MAX IV LABORATORY, MILESTONES AND LESSONS LEARNED

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Abstract

The MAX IV Laboratory is a new scientific research facility based on synchrotron light being built at Lund University, southern Sweden. The accelerator consists of one full energy linear accelerator providing two storage rings at 1.5 GeV & 3 GeV and a Short Pulse Facility. Additionally, more than 13 beamlines are planned to be built among which should be operational for the first users in 2016. The current status and approach of the control system is presented from its technical and organisational point of view, including the stakeholders, as well as the lessons learned from the commissioning as part of our continuous improvement for the future.

STATUS

Since the last ICALEPCS 2013 [1], the status of MAX IV Laboratory has moved toward the official operation milestones, the 21srt of June 2016 when the inauguration will take place. In the mean time the current MAX-lab (MAX I, II, III) will be decommissioned at the end of 2015.

MAX IV Commissioning

The Linac commissioning started in 2014Q2 and for the next 6 months it was focused primary on the 3 GeV storage ring injection. This milestone was reached in February 2014 despite the occurrence of several incident including the replacement of the Thermionic Gun.

The 3 GeV commissioning has just started in August 2015 after 10 months of equipment installation and Sub System Test (SST) but, already, several intermediate milestones have been passed:

- 14th August, 2015: Beam injected
- 26th August, 2015: Beam stored
- 8th October, 2015: Beam stacked at 4mA

The 1.5 GeV installation is going to be installed from the end of 2015 but already SOLARIS[28] which follow the same design has proven the concept, the 1st of October, by achieving 20mA at 1.5 GeV.

Beamlines

In the mean time, SPECIES, a Max II beamline and, FEMTOMAX, a Short Pulse Facility beamline received their first photon with a standard MAX IV control system beginning of 2014. Both are being used as test bench for the standard control system that will be used in the rest of the MAX IV beamlines [2]. BIOMAX, NANOMAX, BALDER, VERITAS, HIPPIE, all 5 3GeV beamlines, have successfully passed the site acceptance tests for their Front Ends and part of their optics.

KONTROLL & IT SUPPORT

The "Kontroll & IT Support" (KITS) group is responsible for providing the development and the support of the standard IT and electronics equipment, spread along the accelerators, the beamlines and also the administration of MAX IV. The group is part of the Science division and divided into several teams organised by business fields, responsible to organise the resource the most efficiently possible while keeping included into different projects as well as the other group of MAX IV, a so-called Hard Matrix organisation.

The KITS project management is based on Lean[3] where the focus is to bring the user value incrementally and as soon as possible without technical overhead. The Control System (CS) has been delivered following the Kanban[4] and the Scrum[5] methods since 2012[1], while adapting continuously the rules to follow the pace and the nature of a synchrotron project.
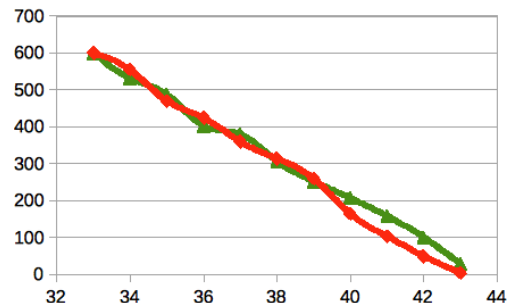

Figure 1: 3 GeV installation Burn down chart between sprint 32 and 44. Sprint estimation in red and done in green, in arbitrary unit

Network and System

The networks are based on TCP/IP v4 with a physical separation between Machine, Beamlines and offices. Each of them is divided by a set of virtual networks, usually corresponding to a subsystem, to minimise the influence of broadcast equipment. The layer 2 is based on Ethernet with 2 levels of switches in order to have a maximum network distance of 4.

All the accelerator and beamlines servers & IOC are virtual machines running by a VMWare hypervisor EsXi cluster of a redundant 36 cores and 384 GB memory. The standard OS is CentOS 6[6] as many providers support the RedHat drivers. All the Tango servers run on virtual machines apart for some specific case where a local control is needed. The definition of this infrastructure profits of the advantage that many equipment are controlled via Ethernet.

