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CONTROL SYSTEM SUITE FOR BEAM POSITION MONITORS AT MAX IV

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Abstract

MAX IV is a fourth generation synchrotron facility at Lund, Sweden. It is composed of a full energy linear accelerator and two storage rings with 1.5 GeV and 3 GeV, which requires hundreds of beam position monitors. In this context, Libera Single Pass E and Libera Brilliance+ are employed as BPM instruments. This paper will present an overview of the control system suite used in the facility, including the communication, data acquisition and storage pipelines, monitoring, configuration and software maintainability.

INTRODUCTION

MAX IV Laboratory [1] is a fourth generation light source located at Lund, Sweden. The accelerator complex consists of a 3 GeV, 250 m long full energy linac, two storage rings of 1.5 GeV and 3 GeV, and a Short Pulse Facility. During 2022 a total of sixteen beamlines are receiving light [2].

TANGO Controls is a toolkit for building distributed object based control systems. The distributed object in TANGO Controls is called a device and is created as an object in a container process called a device server. The device server implements the network communication and links to the configuration database and clients. TANGO device servers and clients can be written in Python, C++ or Java. TANGO comes with a full set of tools for developing, supervising, monitoring and archiving [3].

The TANGO Controls toolkit has been used to build the control systems for large and small physics experiments like synchrotrons, lasers, wind tunnels and radio telescopes, and it has been chosen as the Control System at MAX IV Laboratory.

CONTROL SYSTEM AT MAX IV

The control system at MAX IV Laboratory is distributed and consists of an estimated 370 servers, running 24,000 TANGO devices and providing 500,000 control points. The accelerator control system has a unique TANGO database and contains 200 servers. The servers are hosted in virtual machines running Linux operating systems and, for some applications, the TANGO servers are hosted in industrial computers and embedded systems. Figure 1 represents a small zoom of the control system complexity and interconnections.

Deploying and maintaining such big systems requires proper workflows and tools. MAX IV has been using Ansible [4] to manage and deploy its full control system, both software and infrastructure, for quite some time with great success. All required software (i.e. TANGO devices) is packaged as RPMs (Red Hat Package Manager) making deployment and dependency management easy [5].

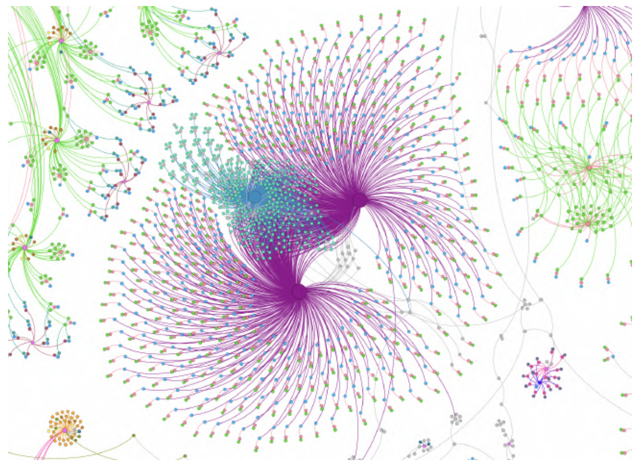

Figure 1: Zoom of the MAX IV 3 GeV storage ring control system. The two big pink stars represent the slow orbit feedback for the horizontal and vertical planes. The big blue star represents the Libera manager device.

BEAM POSITION MONITORS AT MAX IV

MAX IV uses a commercial solution for beam position monitors from I-Tech [6] with a custom firmware for internal needs. There are a total of 72 Libera Brilliance+ units in use in the storage rings, providing 236 beam position monitors (and an extra BPM for 3 GeV ring transfer line): 200 units in the 3 GeV ring and 36 units in the 1.5 GeV ring. For the linac, there are a total of 21 Libera Single Pass E units providing 48 beam position monitors.

Libera Brilliance+ features high precision position measurement of the electron beam in the booster or storage ring. Its digital signal processing supports programmable bandwidth and can facilitate all position measurements required in various regimes: pulsed, first turns, turn-by-turn and regular closed orbit. Acquisitions can be carried out simultaneously on all data paths: from raw ADC acquisition, turn-by-turn acquisition, slow acquisition to fast acquisition [7].

The instrument is based on the MTCA.0 modular technology and hosts up to 4 RAF (BPM) modules, one EVRX (timing) module and GDX (control) module in a single crate. The GDX module is used for the fast orbit feedback and to provide a continuous 10 kHz data streaming. This data is stored temporarily in a data storage cluster and is accessi-

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ble by multiple clients such as MATLAB and Python based applications.

Libera Single Pass E provides position measurement to resolve the bunch position from the very short signals produced by a bunch that is passing the beam position detector. It is a reliable and deterministic building block for fast-feedback building as well as for fast-forward loops, and thus enables attainment of high beam stability [8].

