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THE ESRF EXTREMELY BRILLIANT SOURCE – A 4th GENERATION LIGHT SOURCE

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Abstract

After 20 years of operation, the ESRF has embarked upon a very challenging project - the Extremely Brilliant Source- (EBS). The goal of this project is to construct a 4th generation light source storage ring inside the existing 844m long tunnel. The EBS will increase the brilliance and coherence by a factor of 100 with respect to the present ESRF storage ring. A major challenge is to keep the present ring operating 24x7 while designing and pre-constructing all the elements of the new ring. This is the first time a 4th generation light source will be constructed inside an existing tunnel. This paper concentrates on the control system aspects. The control system is 100% TANGO based.

PRESENTATION OF THE EBS

The ESRF is running an accelerator complex based on an electron linac, a synchrotron booster and an 844m long, 6.04 GeV storage ring. It operates 42 beam lines. The Extremely Brilliant Source (EBS) project, officially started in January 2015, aims to substantially increase the source brilliance and the coherent fraction of the X-ray beam. It consists of constructing a new 844m circumference storage ring with a new magnetic lattice to replace the current storage ring. About 90% of the existing infrastructure will be re-used and the new EBS design has been conceived with greatly improved energy efficiency.

The hybrid multi-bend achromat (HMBA) lattice design for the EBS will give a horizontal emittance roughly 29 times lower than the emittance provided by the current double-bend achromat lattice [1] [Fig 1.]. As second order effect, the small size of the beam makes the insertion device more efficient in creating coherency, and this will lead to a gain of around 100 on the brilliance of a monochromatic beam on the sample at the experimental station.

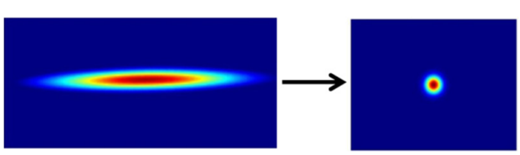

Figure 1: Reducing emittance for increasing brilliance.

The lattice is composed of 32 cells, each cell composed of 7 permanent magnets dipoles and 27 electro magnets. A total of 1180 magnets had to be designed, developed and procured.

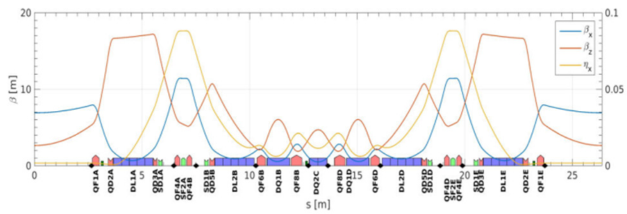

Figure 2: Arc cell optics layout.

Because the vacuum chamber is extremely small, the stability of the beam is critical. This will lead to an increase by an order of magnitude in both the mechanical precision required as well as the control of magnetic field.

CONTROLLING NEW HARDWARE

In addition to the physical hardware elements composing the ring, a large number of new controllers and sensors have been designed, developed or procured to control the new equipment. Their prototype versions need to be properly validated before launching the procurement on a large scale.

Lattice Control

Each of the 32 cells is composed of 27 electro magnets and 33 corrector channels, each one fed by a dedicated power supply channel (totalling 1920 channels to be remotely controlled).

In order to increase the MTBF of the power supplies a hot swap system has been designed. The aim is to detect any problem with a magnet current circuit in order to perform, in real-time, a swap over of the faulty power supply to a spare one, without interruption to the strength of the corresponding magnet. Each hot swap system manages 33 power supply channels for 27 magnetic circuits of 3 different families [Fig. 3]. Such a system will be installed in each of the 32 SR cells.

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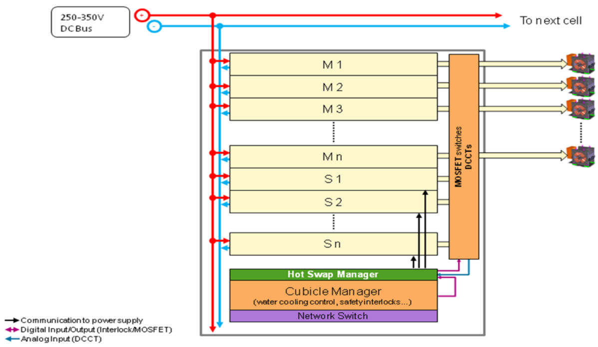

Figure 3: Layout of the Hot Swap manager.

