# EXPERIENCE GAINED DURING THE COMMISSIONING OF THE UNDULATOR CONTROL SYSTEM AT THE EUROPEAN XFEL

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*Abstract*

The European XFEL is a fourth-generation light source, which will start the operation in spring 2017. Three undulator systems - SASE 1, SASE 2 and SASE 3 - will be used to produce photon beams. For operation of all undulator systems, in total 91 undulators have been produced and commissioned. SASE 1 and SASE 3 undulator systems, consisting of total 56 undulator cells, have been installed and prepared for the operation in the tunnel in spring and summer 2016. SASE 2 will be installed by the end of 2016. This paper describes the commissioning process of the whole undulator control system and reports about the experience gained over the entire duration of undulator control system commissioning.

## INTRODUCTION

Commissioning of the undulator control system was a multilayer task and was carried out in several steps. The strategy of commissioning was to test all hardware components at least once before those components would be installed in the tunnel. The same is true for the software development. Each release of software has been tested first using a simulation software and then on the undulator system test setup, before using it for the real undulator system.

## COMMISSIONING OF THE HARDWARE

### *Undulator System Test Setup*

An undulator system consists of an array of up to 35 undulator cells installed in a row in the tunnel along the electron beam. It consists of up to 35 undulator segments and intersections. The system is controlled by a central control node (CCN). It is installed in the control room, which is located about 1 km away from the undulator system. CCN communicates with the undulator cells over optical fibers, and the communication between individual cells is implemented using copper Ethernet and EtherCAT cables. Two media converter racks (MCR) installed from both sides of the system are used to convert signals from copper carriers to optical fiber carriers and vice versa. These two MCR racks are necessary for implementation of the redundant ring topology used for control of the undulator system.

It was obvious that all the envisaged components were to be tested before installation in the tunnel. For this purpose, an undulator system test setup was built in the undulator hall (see Fig. 1). The only difference between the real undulator system and test setup was the amount of undulator cells, which was reduced to four in the test setup. This test setup allowed to test the complete hardware components before installation in a tunnel. It also allowed developing the global control system software three years ahead of the installation of the system in the tunnel.


Figure 1: Undulator system test setup in the hall.

### *Control Components For Undulator Segments*

The undulator control system needed to be commissioned before the magnetic commissioning of the undulator. This process is described in details in reference [1]. The undulator control hardware contains components installed on the undulator frame, as well as in the undulator control rack (UCR). The rack is connected to the undulator using a cable bundle. The first operation of the undulators and UCRs took place at the companies producing the undulator frame. It included only the operation of the motors, encoders and limit switches installed on the frame.

For the magnetic commissioning of the undulator it was necessary to bring it into the magnetic measurement hutch. After placing it in the hutch, the undulator had to be connected to the control rack installed on the rooftop of the hutch. Control of all undulators introduced to the hutch can be carried out using the same rack. Nevertheless, it was decided to commission the undulator with the assigned control rack. During this commissioning, a complete set of tests was carried out. This strategy allowed to check the whole undulator control system before installation in the tunnel and helped to discover of hardware-related problems in more relaxed situation on about 5% of the system.

### *Intersection Control Components*

The intersection control components consist of the hardware installed on the Quadrupole Mover (QM) and Phase Shifter (PS) as well as Intersection Control Rack (ICR). The phase shifters have been produced by three different companies. For production and adjustment pur-

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ISBN 978-3-95450-189-2

poses, as well as for the factory acceptance tests (FAT), dedicated PS control cabinets were produced and delivered to these companies. In a similar way, companies producing the QMs were assisted. The ICRs were produced by one company and also needed to be tested before the delivery to European XFEL. Therefore, one PS and one QM were provided to the company for the FAT.

After delivery of all components to the European XFEL, site acceptance tests (SATs) were arranged. A separate, air conditioned hutch was prepared for the SATs. The hutch was equipped with a granite stone to fix the QM and PS. The tests with QMs and PSs were carried out in full compliance with technical specifications [2, 3]. If any of the components didn't match the specifications, this component was sent back to the manufacturer. Our experience has demonstrated that after the SAT only 1% of the delivered QMs and PSs needed to be returned. Approximately the same failure rate has been observed for ICRs.

