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REVIEW OF COMMISSIONING AND FIRST USER OPERATION IN RESPECT TO HIGH LEVEL CONTROLS AT THE EUROPEAN XFEL

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Abstract

In September 2017 the European XFEL entered user operation after several years of construction and commissioning. To provide a fast and flexible commissioning of the various sections of the machine, the high-level control software was essential already from the beginning. While progressing in commissioning and increasing operation parameter space, the enormous complexity of the European XFEL put hard requirements on the control and operation concepts. Having now the full baseline parameters reached, this paper will review the concepts and architecture of the control system in respect to effectiveness, reliability and ease of operation.

Basic software concepts and design ideas but also general operation concepts, interoperability between various systems can now be reviewed in respect to the overall facility performance.

SOME HISTORY – BIRTH OF THE HIGH-LEVEL CONTROLS GROUP

Already in summer 2014 a group of people from various machine related sub-groups came together to form the so-called High-Level Controls (HLC) group. This concept arose from the lessons learned at the Free Electron Laser in Hamburg (FLASH) in Germany and the commissioning of the Linac Coherent Light Source (LCLS) in the US. Within both of these projects it showed up that a simple bottom-up approach for implementing higher level software often falls short. The complexity of such modern machines today is that large that a step-by-step commissioning of individual sub-components is often either not possible or at least not economically efficient. These days the software plays a key role when it comes to integrating sub-systems and establishing full interoperability between the various components. The proper functionality of sub-systems can mostly only be established if the whole software envelope is in place and active.

To overcome these now known problems it has been decided to form an expert group concentrating on these topics exclusively. Even though at this point in time only the injector complex, consisting of a photo cathode gun and two accelerating modules existed, the group already addressed topics still years ahead. This allowed for grasping possible very complex and therefore time-consuming tasks and addressing these already at this early stage.

One such example is the proof of concept for the, that days only envisioned and later on implemented, central data acquisition system (DAQ) (see [1] and [2]). Using some of the already existing server nodes a simulated environment has been set up to mimic the estimated data rates such a DAQ system would need to cope with. Even if the aim of this setup has been to show that such an architecture can cope with the data rates, soon it showed up that such a system can serve for many testing and development purposes. Such a virtual accelerator not only allows to test and debug software components but also can serve as a testbed for graphical user interfaces. E.g. have here new concepts and ideas for the visualization of the complex beam distribution and bunch train dimension been developed. The system has later on been called the Virtual European XFEL and is still being developed further [3].

Even thus within the first years the commissioning of the injector complex had highest priority, the scope had always been to establish software components, interfaces and the overall architecture with the full facility in mind.

Fundamental decisions like supported languages, operating systems and control system interoperability have been a major topic at this stage. A lesson learned – here from the European XFEL commissioning – is to fix these decisions prior to starting the work, but also allow for late changes. Thus has the decision to support the python language been taken at a late stage, but the strong requests and lively discussions finally resulted in this outcome, which nowadays no one would question.

GETTING THINGS DONE

With the proven capability to cope with the expected data rates the already at FLASH running centralized DAQ architecture has been accepted. This paved the road for some of the foreseen central services we envisioned within the HLC group. Table 1 shows some of the servers and their purpose.

Table 1: Some of the DAQ Attached DOOCS (see [4] or [5]) Middle Layer Servers – these Servers offer most of the Core Functionality for e.g. the Display Layer

Server	Purpose
Charge ML	Transmission information
Charge Calc.	Long term charge integrator
Orbit ML	Various orbit information
Beam Energy Measurement	Beam based energy calc.
Energy Profile	Higher level energy calc.
Longitudinal FB	Slow energy, chirp, … FB
BLM ML	Higher level BLM calc.

With this architecture and concept at the hand the implementation and configuration of these servers could to great extend be ‘copied’ from FLASH to the European XFEL ecosystem. This is especially true since much software at FLASH has already been designed to be later on ported to the European XFEL.

