STATUS OF THE EUROPEAN SPALLATION SOURCE CONTROL SYSTEM

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Abstract

The European Spallation Source (ESS) is a collaboration of 17 European countries to build the world's most powerful neutron source for research [1]. ESS has entered the construction phase and the plan is to produce first neutrons by the year 2019 and to complete the construction with 22 neutron instruments and reach the target 5 MW beam power by 2025. The Integrated Control System Division (ICS) is responsible to provide control systems for the whole facility.

The unprecedented beam power and the construction of the facility as a collaboration of the member countries, with many components delivered in-kind presents a number of challenges to the control system. The Integrated Control System Division has to prepare systems and specifications so that the work can be effectively shared between the contributors and staff on-site. The systems need to provide sufficient performance for successful operation of the facility, be standardized to a level that allows easy integration into the facility during a short installation period and have to be maintainable by the in-house staff after the construction has finished.

INTRODUCTION

The European Spallation Source (Fig. 1) is an accelerator-based facility currently in construction in Lund, Sweden. The facility will provide neutron beams for various fields of research, using a variety of instruments in neutron beam lines. Different components of the ESS will be delivered in-kind by several institutions in the member countries. This applies to all parts of the project, including the control system.
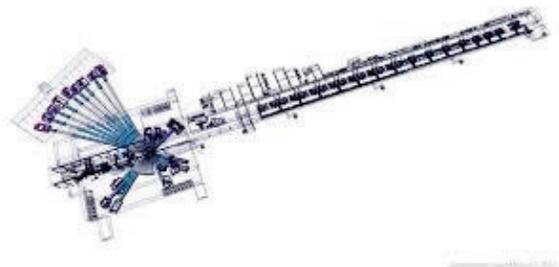

Figure 1: A schematic view of the ESS facility.

In ESS, a high power proton beam hits a spallation target to produce neutrons. The proton beam is generated in a proton linac (Fig. 2) which operates at 14 Hz repetition rate and 5 megawatt average (125 MW peak) beam power. The about 600 meters long linac consists of a proton source, normal conducting ("warm") section, a superconducting section and finally a high energy beam transport section towards the target [2].
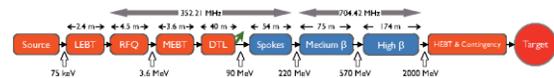

Figure 2: The ESS linear accelerator.

The ESS accelerator produces long pulses of 2.86 milliseconds in normal operation. This pulse lenght allows a great flexibility for designing the neutron experiments.

The accelerated proton beam hits the neutron target (Fig. 3), a rotating tungsten wheel divided into several sectors. The produced spallation neutrons go through moderators and neutron guides to the neutron instruments. The accelerator operation has to be synchronised with the rotation of the wheel so that the beam pulses hit the middle of each sector. A rastering magnet system expands the beam before it hits the target so that the heat load is distributed to a wider area.
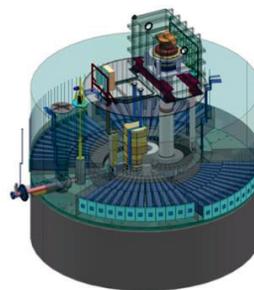

Figure 3: The neutron target of ESS.

Neutron beam lines carry the produced neutrons to the instruments for detection. The neutron beam lines have among other components several choppers on the way to select the neutron energy, or wavelength. The choppers have also to be synchronised with the beam operation.

THE INTEGRATED CONTROL SYSTEM

The Integrated Control System Division (ICS) is responsible of building control systems for all parts of the facility, from integration of the site infrastructure, the accelerator, target and providing EPICS control of the instrument components. The integration of the instruments and handling the scientific data is the responsibility of the Data Management and Software Center (DMSC), located in Copenhagen. This obviously requires a close collaboration between ICS and DMSC.

ICS will provide the integration of all systems up to (but excluding) the instruments so that the facility can be operated as a single unit from a central control room. This includes a global timing system to synchronise the operation of the whole facility, as well as the machine protection system to protect the facility from beam-induced damage. In addition, ICS is responsible of building the Personnel Safety System (PSS) to protect the personnel from hazards when working in the facility. ICS will also provide the computer networks for connecting the control systems and a local data centre with servers to run the services required by the machine operation [3].

CONTROL SYSTEM ARCHITECTURE

The control system will be based on the EPICS [4] software toolbox. EPICS will be applied to all parts of the facility, from control and monitoring of the site infrastructure systems up to control of the neutron instruments. All components that require control or monitoring will be integrated into EPICS. At this stage it is difficult to precisely estimate the number of process variables but in any case it will be in the range of a million and probably even higher.

