% of the CPU resources for the PLC task execution are attributed to the standard TwinCAT installation used by EMBL. The TwinCAT development environment and the TINE installation are installed on the Windows partition. They have access to 20% CPU resources in this configuration. The PLC and NC host the critical processes for real time operation and communication including the IOC data traffic based on the EtherCAT [3] protocol.

After programming the TwinCAT PLC, code is downloaded to the real time OS part of the PC and executed in the real time partition. The real time EtherCAT protocol passes through all field bus modules and exchanges data with the IOC modules on the fly.

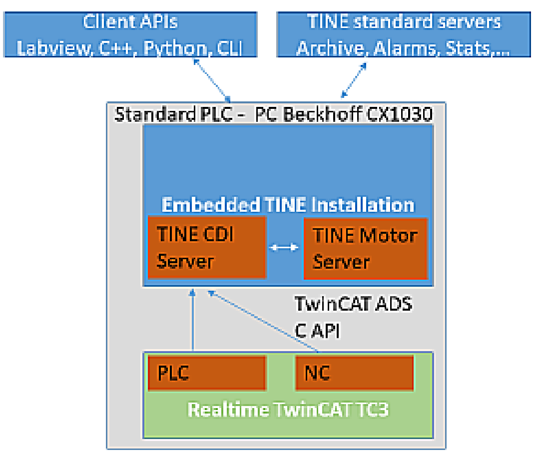

Figure 4: Motion control architecture.

ADS is also the API for communication between Beckhoff [4] and the TINE protocol. The bus plug for TwinCAT based on ADS communication gives access to all defined ADS variables, if configured. Fast access to IOC data is integrated through this interface. Motion control under TINE is performed with the TINE Motor server. The TINE Motor server is equipped with a TwinCAT NC interface (see Fig. 4).

CHOPPER MOTOR AND MOTOR CONTROLLER

A fast rotation 4-pair DC motor with 9000 RPM has been chosen for driving the chopper wheel (AM832, Beckhoff). The corresponding motor controller (AX5000, Beckhoff) operated by the TwinCAT NC offers different motion profiles. The "velocity control" profile has been chosen and implemented for the chopper application.

The rotation velocity of the motor runs in a feedback loop where the drifts of the velocity are corrected with respect to the nominal frequency supplied by an external frequency generator. For this purpose, a function generator (HP3314) has been implemented. Alternatively, the bunch clock of the PETRA III synchrotron, provided by DESY, has been integrated in a second step of the development and can be used for the velocity control and the timing of the experiment. Due to the insertion of the bunch clock, a synchronization of the data acquisition with respect to the revolution frequency of the PETRA III electron beam can be achieved (see schematic in Fig. 5).

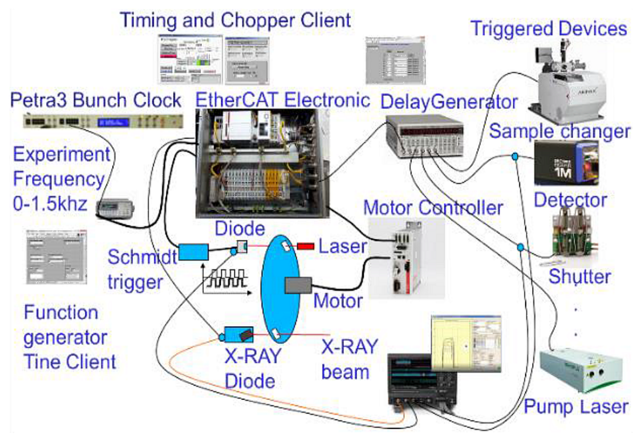

Figure 5: Layout of chopper control including connectivity for timing of the experiment.

A diagnostic laser has been installed at the chopper disk in order to monitor the speed of the disk. The laser beam is chopped by the same slot pattern of the disk as the X-ray beam. This way, the signal of the X-ray and the laser beam have the same timing pattern. The signal of the chopped laser beam is detected by a fast photo diode (Centronic) that has a signal rise time of <2 ns/100 mV and an afterglow of less than 10 µs. The diode signal is then fed into an adjustable TTL Schmitt trigger. The TTL output signal of the Schmitt trigger indicates when the X-ray beam is blocked or transmitted by the chopper. The advantage of using this additional diode signal is its fast readout and to have the information for synchronization available also without the X-ray beam permanently available. The feedback control is implemented in the TwinCAT PLC for which the fasted available cycle time has been adjusted to 50 µs whereas the NC cycle time is 2 ms. With these parameters, drifts of the disk velocity can be corrected.