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Beside these core services which as sketched have been implemented in well supervised central layer of the control system, many tools and applications have been envisioned and discussed. These developments mostly followed the current state of the commissioning and thereby allowed for rapid reaction to actual tasks and problems.

With the decision to also support the python language, the newly created applications and tools where mostly implemented in either Matlab or python. A rough estimate shows that the number of python applications is increasing while the ratio of Matlab to python applications used in the daily operation is nowadays 3:1.

With the progressing commissioning of the facility, from injector to main Linac to the undulator beamlines, the topics for the HLC group also changed accordingly. E.g. where main developments concerning the energy management and phasing of modules naturally done while the main Linac has been commissioned. While after achieving first lasing in May 2017, automation and fine tuning of the undulators has been an important topic. For of this task proper servers or applications could a) be set up rapidly and b) be constantly adapted to the needs and (often changing) requirements. This has been possible mainly due to the already existing libraries and toolboxes, the HLC group prepared and tested already partly already years before.

USER OPERATION – TODAYS NEEDS

With entering the user operation phase in September 2017, a solid foundation of servers (see also Table 1) was in place to form the core of the control system for basics like transmission- or orbit displays, slow feedbacks, etc.

Compact Displays

Daily topics changed from getting hardware into play during the commissioning to e.g. providing compact operation status overviews, automating procedures or monitoring and tweaking performance parameters. Here small things like the introduction of the *sparkline concept* as shown in Fig. 1 and the design of clean and robust displays where key to allow to focus on that days topics, like improving lasing output or modifying beam distribution patterns.

Figure 1: Some examples of using sparkline graphs for compact visualization of a bulk of parameters.

With reaching the all requested baseline parameters (like prove of nominal e-beam energy in July 2018, full bunch train to dumps November 2018, …) the fast and proper setup or change of machine parameters went into focus.

Patterns, Words and Wizards

The full functionality of the timing system has already been in place from the first hours on, but during the commissioning only a small subset of the existing functionality had been used. With the increasing demands from the user side interfaces for creating and modifying patterns where largely extended and further developed. Even though the complexity and flexibility of the timing system is overwhelming, the operators are well able to handle complicated user requests without need for expert intervention.

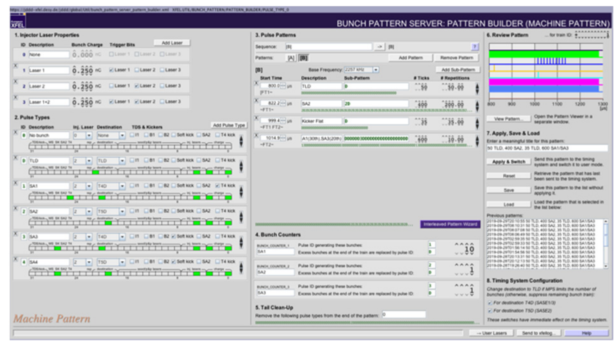

Figure 2: The pattern builder display allows to create even complex beam patterns in a very intuitive way.

Here the combination of C++ DOOCS server implementing the busyness logic plus a flexible and well-designed jddd display [6] has been used to provide an easy to use and robust interface shown in Fig. 2 [7]. In its latest version a wizard for creation of interleafed patterns between two beamlines eases even this step which can be cumbersome for a human being.

Feedbacks and Procedures

Orbit feedbacks as developed at FLASH have been used from the beginning and provided robust and reliable orbit stabilization (see [8] and [9]). With entering user operation, it showed up that also the orbit feedbacks can be used in a different way to e.g. support fast and easy wavelength changes or even help on steering the photon beam pointing. This could be accomplished since the orbit feedback software has from the beginning on been designed to be simple and modular. By simply adjusting the configuration to the different use-case scenarios one is able to adapt to the new situation (e.g. use different sets of monitors and actuators). Also simple concatenating of usage of some higher level software components often shows nice results, like e.g. the in Fig. 3 shown interplay between the so-called adaptive orbit feedback [10] and the classical one. This shows a typical sequence of actions used to increase the x-ray intensity, while in delivery mode the classical feedback is used to avoid any drifts or movement of the photon beam pointing.