## SOFTWARE FOR COMMISSIONING OF AN UNDULATOR SYSTEM

A specific feature of undulator systems for free-electron lasers is the large number of recurring elements. Each undulator cell in the system at European XFEL is controlled by a local control node (LCN). The LCN is an industrial PC produced by Beckhoff Automation GmbH running a Programmable Logic Controller (PLC) implemented in the TwinCAT system. The TwinCAT runs under the Windows operating system. The software running on each LCN must be identical, although each cell component has its individual settings. The other aspect which should be taken into account is the need to have possibilities to update the version of the TwinCAT software as well as specific firmware. These arguments lead to the decision to develop software which will automate this process.

### *Setup, Configuration and Maintenance of the Undulator Control System*

The Image Deployment Automation (IDA) software was developed in preparation of making the system operational [4]. The main objectives of IDA are following:

- Minimize the time used to set up, configure and maintain undulator systems;
- Interlink the configuration to the Undulator Systems Database (USD);
- Automate as many operations as possible;
- Provide possibility to create a master image and follow the version numbering of the images;
- Distribute the master image to the LCNs;
- Provide capability to quickly update Beckhoff TwinCAT, whenever an update is released
- Minimize presence in the tunnel;
- Eliminate errors arising from manual work.

IDA components are distributed between CCN, LCN and database (see Fig. 2). The DESY network and the private LAN of the undulator system are separated from each other, but interlinked by the CCN. DB Proxy is establishing communication between the Undulator Systems Database and the Client, which is residing on the LCN. The Image Manager is issuing different commands to the Client. Preboot eXecution Environment (PXE) technology, implemented in the BIOS of the LCN, made it possible to develop IDA. A tiny Linux Distro, which is loaded on LCN through PXE, is intended to write or clone images. At the same time the CCN is serving as storage for LCN images. The Client application is performing the actual work of configuration.

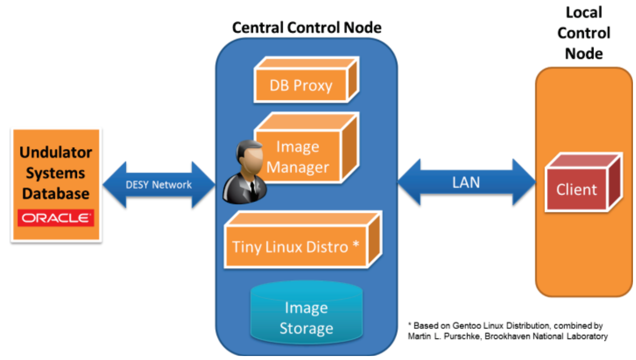


Figure 2: Schematic layout of the components of IDA.

One of the main functionalities of IDA is updating the images on the LCNs. The actual command is issued from the Image Manager application. The Image Manager is triggering an update command to LCN and rebooting it. As a result of the master boot record (MBR) handling, the LCN is not booting from compact flash, but starts to boot the operating system from the network using PXE. Afterwards, Tiny Linux distribution is booting on the LCN and running a dedicated script. The script, in this particular case, is reading an image from CCN Image Storage and writing it onto the LCN disk. Then LCN reboots into normal Windows. Lastly, the Client application starts running on the LCN, connecting to DB through the DB Proxy and configuring LCN according to its location. The main user interface after accomplishing the update of LCNs is illustrated in Fig. 3.

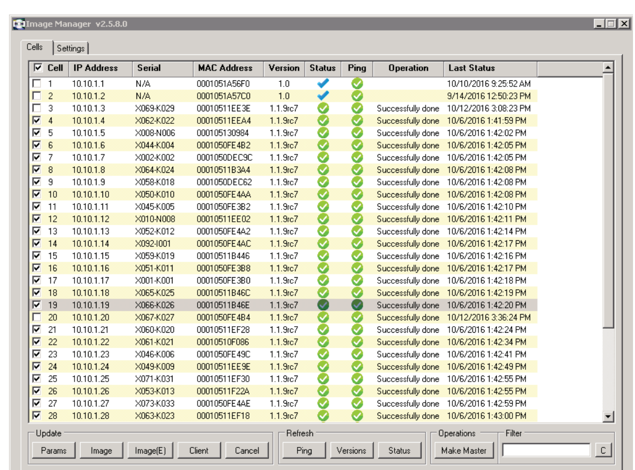

Figure 3: Main user interface of the IDA.



ISBN 978-3-95450-189-2

After the assembly of the undulator system in the tunnel the procedure of putting the system into operation took two working days. The main problems encountered were related to the quality of the Ethernet connections between the LCNs. The performance of IDA for distribution of an image to LCNs, is strongly dependent on the network bandwidth. For an undulator system with 35 cells, it takes approximately 3 hours.