Our goal is to build the system based on the EPICS Version 4 [5]. All our low-level controllers as well as software applications use the version 4 structured data and normative types at the application level and communicate using pvAccess. This enables us to simplify and improve the integration of different systems beyond the pure control capabilities of EPICS version 3. The handling of scientific data in a direct connection to the EPICS systems and services will enable many applications that would otherwise be cumbersome or even impossible to implement. The development of EPICS 4 has progressed to a state where the reliability and performance has been proven in real-life applications [6]. A number of components like process variable gateways need still to be developed to enable running a large facility but they are within reach so the goal is realistic. As a side benefit we hope that this will also help to push the EPICS community forward.

The control system will also provide a number of supporting services. A part of the services is directly related to EPICS, like the archiving system to store time-series data of the process variables. Other services like the Controls Configuration Database (CCDB) provide the

support for building, operating and maintaining the control system.

GLOBAL SYSTEMS

Timing and synchronisation of the facility will be based on a global event system, developed by Micro-Research Finland [7] that is used in a large number of accelerator and other similar facilities. The system has gone though several developments since it was first deployed [8]. The ESS will use the latest generation of the event system. The timing system provides a global distribution of RF-synchronised triggers and beam parameter data to the facility. Actions like acquiring data at the device level are synchronised by this system and synchronised timestamps are provided so that all measured parameters can be correlated system-wide.

The timing system consists of a central timing master node that steers the whole operation of the ESS. The timing master sends out a sequence of timing events that trigger the machine operations at proper times. Several parameters for defining the operation cycles are also distributed by the timing master. The master node generates an event stream signal that is distributed to the receivers through a fan-out system. The latest generation of the event system hardware can compensate the propagation delay through the fan-out system to the receivers so that the propagation delay can be kept constant, thus relaxing the requirements for cable routing and temperature stability in the buildings.

Machine Protection is a system to prevent beam-induced damage to the facility and also to minimise unnecessary activation of the components. The part that makes the decisions to allow or stop the beam, the Beam Interlock System (BIS) is connected to a number of local protection and beam monitoring devices and to systems to switch off the beam and thus mitigate the beam loss. The MPS (including BIS) has to be able to switch off the beam in the middle of a beam pulse, in the range of $5~\mu S$, depending on the location where beam losses or system malfunction is detected [9].

Personnel Safety System protects the personnel from hazards caused by radiation or oxygen depletion in the accelerator tunnel or in the target and instrument areas. PSS is a safety-credited system and will be built according to state of the art standards like IEC 61508[10].

HARDWARE STRATEGY

The control system will have a very large number of I/O channels to interface to. To do that in a cost-efficient way, we have decided to apply a hardware architecture consisting of three layers. One layer is used for systems that require very fast signal acquisition and online signal processing, typically implemented in FPGAs or similar, and a capability to transport large amounts of data. These systems also require very short latencies and operate in hard real time. This layer of systems will be built on the MTCA.4 standard [11].

For MTCA.4-based applications we plan to provide a standard digital processing platform that can handle most of our fast real-time applications. This will happen in collaboration with the Paul Scherrer Institute in Switzerland and be based on an upgrade of an earlier development [12] which is being used in several applications at PSI. The common platform enables us to share several applications that have already been implemented, as well as co-developing new ones together with other ESS partner institutes. It also simplifies our hard-, firm- and software management.

Many systems require distributed I/O and real-time responses, but at more moderate data rates. Implementing these on MTCA.4 would not be cost-effective and require the development of several components that are not readily available on that platform. For these systems the EtherCAT [13] standard provides a cost-efficient and flexible solution and a wide variety of available I/O modules off the shelf. We plan to use the EtherCAT in two flavours: one is for direct I/O using a regular computer (e.g., a MTCA.4 CPU) as an EtherCAT master and connect it to a number of slave modules. For the cases that require more complicated handling of the bus modules, for instance control of complex motion it seems better to use a dedicated EtherCAT Master from Beckhoff GmbH that provides a lot of software support in its TwinCAT suite that would be hard to implement otherwise.

In addition to the tasks that require real-time, beam synchronised operations there is a large part of more process-type control. For that, industrial PLCs are the most appropriate solution and have also been widely adopted for fields like control of vacuum and cryogenic systems. A standardisation process of the PLC hardware hast recently come to a conclusion. Most systems in the target seem to naturally fit into this category.

SOFTWARE

The ICS will provide a set of services for people who develop or contribute data to the control system.

The most fundamental support for integration and management of the I/O devices and signals is a naming convention that is available for all the system contributors. That has been developed early on and is supplemented by naming service to record, manage and check the syntax of the entered device names[14].

ESS has been participating in the DISCS [15] collaboration that develops software tools for use in accelerator and other EPICS-based laboratories. One of the products from that collaboration that we have adopted and are further developing to fulfil our requirements is the Controls Configuration Database (CCDB). CCDB will be used to store data about control system components and their hierarchies, plus several types of metadata. The CCDB has two foremost goals: to provide means to track an EPICS PV from a control screen down to the physical hardware, through paths of powering, housing and control. The other goal is to store the component and

hierarchy data so that it can be used to configure and manage IOCs.