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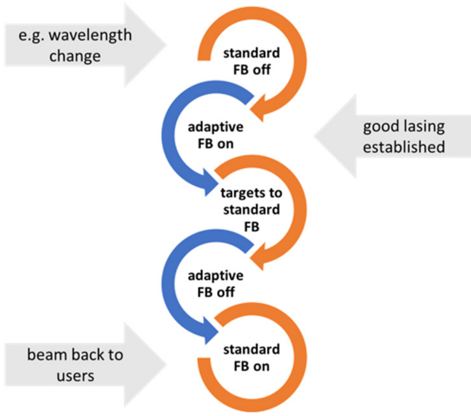

Figure 3: Typical sequence of interplay between using the standard and the adaptive orbit feedback.

Stability and Performance

With users at the end of the beamline first experience concerning stability of x-ray intensity but also pointing is reported back to the machine operators. Many measures needed to be taken on the photon transport side to ensure that this part of the machine is not adding reasonable jitter to the overall budget (e.g. simply slow feedback loops for adjusting mirrors to changing environmental conditions).

Since there is still often discussion about not optimal pointing stability a small group of people on DESY side and from the XFEL GmbH are addressing these topics, which in addition seam not to be constant if seen over longer time ranges. Here the goal is to establish precise agreed upon check marks for verifying certain systems performances (e.g. orbit within the undulator lines but also basic performance parameter like electron beam energy, …). For this, the interaction between control systems on both sides is crucial and paved the road to build up online monitoring of such critical values. As an example, shows Fig. 4 a Matlab program for evaluating jitter correlations between electron orbit and photon beam position at the experiments end-station.

OUTLOOK

The topic of stability and performance will for sure stay for longer times (or might even persist forever), so that the development of robust and reliable software to produce key performance values will be one of the top topics for the HLC group.

With greater emphasize of the performance also procedures for automatic setup and tuning will be of high importance. While we are partly already relying on advanced optimization tools like the adaptive orbit feedback, there is still much room for improving setup and tuning times by usage of such 'smart' tools.

This directly leads to the topic of machine learning and the possible usage of such techniques at the European XFEL. Some first steps towards this direction have been done and we are just about to implement more formal ground for a) setting up groups of people (similar to the HLC group, but b) are exploring in which fields such algorithms and techniques might be useful.

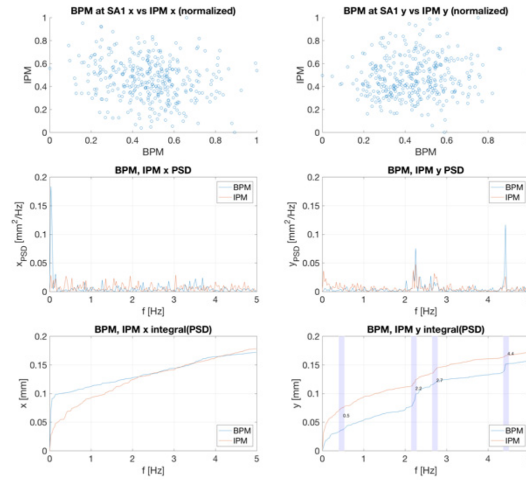

Figure 4: Example of using data from both sides: machine – here BPMs and experiment side – here the so called IPM (intensity-position monitor).

CONCLUSIONS

Many concepts, standards but also architectural design has been discussed and later on implemented within the high-level controls group. This effort started already at a very early stage of the overall European XFEL project. Looking to the control room these days, it clearly shows up that without this approach many displays, tools and general operation concepts would not have been in place in time! Topics of the HLC group changed over the years, but having this group constantly working on the higher-level topics ensured a good level of quality and standardization thereby ensuring proper functionality of all operation relevant software and thereby overall uptime of the whole facility.

ACKNOWLEDGMENTS

Even though I didn't name them, I would like to thank all people involved in the commissioning and first years of user operation. This naturally includes the members of the HLC team but also much more personal, without which the HLC team would never have been so successful and fast in getting this large facility into operation.

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