Ansible [7] is used for the configuration management of all the CS computers from the OS settings to the specific role (workstation, database or IOC) as well as the software versioning.

A Continuous Delivery process has been set up with the help of the RPM system, Jenkins a continuous integration server and Ansible. A dedicated MAX IV software toolkit, DSCONFIG, is used to reconfigure the Tango system and to track any changes in version with GIT.

Hardware

The standard motion equipment ICEPAP[8] is provided by the KITS group. Around hundreds of axes have been installed to mainly control the phase shifters, some diagnostic equipment like screens, lenses, scrapers and the diagnostic beamlines. All the beamline optics are steered through this controller except one axis. The EPU and InVacuum undulators will also be steered via ICEPAP.

The first standard Input Output Controller (IOC) have been installed in the SPECIES beamline to accurately read the encoder positions. The IOC is based on Adlink IPC, ADC, DAC and National Instrument for the counter card. This equipment is intended to be used as a General Purpose Input Output acquisition system on the experimental station of the beamlines

The IT group provides also the entire timing system[9] for the facility, based on Micro Research Finland (MRF). A special development of the Libera Brilliance Plus timing card, done by ITech, allows to use them as a compatible event receiver. The last status and development are described in another article[10].

The beamline control system will benefit to the standard equipment. The number of XBPM per beamline is estimated up to 20 per beamline, controlled by a new Electrometer[11] developed in collaboration with Alba, based on the first version deployed at Alba. The development consists of assembling 4 of the current amplifiers in the same chassis, controlled and synchronised through a backplane steered by an FPGA. This will allow synchronised measurement and the possibility to embed custom algorithm for a control loop to steer, for example, a piezo fine tuning based on current (Licence Open Hardware[12] and Open Source). In location where the signal/noise ratio is expected to allow it, a multiplexer will be used to reduce the number of amplifiers. This multiplexer is currently in development at MAX IV.

User Software

The control room workstation runs the client applications from several PC with a maximum of 8 screens each. The CS is driven with 39 GUI and monitored by 3 main web applications, the archiving & alarms database front ends and the maintenance scripts executor based on Jenkins. Additionally the operators have access to a logging system, ELOG[13] from PSI, to keep track of the commissioning progress and the changes on the system.

Among the applications several piece of software have been developed by the operators themselves[14]. Their GUI allows to monitor valves, rf structure, PSS, magnets resistances... These tools have been mainly develop with Tango JDraw[15], Taurus designer and Taurus gui[16] or Igor with the Tango binding.

The GUI proposed by KITS are mainly based on the Taurus framework that allow a rapid creation of the application without development (TaurusGUI). By this way several dedicated subsystem GUI have been developed for the commissioning of the Accelerator subsystems. The composition and the layout of the panels can be easily changed by the operators.

In the overall the initial specification of the accelerator control system allowed the reuse of widgets, panels and applications coming from the ALBA Synchrotron. The best example is the VACCA[17] application for the monitoring of the 3 GeV storage ring vacuum subsystem and also the beamlines.

Some requirement could not be fulfilled with the standard framework. This is the case of the Synoptic application[18], showing the logical representation of the system like a map and the State Grid application, showing the states of the control system by a reduced Subsystem by Location matrix. These applications make use of the web technologies.

Middleware

On the back end side the Tango control system version 8[19] is used as a middleware. For each type of equipment KITS develops the Tango device, software process to establish the communication with the hardware. In some case the drivers software have been contracted within a framework agreement with the manufacturers (Scandinova RF modulator[20], Libera Single Pass e and Brilliance Plus from ITech[21]) who have developed a compatible Tango server.