Alignment

The magnets are mounted on 128 girders, each 5 meters long. The girders [Fig. 4] have 4 motorized legs able to correct precisely the height and the tilt of the girder. A Hydrostatic Levelling System (HLS) measures the relative height of each leg with micron precision. This system will be used to correct the slow natural movement of the ground over the time. The ring will be aligned by 512 stepper motors moving simultaneously with beam.

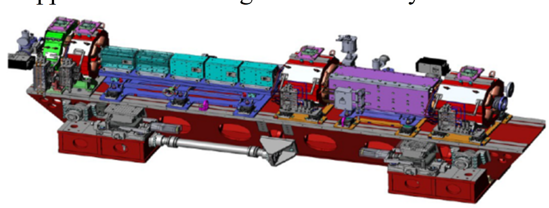

Figure 4: A motorized girder.

Beam Diagnostics

192 of the current 224 BPM systems which are based on Libera brilliance will be reused. They will be completed by adding 128 new generation of BPMs based on the Spark-R systems. This makes a total of 320 embedded Linux acquisition systems connected to Ethernet. In addition to that, 32 new generation beam-loss detectors are also planned. All these devices are being progressively deployed so they can be validated on the current ring. Several other diagnostics tools are being designed for the new ring: beam tune measurement system, beam imaging systems, injection perturbation damping system and several others...

Radio frequency systems

The present 352 MHz 1.3 Mw klystron based transmitters will be re-used. However their control systems are being refurbished with new hardware electronics and new software. Two Solid State Amplifiers will complete the installation. The waveguide network and the accelerating cavities are composed of 13 new mono cell cavities. The overall RF control will have to be re-organized.

Vacuum System

Since the entire vacuum chamber system has been redesigned, the vacuum instrumentation control has to be renewed. A part of the existing pump controllers and vacuum gauge controllers connected via RS422 will be re-used. A new generation of vacuum controllers and residual gas analysers will be added.

The vacuum interlock system is being redesigned.

Front-ends and Insertion Devices

Both the Front-Ends and Insertion devices will be dismounted and re-placed at the exact same location in the EBS ring. Therefore no work has to be done on this part of the control system

PROJECT MANAGEMENT

The present ring stays in operation 24x7 while the mounting of all the EBS elements on the 128 girders is done in parallel in a dedicated building. This imposes heavy constraints in terms of resources and space management.

A Challenging Planning

A master plan has been established [Fig. 6] to guarantee the correct schedule of procurement, human resource allocation and space allocation to fit the objective.

The procurement of all the lattice pieces has been scheduled for a gradual delivery to fit the planning. A full-size mock-up of an EBS cell composed of 4 girders (24m long) has been constructed [Fig. 5]. It is being used to verify the correct mounting of each element, and to build the construction sequence as precisely as possible in terms of time spent, necessary tools and human resource allocation. This mock-up is also used for training the teams who will mount the girders and design the necessary tools to manipulate all the pieces.

Figure 5: The EBS cell mock-up.

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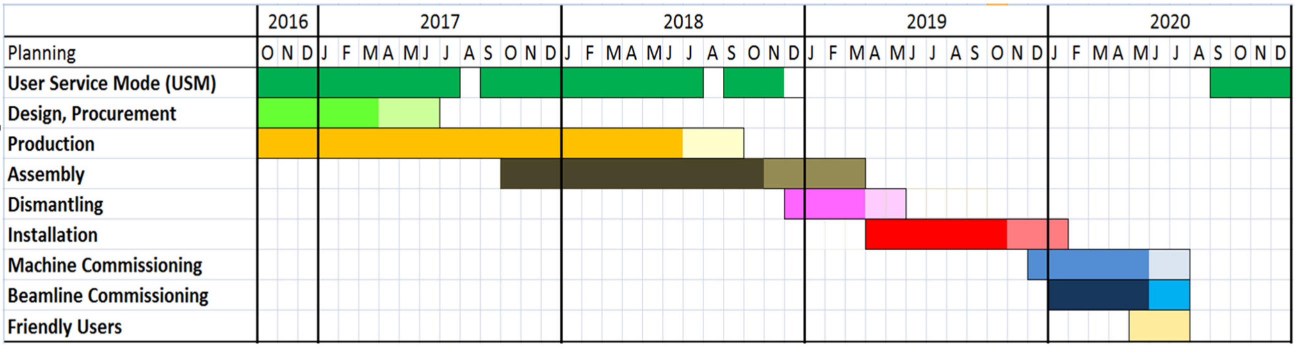