TANGO DEVICES FOR BPM

Figure 2 represents the TANGO devices for BPMs used in the storage rings at MAX IV. In total there are three layers and they are described in the following sections.

Figure 2: Control system schema for BPMs at the storage rings.

Figure 3 illustrates the amount of devices in production. Apart from those, there is one manager device per storage ring.

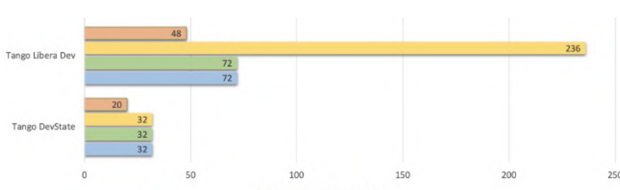

Figure 3: Representation of amount of TANGO devices for BPMs at MAX IV.

General Libera Device

This layer is based in the initial TANGO device class implemented by I-Tech, with internal modifications and developments made for MAX IV needs. This layer is responsible for exposing the different attributes and registers from Libera to TANGO. The device is written in C++ and runs embedded in the MTCA crate hosting an Ubuntu 14.04 operating system.

There are a total of four different devices classes, one per module, such as EVRX, RAF, GDX and SPE. For the RAF (BPM) module, there is one device per BPM. In general, the device loads a file that maps the internal registries and exposes them dynamically into TANGO as attributes. It is totally configurable and possible to have different attributes per crate, if needed.

DevState Device

The general Libera device only exposes the registries into TANGO and does not have any state management, meaning, that it is not possible to verify if actual state of each module (i.e. FAULT, ALARM) and this is the main goal of DevState device.

The idea of DevState device is to make an easy and configurable state machine representation of the BPMs subscribing to several registries exposed by general device class and compute the state machine. It is written in Python and runs in a virtual machine. A TANGO class property is used to map and generate the state machine / conditions using the registries exposed by the general device. Each state can have several status messages associated and propagated to the destination user.

The DevState device also contains another important feature which is the configuration of each individual registry, such as bit mask, interlock, among other attributes. It also verifies if the run-time configuration matches with the expected one and can serve a certain quantity of crates, usually. There is one DevState per storage ring achromat that serves three crates.

Manager Device

The principal of the manager device is to be a high level representation and a single point of configuration that reaches all BPMs. Like the DevState device, it is also written in Python and runs in a virtual machine. Basically it exposes several commands (i.e. Synchronize) that takes actions over the DevState devices and then distribute to each individual unit. There is a single manager device per storage ring.

MAINTAINABILITY

As mentioned above, Ansible is used at MAX IV to maintain software and firmware versions, repositories, general configuration, hostname, OS, file system, NTP, users, among other things like calibration.

Figure 4 shows a few of the Ansible AWX templates available for Liberas. AWX is an open source web-based user interface, REST API, and task engine built on top of Ansible [9].

The Liberas are organized by groups, one per storage ring and one for the linac and then, different firmware and/or software versions can be applied for individual groups.

The basic Ansible playbook starts configuring in sequence: hostname, users, repositories, software installation, firmware installation, system services, configuration, control system deployment and monitoring. Ansible opens the possibility to have a snapshot of the system and to retrieve the system to a certain state in the past with the versioning control, if

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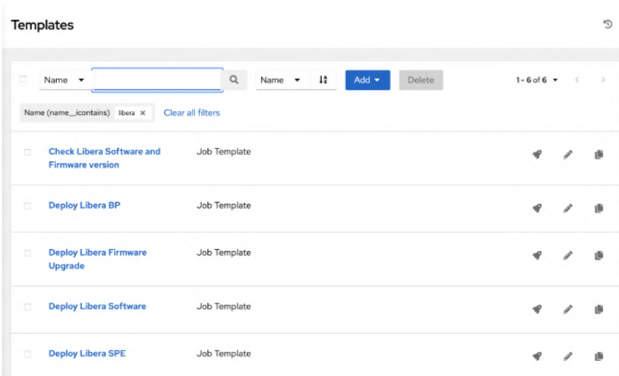

Figure 4: Example of Ansible AWX templates.

necessary. Also facilitate the maintainability since it can execute remote updates simultaneously for all units at MAX IV. TANGO devices and properties configuration are also maintained by Ansible.

There is a continuous integration and continuous deployment setup using GitLab CI/CD [10], that builds, tests, and publishes into the internal repository and triggers Ansible AWX templates if necessary.

MONITORING

MAX IV developed a Python Prometheus [11] exporter built into the Libera crate to export the required metrics to a Prometheus cluster and then stored by the Victoria metrics [12] into an internal Logging cluster.

The Libera Prometheus exporter is configurable and exposes hundred of metrics such as temperatures, fan speeds, voltages and currents.