Additionally MAX IV received a software API from different collaborators and manufacturers. Budker Institut have provided a complete suite of software to control and set up their pulsed power supply via a web gateway[18] and Solaris has developed the Tango Server integration. Danfysik[22] and Itest[23] have provided a C++ libraries for their respective power supplies. In total 90 different classes of devices, mainly written in python, compose the catalogue of supported hardware and services for the MAXIV CS. For example on the accelerator the control system represents:

- 106 hosts
- 1187 server instances
- 7921 devices
- 287378 control points

- 132833 attributes
- 83735 commands

High Level Software

Parts of the control system can now be steered in the units of interest to the user, by putting a higher layer of intelligence on top of the minimal hardware control. For example, the magnets of the accelerator can be steered by magnetic field, via software on top of the power supply devices that interpolate the current-field calibration data provided by the manufacturer. The operators use Matlab high level scripts to set the required fields. The physical magnets are connected such that one power supply may control several magnets in series. An intermediate Tango device, the magnet-circuit, uses current-field calibration data that are an average of all the magnets on that circuit. This allows the operators to set an average field (converted to a single current set point on the power supply) but each magnet device in the circuit reports its own fields based on its individual calibration. Additionally, some magnets have a trim coils with independent power supplies that can be configured in different modes selected through a switch board (corrector, quadrupole, sextupole). The magnet Tango device must report the state of all its dependencies; the main and trim coil power supplies, the switch board device, temperature interlocks. The total field is also reported as a function of the main and trim circuits. For the operator the circuit device propose more features like the cycling and a redundant software interlock by monitoring the coil resistance.

Scientific Software

Matlab and the Matlab Middle Layer (MML) [24] have been the primary choice to run the scientific software on the accelerator thankful to the Tango Matlab binding[25]. The operators can easily program scripts and applications while reducing the lead time between requirement and operation. The MML is a collection of application to monitor and steer a Synchrotron. This software has been develop for the control of SLAC and extended by several facilities world-wide.

Data Management

The user of MAX IV will access a High Performance Computing (HPC) to run the off line analysis on their data through a remote CentOS desktop solution, ThinLinc[26], running the application in seamless mode from a native OS node (no emulation). A high performance storage system GPFS/InfiniBand will be installed next year.

The current user data policy is provided for giving the ownership to the users and for keeping the data during the next following 3 months after the experimentation. The HDF5 format and Nexus when applicable has been defined as the standard format for the data storage, and the control system component like Sardana[27] or the Fast

Data Archiver[28] have proved their compatibility and performance.

All the IT systems at MAX IV will enforce a security at 2 factors authentication, One Time Password foresee. The ability to connect through different ID providers like the Umbrella project is also part of the expectation. In this context MAX IV leverages the collaboration with the partners like the Lund University[25] and especially with LUNARC [26].

The Digital User Office system (PSI version adapted to our need) has been successfully tested at the current MAXLAB facility. Some experimentation has been done for the data catalogue with ISpyB[27] on one MX beamline. There is a plan to extend this application to a more general Laboratory Information Management System (LIMS) i.e to others fields than MX.

LESSONS LEARNED

Sharing Technology

A large effort was done by the beamline workgroups to use identical equipment where possible, saving by consequence the resource in development. The same strategy was applied for the storage rings where more than 80% of the equipments are reused from the Linac.

The CS team had to integrate a majority of "off the shelf" equipments. Although the level of integration was simply defined by having an Ethernet connection and an API, the choice the software API was longly discuss during the procurement with the supplier. This has paid off as several of the company sold their equipment along with Tango device and by consequence bringing Tango in the industrial scene.

Finally MAX IV benefits a lot of the experience and collaborations with other facilities. The reused software, like Sardana, reduce the pressure on the resources.

Agile and Lean

Lean give definitively the guideline for managing the MAX IV project by:

- keeping focus on the priority
- working on what is known
- bringing the user value as soon as possible and get from them a feedback on the progress
- avoiding spending resource on unused programs

The team was able to adapt quickly the organisation from SCRUM with 2 weeks iteration for the development phase to KANBAN during the 3 GeV commissioning phase to face the flow of operational issues as fast as possible. The Just In Time leads us to some trouble during the Linac installation because of the late delivery of the equipment. The simulation was not an option as it doesn't brings any value for the user representing only a perfect system. We learned at the opposite that the automatic test

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help to deal with this situation by securing the known part, the user interface.