Figure 6: EBS master planning.

A major challenge is the management of the space for storing all the pieces before they are mounted, and then to store the mounted girders before their installation in the tunnel.

As soon as the operation of the current ring is stopped (December 2018) it will be dismantled and the tunnel will be emptied. Insertion devices and front-ends will be stored with a view of being re-installed, all others pieces such as magnets, vacuum systems, diagnostics equipment will be stored ready to be disposed of at a later time. All the cables going from the technical zones to the tunnel will be cut and dismantled. Once the tunnel is cleared and cleaned, each of the 128 pre-mounted girders weighing 12 tons each will be moved in the tunnel and connected to each other. A special vehicle and a dedicated gantry crane have been designed for this phase.

Validation of Equipment Control Interfaces

All the electronic devices, embedded systems, power-supplies and various controllers should be validated for their ability to be correctly remotely controlled and integrated into the TANGO control system.

CONTROL SYSTEM INFRASTRUCTURE

Networking Installation

The new hardware equipment is massively Ethernet connected. Many of them, such as the magnet power supplies and the beam position monitoring, are using Power over Ethernet (PoE+). A renewing of the network infrastructure to cope with the requirement of EBS is in progress. It is planned to deploy the new network switches on the present installation by mid 2018.

50 network switches of 48 or 96 ports each will be installed in the technical gallery of the storage ring tunnel. These switches are equipped with a dual power supply 230V AC and 48V DC. The 48V DC network will be backed-up by battery banks for sustaining the network switches in case of a power-cut. Each switch is able to power at least 20 PoE+ plugs. i.e. 600W

In preparation of this installation, a campaign of re-cabling of all the technical zones is in progress. The goal is to re-route in dedicated cable trays the control and network cables to allow an easy and secure dismounting of other cables in 2019. This re-cabling is being done cell by cell during each ESRF maintenance shutdown. The need of maintaining a reliable operation of the present machine is a difficult constraint for this phase.

Computing Infrastructure

The system is composed of 160 physical computers among which 25 computer servers located in the computing room, 110 industrial computers distributed all over the technical zones and 15 work stations in control rooms. The virtualization of the server computers based on KVM is in progress. Unfortunately, the 110 rackable computers are still necessary in each technical zone to connect the large number of locally controlled devices (vacuum controllers, radiation measurement, insertion device controls, infrastructure management, FPGA PCI-E boards etc…). To ease the management of these computers, the hard disks are used only for running the native operating system. All the software packages are installed on a centralized disk server accessed via NFS by each computer. Generic hot-spares are ready to replace any local computer without any package installation phase. Figure 7 (below) describes this infrastructure.

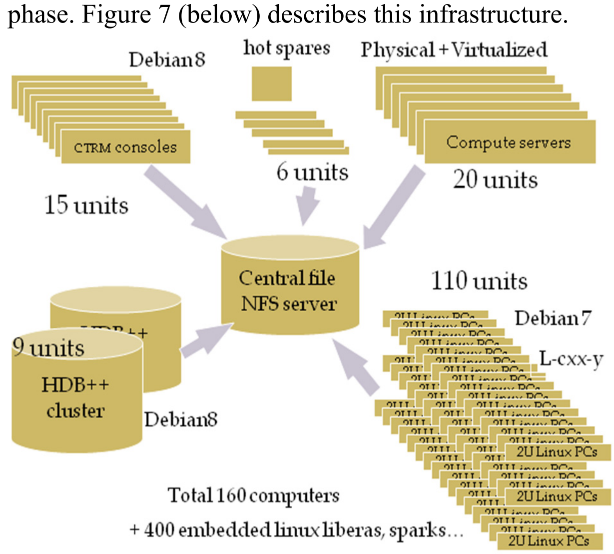

Figure 7: EBS computer infrastructure.