Data visualization is done through Grafana dashboards [13]. Figure 5 illustrates a Grafana dashboard used for EVRX modules at 3 GeV ring. Several dashboards are available for daily monitoring and diagnostics. Dashboards are easy to make and anyone can create and share their own dashboards using the available metrics.

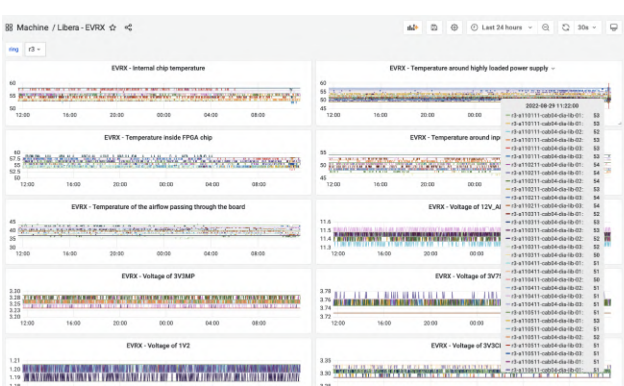

Figure 5: Grafana dashboard example for EVRX modules at 3 GeV ring.

There is also an alarm and notification system available which can be linked to group chats (bots), e-mail notifications, and other other functionalities.

APPLICATIONS

Several Python/PyQt [14] user interfaces are available for beam diagnostics in order to verify disturbances and actuation of feedback and/or feedforward systems. All the user interface applications follow the same procedure of continuous integration and deployment. The deployment and versioning control is managed by Ansible in the same way as the TANGO devices.

The storage ring slow orbit feedback (SOFB) loop uses a total of 200 BPMs in the large ring and 36 BPMs in the small ring for vertical and horizontal planes, resulting in 472 measurement points as inputs to the feedback system. The attributes push events thought TANGO at 10 Hz rate of the "slow" Libera data acquisition system. The events are synchronized in that all Libera Device Classes follow the same clock, so the position data from all BPMs are read and pushed every 0.1 s stamped with the same hardware time. The SOFB TANGO device subscribes to change events on all position attributes and will synchronize itself with the 10 Hz rate and write to the slow correctors. Figure 6 shows a user interface streaming 10 Hz data from BPMs and Figure 7 illustrates the differential value from measured orbit versus stored one [15].

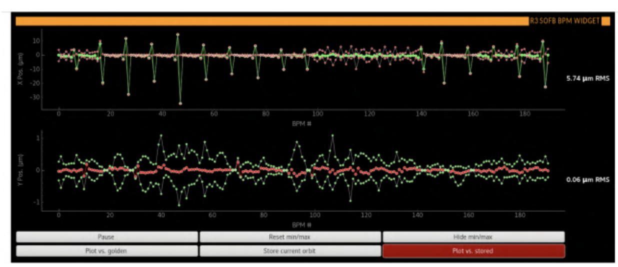

Figure 6: SOFB application displaying the beam position at 3 GeV ring, updated by SOFB iteration at 10 Hz. An alternative view in the application can show the kicks being applied to the corrector magnets.

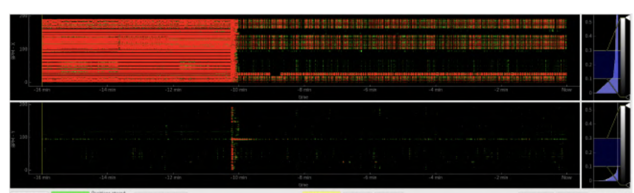

Figure 7: Example of BPMs differential trends versus stored orbit.

The fast orbit feedback (FOFB) makes use of the GDX fast (10 kHz) data stream from the same BPMs used as sensors in the SOFB. However, dedicated fast corrector magnets are used as actuators. The Libera Brilliance+ system is extended with custom SER modules having a RS485 interface to directly output the fast corrector set values. The feedback PI controller calculation is implemented in a FPGA running in the GDX module [16]. A TANGO device to interface to this system allows, for example, download of the response

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matrix and the position reference values. Other control loops are also in place, such as a trajectory feedback for the linear accelerator.

FUTURE DEVELOPMENTS

X-ray beam position monitors (XBPM) at MAX IV are blade BPMs based on Alba Electrometer [17] for current measurement. They are not yet following the same control system stack as other beam position monitors (such as data acquisition and standard user interfaces). There is an idea to replicate the same control system structure as the RF BPMs to the XBPMs.

Currently, the XBPMs are located at the 3 GeV beamline frontends and it is an important diagnostic tool that is showing new, unprecedented information about the 3 GeV storage ring, its alignment, its stability and its insertion devices [18] and can be used in the future for control loop systems.

CONCLUSION

The control system suite for the beam position monitors at MAX IV Laboratory allows easy and quick maintainability, versioning control, snapshots and change-logs for troubleshooting, efficient continuous integration and deployment, and well proven efficiency for control loops at all accelerators with aim on beam stability.

All software developed by MAX IV is open source and available to everyone interested.

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