The Agile method helped to handle quickly the features discovered during the testing phase. Together with the product owner the focus of the SST was changed regarding the estimation of the sprint planning meeting to secure more the low level of the CS than the GUI. The daily standup meeting help to improve the communication within the team as well as the sprint planning meeting with the product owner, stakeholders.

Organisation: Conway's Law

The architecture of the system is the reflect of the company organisation. Since the MAC 2014Q2 the organisation of the project has changed to improve the communication channels with all the subsystems. Each one of the control team member is the contact person to one or several other subsystem like magnet, vacuum, PSS... A product owner, as defined by Scrum, has been settled to coordinate the overall requirement and make the priority between the hundreds of request, in synchronisation with the Scrum master. This organisation helped to be more focused and efficient on the most valuable features for the users.

In 2014Q4, a similar approach was defined for the beamlines projects. But in 2015Q1 a workshop organised by the beamline staff and the CS team revealed that the organisation should follow the technical structure instead of the company organisation. The constraint of resource would benefit on the following up of the common beamline components (monochromator, mirrors, front end, undulator...) whereas the management per beamline would cover the specific beamline requirements.

Test

The CS has make profit of the current MAX-lab Laboratory to test the system and from the operators to report an early feedback. But the Linac was a new installation involving the entire organisation. Many new issues were discovered during the installation and the start of the commissioning that the focus stayed on the basic control. For example the H/V correctors got inverted along with the polarity of the power supply or a lack of the robustness that keeping loosing the communication.

For the 3 GeV a large part of the project was spent on the subsystems tests. The goal was to deliver the system ready for the commissioning with the fewest experienced defects. The SST helped to discover the discrepancy in the connection chain. For example the steering and the protection system of every single magnet has been all tested from the power supply to the report of the correct field of the magnet on the synoptic GUI.

The configuration was indeed much more complex as it cover not only the hardware level of control but also the GUI. So, decided early in the 3 GeV planning, all subsystem had to include the CS in their test suites. The tests included the access to the functionalities but also the

performance and the quality of the responses. The improvement in the configuration management allowed a very fast reconfiguration without regression for all the different subsystem.

The immediate results noticed by the operators is that they never experienced the same problem than the linac at the same phase. Only with the new 3GeV specific equipment that could not be fully tested causes trouble during the commissioning. The time and resource constraints to test more 'on the bench' the BPM as the accelerator could not be run without beam before to start the commissioning. Many false-positive alarms consider as counter productive for the commissioning were quickly disabled thanks to the high coverage of the configuration management.

Ethernet Based

MAX IV choose to participate to the development of a new Libera Brilliance Plus with the risk to use the commissioning time. But the new model simplify the integration to the timing system. The chosen architecture bring the advantage to be IOC free by relying on the Ethernet network for the primary CS. MAXIV learned a lot about industrial Ethernet integration. Even the PSS rely on the Ethernet switch it means more pressure on the reliability.

User Experience

The User eXperience (UX) has to be adapted to the culture and the context. Tango give more structure and standard compared to a home made CS. The CS representation looks like very complex but, thankful to the naming convention, very easy to navigate and to integrate new equipment. However the new comers may find difficult to deal with the control system because its complexity is still high. The heavy use of Matlab and command line, compared to the previous accelerator, give more flexibility for the experimental part of the commissioning. The user reported that the applications like the State Grid could have been helpful during the SST and especially for the Linac.

A progress has to be done on the integration of the recovery of the accelerator state. Hopefully more sequence and automation will progressively tend to push the functionalities to the GUI to have a better and simpler interface for the operators. On the other hand the Linac did not use too much scripts and leads to the development of the Synoptic GUI. The SPECIES beamline, as well, where a specific acquisition GUI has been develop to simplify the interact of their Users.