Modernizing the Electronic Interfaces

A large part of the existing installation, such as the booster, the linac, the injection elements, the common infrastructure will be re-used. The control of this equipment is often obsolete and needed to be refurbished.

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A modernization plan has been established to replace the old VME based systems and old field busses with state-of-the-art systems often based on Ethernet connected embedded systems. This modernization is done on the running machine in the short shutdowns between each run.

CONTROL SYSTEM SOFTWARE

The newly installed equipment should inter-operate with the existing equipment. Therefore a high degree of compatibility between old and new equipment control is necessary. The high level software and graphical user interfaces should be able to control both old and new equipment. Furthermore, some high level processes, such as the orbit correction systems, radio frequency system application and vacuum application should be able to control, in a transparent way, both old and new pieces of equipment.

Commissioning of Individual Equipment

New physical equipment will have to be commissioned, together with their remote control software, as soon as it is installed. The control software and Human Machine Interfaces have to be ready as soon as the new hardware is installed.

Some devices, such as the BPM systems or beam-loss detectors are supplied with a native TANGO server. For other controllers, the ESRF needs to develop a TANGO server and a GUI tool for the commissioning. The design and development of the first version of device server is done on the basis of the specification document given to the suppliers, then, when the first prototype is ready, the software interface must be validated and modified because the real hardware is often not behaving exactly as expected.

This is the case for complex diagnostic systems, vacuum devices, power-supplies systems, radio frequency devices and many other systems. Often, the software interfaces protocols documentations are difficult to obtain in advance because control has not been yet addressed by the suppliers. The definitive interface is defined very late after the factory acceptance test of the hardware itself.

Operation Software

The operation software refers to the tools used by the control room staff to operate the EBS in routine operation. It is composed of high layer device servers, GUI application and sequencing tools. It aims to control all the equipment together.

To develop and test this type of software before the installation of the hardware, we need to simulate the entire infrastructure. A simulated model of the new accelerator has been developed for this purpose. It is described below.

TANGO Software Framework

The TANGO control system [2], originally initiated at the ESRF, has been adopted over the years by the majority of the light sources in Europe. Since then, TANGO has continued to be developed and improved collaboratively and became the de-facto standard control system for light sources, lasers and telescopes in Europe.

This large community guarantees the long term sustainability of the control system and allows fruitful exchanges between the different control teams and industrial partners sharing the same technology [3].

Thanks to the continuous development effort in recent years, the present system is ready to satisfy the requirements for the control of the EBS accelerator with no critical challenges in terms of software characteristics. TANGO is based on the concept of distributed devices which implement micro-services and is still considered as state-of-the art today.

The EBS Simulator

A storage ring simulator based on the Matlab Accelerator toolkit simulates the behaviour of the beam to the strength of each magnet. It has been interfaced to TANGO in such a way that the simulated models of each power-supply generate the effect on the simulated beam parameters. [4]

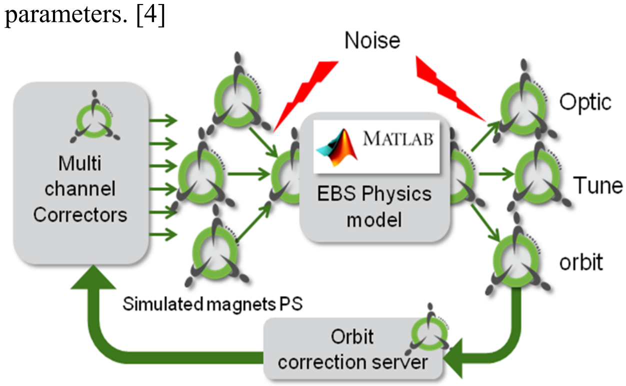

Figure 8: The EBS simulator layout.