TIMING SYSTEM

The timing system, implemented as PLC in TwinCAT, is based on an XFC (extreme fast control) module of Beckhoff. The module can generate outputs with nanosecond accuracy. The distributed clock functionality of the Beckhoff system has been used to generate precise trigger timings for the connected devices like detector, laser, or sample delivery system. Depending on the experiment, the timing system

ISBN: 978-3-95450-237-0 ISSN: 2673-5512 doi:10.18429/JACoW-PCaPAC2022-THP13

offers different modes of operation for which different setups are used. The trigger distribution is based on a frequency divided input signal generated by the bunch clock.

Bunch synchronous outputs with 100 Hz, 1 kHz, and 10 kHz frequencies are supplied by the frequency dividers. These signals are used to create the master trigger signals for the experiments which in turn serve as input signals for either an EtherCAT delay generator (EL1258/EL1259) or, as a high-performance alternative, a pulse and delay generator (StanfordResearchSystems DG 645) with up to 4 outputs with picosecond accuracy.

In "variable frequency" control mode the frequency generator creates master trigger pulse patterns which can be delayed by the trigger distribution. A single trigger or series of triggers can be generated.

In "free running" mode the frequency is defined by the EtherCAT master clock. A start pulse to trigger the experiment is provided as input to the trigger distribution module.

CONCLUSION & OUTLOOK

The chopper system has been implemented into the setup of the P12 beamline and is available for time resolved SAXS experiments for the user community. The different slot lengths of the chopper disk in combination with the possibility to vary the speed of the chopper motor enables a flexible timing for each individual experiment. The timing system provides trigger outputs for several devices in different experimental modes with variable pulse length and the option to run with variable repetition rates.

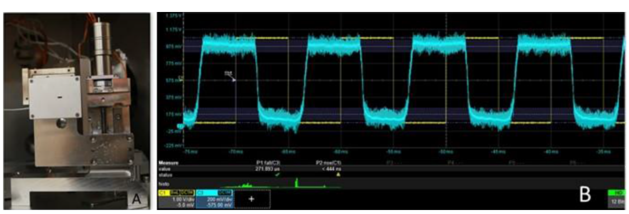

Figure 6: EMBL/SmarAct fast shutter operated at maximal repetition rate of 100Hz at the EMBL P12 Beamline.

The functionality of the system can be further enhanced by inserting an improved fast beam shutter. By combining the X-ray chopper with a millisecond shutter it will be possible to isolate single exposures or pulse trains determined by the exposure length of the chosen chopper slot. A prototype of such a shutter (Fig. 6) has been designed and built in collaboration with the company SmarAct [12] specialized on piezoelectric applications. The shutter has an opening/closing time of 500 µs.

REFERENCES

[1] U. Ristau *et al.*, "The EMBL Beamline Control Framework BICFROCK", in *Proc. PCaPAC'14*, Karlsruhe, Germany, Oct. 2014, paper WPO012, pp. 60-62.

[2] T. Graber *et al.*, "BioCARS: a synchrotron resource for time-resolved X-ray science", *J. Synchrotron Radiat.*, vol. 18, pp. 658-670, 2011. doi:10.1107/S0909049511009423

[3] EtherCAT, https://www.ethercat.org

[4] TINE (Three-fold Integrated Networking Environment), https://tine.desy.de

[5] National Instruments, https://www.ni.com

[6] Beckhoff, https://www.Beckhoff.com

[7] M. Gembicky *et al.*, "A fast mechanical shutter for submicrosecond time-resolved synchrotron experiments", *J. Synchrotron Radiat.*, vol. 12, pp. 665–669, 2005. doi:10.1107/S090904950501770X

[8] U. Ristau *et al.*, "The Concept of EMBL Beamline Control at PETRA III", in *Proc. PCaPAC'08*, Ljubljana, Slovenia, Oct. 2008, paper MOZ02, pp. 22-24

[9] R. Bacher, "The new Control System for the Future Low-Emittance Light Source PETRA3 at DESY: Sprinting to the Finish", in *Proc. ICALEPS'07*, Oct. 2007, Knoxville, TN, USA, paper TPPB27, pp. 217-219.

[10] U. Ristau *et al.*, "Control of the New EMBL-Hamburg Sample Changer", in *Proc. PCaPAC'08*, Ljubljana, Slovenia, 2008, paper WEP019, pp. 210-211.

[11] P. Duval and H. Wu, "Using the Common Device Interface in TINE", in *Proc. PCaPAC'06*, Newport News, VA, USA, pp. 17-19.

[12] Smaract, https://www.smaract.com