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REFERENCES

[1] J. Lidon-Simon et al., "Status of the MAX IV Laboratory Control System", MOPPC109, ICALEPCS'13, San Francisco, USA, (2013).

[2] M. Linberg et al., "Motion Control on the Max IV Soft X-Ray Beamlines With Tango and Sardana", MOPGF065, ICALEPCS'15, Melbourne, Australia, (2015).

[3] The Lean Enterprise Institute, website: http://www.lean.org/WhatsLean/.

[4] Kanban from Wikipedia, website: https://en.wikipedia.org/wiki/Kanban

[5] Scrum, the agile software development framework, website: http://www.scrum.org

[6] CentOS, the Open Source Linux distribution, website: https://www.centos.org/.

[7] V. Hardion et al., "Configuration Management of the control system", THPPC013, ICALEPCS'13, San Francisco, USA, (2013).

[8] The ICEPAP motion controller from ESRF, website: http://www.esrf.eu/Instrumentation/DetectorsAndElectronics/icepap

[9] J. Jamroz et al, "Timing System at MAX IV", THPPC103, ICALEPCS'13, San Francisco, USA, (2013).

[10] J. Jamroz et al, "Timing System at MAX IV – Status and Development", WEPGF120, ICALEPCS'15, Melbourne, Australia, (2015).

[11] O. Matilla et al, "Em# Platform: Towards a Hardware Interface Standardization Scheme", WEPGF081, ICALEPCS'15, Melbourne, Australia, (2015).

[12] The CERN Open Hardware Licence from Wikipedia, https://en.wikipedia.org/wiki/CERN_Open_Hardware_License

[13] The ELOG Home Page, https://midas.psi.ch/elog/.

[14] V. Hardion et al., "Manage the MAX IV Laboratory Control System as an Open Source Project", MOPPC086, ICALEPCS'13, San Francisco, USA, (2013).

[15] A. Gotz et al., "The TANGO Controls Collaboration in 2015", WEA3O01, ICALEPCS'15, Melbourne, Australia, (2015).

[16] Sardana control user environment, http://www.tangocontrols.org/Documents/tools/Sardana

[17] S. Rubio-Manrique et al., "Unifying All TANGO Control Services in a Customizable Graphical User Interface", WEPGF148, ICALEPCS'15, Melbourne, Australia, (2015).

[18] J. Forsberg et al., "A Graphical Tool for Viewing and Interacting with a Control System", WEM309, ICALEPCS'15, Melbourne, Australia, (2015).

[19] Scandinova, website: http://www.scandinovasystems.com/.

[20] I-Tech Libera Brilliance Plus, website: http://www.i-tech.si/accelerators-instrumentation/libera-brilliance-plus

[21] A. Panov et al., "TANGO Integration of a Specific Hardware through HTTP-server", MOPGF111, ICALEPCS'15, Melbourne, Australia, (2015).

[22] Danfysik, website: http://www.danfysik.com

[23] Itest, website: http://www.bilt-system.com/.

[24] G. Portmann et al., "An Accelerator Control Middle Layer Using MATLAB", FPAT077, ICALEPCS'05, Geneva, Switzerland, (2005).

[25] L.S.N. Nadolski et al., "High Level Control Applications for SOLEIL Commissioning and Operation", ROPA005, ICALEPCS'05, Geneva, Switzerland, (2005).

[26] P. Bell et al., "100Hz Data Acquisition in the TANGO Control System at the Max IV Linac", MOPGF049, ICALEPCS'15, Melbourne, Australia, (2015).

[27] ThinLic, website:, https://www.cendio.com/thinlinc/what-is-thinlinc

[25] Lund Universitet, website: http://www.lunduniversity.lu.se/

[26] LUNARC website, http://www.lunarc.lu.se/.

[27] ISpyB, website: http://www.esrf.eu/UsersAndScience/Experiments/MX/How_to_use_our_beamlines/ISPYB

[28] P.P. Goryl et al., "Status of the Solaris Control System - Collaborations and Technology", MOPGF151, ICALEPCS'15, Melbourne, Australia, (2015).