This simulator is interfaced to TANGO in such a way that software modules can be connected to the simulator or to the real machine transparently [Fig. 8]. It includes the simulated version of the low level control of all individual equipment. It is used to develop all the middle layer and GUI software for the future operation. The software layers used to manage the lattice and the interface to the thousands of power supplies have been designed and tested in this way. The beam orbit correction device server, the beam optic programs, the tune feedback, and many other programs have been developed and tested on this simulator. The entire EBS simulated vacuum system is being built. A set of virtual computing machines are used to run an instance of the control system above the simulator.

The Magnet Power Supply System Software

The hot-swap manager software is in development and is being tested on the simulator. A simulator for the future dc-dc converters and for the correction power supplies has been developed. They are both controlled via a Modbus TCP interface. Each simulator is built using the

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tango-simlib library developed by the SKA team in South Africa for the TANGO community [5].

Preparing the Injector Control

In preparation of the EBS, the injector is being progressively refurbished. This is a challenge because the refurbishment has to be performed on a system in operation every day without reducing the reliability. The old system was operating on the basis of 2 injections per day using a resonating power-supply system at 10Hz. The new system is operating in top-up mode with a ramping power-supply system at 4 Hz [6]. All the injection elements had to be adapted to the new injection frequency. The injection sequence has been automated. The linac control has also been modernized. A bunch cleaning system has been developed.

Following these improvements, the injector system is now ready to fill the future EBS ring.

THE NEW TIMING SYSTEM

The present ESRF timing system was built around a centralized RF driven sequencer distributing synchronization signals along copper cables. A new system [7] based on the White Rabbit system [8] is being developed by ESRF to replace it. The White Rabbit system has been enhanced to carry RF over Ethernet. The WHIST module embeds the master RF sequencer and 12 triggers outputs. All WHIST modules in the network run in phase and duplicate a common RF driven sequencer [Fig. 9]. A master module broadcasts the RF and the injection trigger. The central RF sequencer will be put in operation first half of 2018 and all the injection extraction timing will be upgraded and commissioned by end of 2018, before the dismantling of the present Storage Ring.

A set of TANGO device servers and graphical user interfaces are being developed to configure and supervise the system. Its integration to the control system will be done on the present Storage Ring

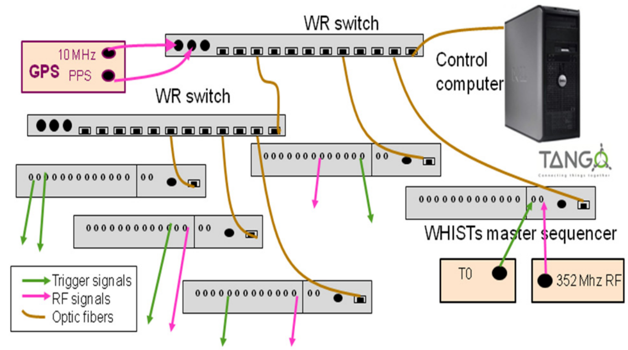

Figure 9: Schematic view of Whist infrastructure.

THE NEW ARCHIVING SYSTEM

The former ESRF History Database was designed 20 years ago for the TACO based control system to archive a limited number of signals at a rate which is much lower than the needs of the EBS. The system had been interfaced to TANGO so that currently the majority of data comes from TANGO device servers but both the hardware and the software need to be fully redesigned to fit the new requests.

In view of the EBS project ESRF has developed together with ELETTRA, a new archiving system [9] able to cope with the requirements of EBS [Table 1]. The TANGO HDB++ project is a high performance event-driven archiving system which stores data with micro-second resolution timestamps, using archivers written in C++. ESRF developed the Apache Cassandra back-end [Fig. 10]. The Cassandra back-end is using Cassandra's TTL native feature underneath to implement the time-to-live feature. The HDB++ and all its associated tools are presently running in operation in parallel with the former Oracle based archiving system.