### *Undulator System Tester (UST)*

The next step after putting the undulator system into operation is the commissioning of all control components that belong to it.

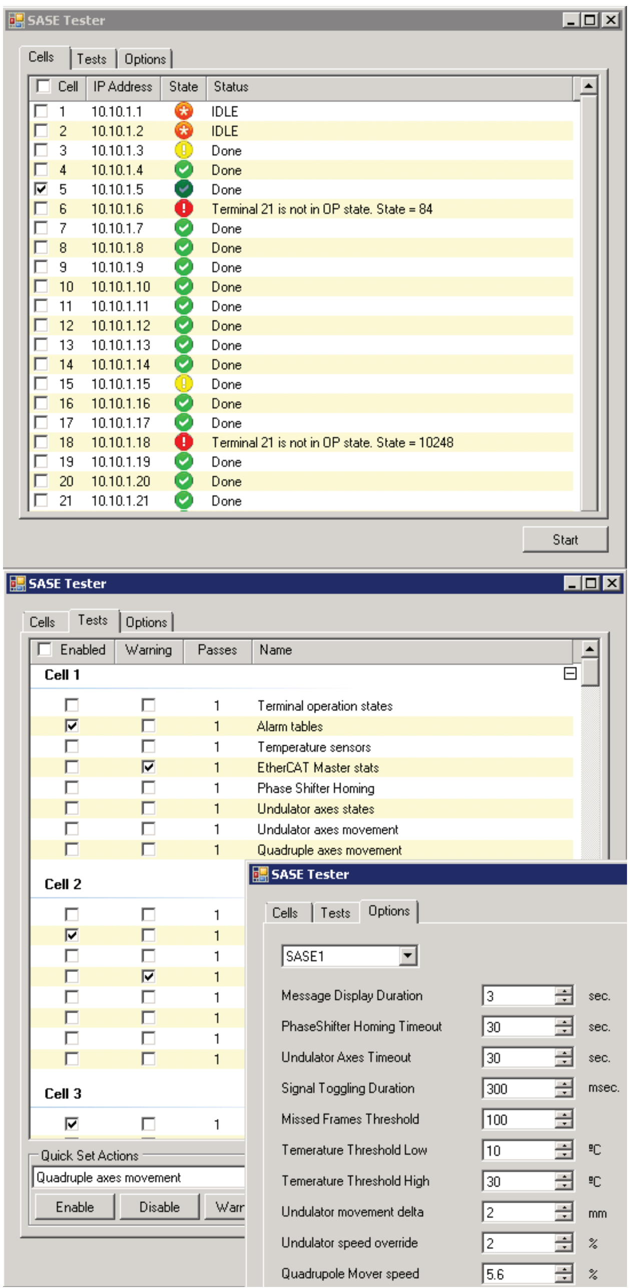


Figure 4: Main user interface of the UST as well as interfaces for configuration of the test scenarios and the setting values of the tests.

This task could be time consuming, taking into account, that several hundred values per system must be examined. This was a motivation to create a supervisory control and data acquisition (SCADA) program. This program is running on the CCN and is sending commands to the LCNs. After the execution of the commands, the program receives a feedback value. If the value is inside of an expected range, then the test is accepted; otherwise the test is marked as not successful. A double-click on the individual cell brings a popup log window. The error log provides precise information about the failure. The program provides a possibility to configure the test scenario for each individual cell. One can select what kind of tests must be carried out on which cell, how the feedback results must be interpreted, or in which case the test must be stopped. These are the settings of parameters, parameter ranges and timeouts for the test (see Fig. 4).

The executions of these tests are taking place simultaneously on each undulator cell. Depending on the test scenario, the complete test of the undulator system may take, only 10 to 30 minutes.

## CONCLUSIONS

Our experience shows that after the assembly of the two undulator systems - SASE 1 and SASE 3 - in the tunnel, the full process of commissioning of the undulator control system takes approximately one week per system. This time was spent for fixing the problems with hardware used for the first time, in particular improving the quality of Ethernet and EtherCAT copper cables or fixing problems with wrongly swapped optical fibers.

The selected strategy - to test each piece of hardware before installation in the tunnel - fully justified itself, since the problems were solved during several years of hardware production and commissioning, in a more relaxed situation.

The software developed for setting up, configuration, commissioning and maintenance of the undulator control system allowed to reduce the final work in the tunnel to a couple of weeks instead of several months.

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ISBN 978-3-95450-189-2