For software development, a unified development environment (Figure 4.) will be provided. The development environment has to take into account that system development happens not only on the Lund site but also in the collaborating institutes. That software has to be integrated into the ICS system when the components are delivered and need to be operated as a part of the system. To satisfy these requirements ICS has developed a system that enables full management of the development process from the Lund site. Users can set up computers (virtual or real) using Vagrant [16] and Ansible [17] playbooks that have been set up by the ICS team in Lund for different profiles, containing the required software tools, libraries and configuration for the particular task. For developing EPICS applications on the I/O Controllers (IOC), the system includes the ESS EPICS Environment (EEE). This system is based on the concept of dynamical loading of EPICS libraries [18]. The EPICS application is composed by dynamically loading, linking and configuring pre-compiled modules at start-up. The system also tracks dependencies between modules so that the user just needs to define what modules are used by the application. The EEE consists of these modules plus a build system that can be used to create new modules.
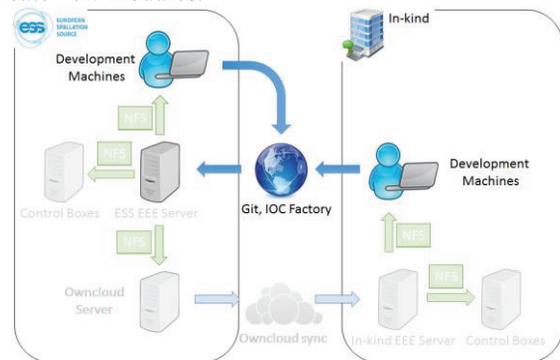

Figure 4: The ESS development environment.

The pre-compiled modules and configuration scripts for the EPICS I/O controllers reside on a network (NFS) drive, which is mounted by all IOCs. Thus each site needs its own NFS server. When this is set up, the ownCloud file sharing system [19] synchronises the remote servers with the central system.

The sources for the EEE software are kept in our git-based BitBucket [20] repository. A system that allows us to do systematic quality control of the software, consisting among others from a continuous build server (Jenkins) [21] etc., has been set up.

For setup and management of the EPICS IOCs we are developing a tool called IOC Factory. This is a web-based tool that enables setting up an EPICS IOC using information from the CCDB database and EPICS modules in the EEE. This way, an IOC setup consists only of configuration metadata; all logic will be contained in the EPICS modules. The first version of IOC Factory is

going to be released for production soon, however it will probably still need several refinements before it reaches the maturity for large scale deployment of systems.

All the services required for this development environment are web- or network-based. This makes it possible for us to keep the configuration data and the software modules under control at the Lund site without the need of replicating the data sources but still enable all developers to work using exactly the same set of tools.

In the developer toolset we also include tools from the EPICS community that have been selected based on their suitability to our purpose. For instance we are using the Archiver Appliance [22] for time series archiving of EPICS data. Control System Studio [23] has been selected as the toolbox to produce applications, first and foremost configuring GUI screens using BOY, BEAST for alarm management and so on. We also plan to invest in further development of tools in that framework.

We have been collaborating with the Spallation Neutron source SNS to build an accelerator online physics model based on OpenXAL [24]. In collaboration with SLAC we also have installed SLAC's EPICS 4-based set of services and applications and intend to use that as a basis for developing the accelerator physics applications for accelerator commissioning. For easier programmer access, interfaces to the Python language are provided for application writing. Python provides a powerful set of mathematical and utility libraries for scientific applications.

MACHINE OPERATION

The ultimate goal of the control system is to allow the ESS facility to be operated in a simple and efficient way. The characteristics of the machine set some constraints on how the machine is to be operated. For instance, one cannot start immediately with the highest available beam power but has to be able to smoothly go up from a low power mode to the full power operation. This has to happen so that machine protection is guaranteed at each step of the process. Details of this are still under discussion but the basic idea is to define a set of beam modes, namely beam power "envelopes" and conditions for operating within each envelope. A beam mode envelope is a combination of beam repetition rate, proton current and proton pulse length. Any of these parameters may be changed within the envelope, so that operation is still safe. Several conditions for machine safety have to be met before the beam mode can be changed. As one example, wire scanners can be used to measure beam profile only in modes where the beam power is low enough that it will not damage the wires. In higher power modes, operation of the wire scanners is not allowed.

The initial ideas for controlling the operation in these modes include distributing the mode and beam parameter information through the timing system and a system for redundantly cross-checking that the mode has been correctly propagated to the facility before allowing switching to a different beam mode. This requires a lot of

coordination between the control system, machine protection and the accelerator components.

CONCLUSION

Although operation of the ESS is still some years ahead, we already need to support the development of the early systems in our in-kind partner laboratories. There is still a lot to do but a number of standards and structures have been set up to enable development.

Our strategy is to build a system using a combination of best practices and technologies from the community, new emerging technologies where they fit plus our own developments where required but as much in collaboration with the community and partners as possible.

ACKNOWLEDGMENT

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