Table 1: Comparative Performances of Old and New HDB

	former HDB	HDB++
Time precision	1 s	1 µs
Insertions/hour	120K	6M
Filling mode	Polling/events	events
No. Signals total	6K actives	24K/56K
Beam line signals	2K	10k
Extraction tools	C GUI	Java /Python /Matlab /web
Database size	0.5TB/y	20TB/y
Online capacity	9 months	Unlimited
Database	Oracle	Cassandra

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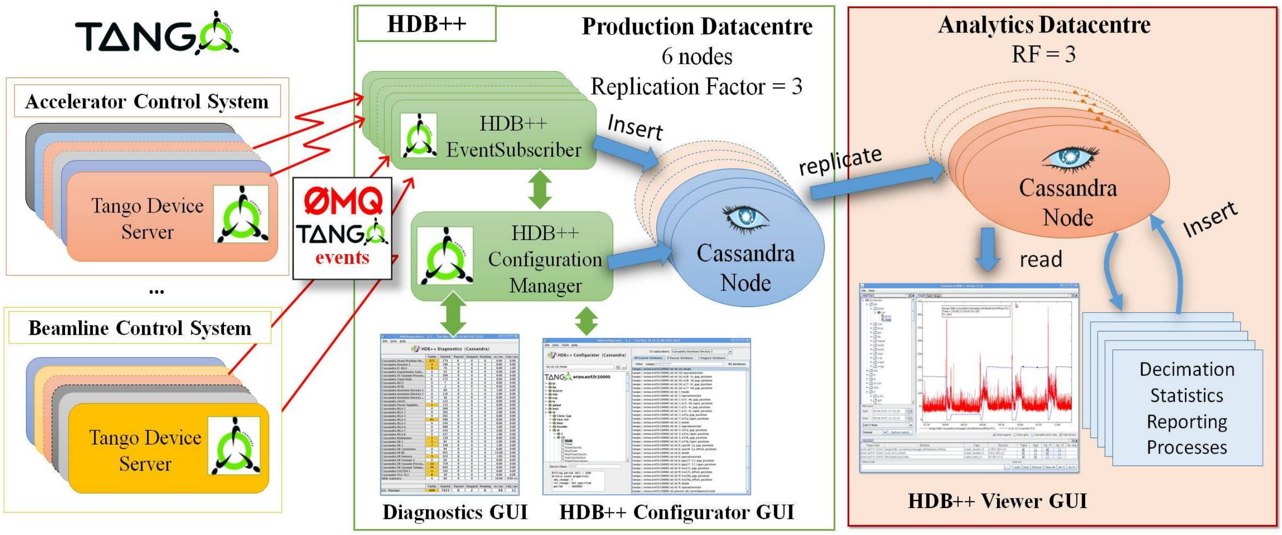

Figure 10: Synopsis of the HDB++ TANGO archiving system.

EXPERIMENT CONTROL UPDATE

In parallel of the EBS accelerator construction, a lot of work has been initiated on the beam line side. 14 beam lines have been refurbished and 4 brand new beam lines are in construction. All of them should adapt to the new highly concentrated beam. In order to benefit from the extreme brilliance of the new photon beam, they need to enhance their detectors and their data management setup for accepting high data throughput. On the software side, a re-design of the experiment control software has been started [10]. It provides a global approach to run synchrotron experiments and enable online data analysis. Thanks to hardware integration, Python sequences and an advanced scanning engine, it aims to enhance scientist's user experience to fully benefit from the enhanced characteristics of the photon beam.

STATE OF THE PROJECT IN OCT 2017

In October 2017 the delivery of all the magnets, girders and vacuum chambers has been nearly completed. The assembly phase of the magnets on the 128 girders will start in November 2017. Meanwhile, the work on the power-supplies and hot-swap manager is in progress. The accelerator simulator has been in operation for one year and is used daily to develop the higher level software. The vacuum system is nearly defined and it's simulated version is on the way to being completed. A set of GUIs is being developed to prepare for the commissioning of each individual piece of equipment. The GUI tools for operating the EBS are partially developed above the simulator and tested on the present Storage ring when possible. Even if several new features are still in development, the HDB++ archiving system is in operation on the present ESRF installation and is ready to cope with EBS as soon as new signals have to be archived.

The critical phase in terms of human resource management will be the simultaneous need of commissioning of all the equipment from mid 2019 and the commissioning of the overall machine in November 2019. At this time, every single piece of software should be operational with its remote control.

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