STATUS REPORT OF THE FERMI@Elettra CONTROL SYSTEM*

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Abstract

FERMI@Elettra is a new 4th-generation light source based on a seeded Free Electron Laser (FEL) presently under commissioning in Trieste, Italy. It is the first seeded FEL ever designed to produce fundamental output wavelength down to 4 nm with High Gain Harmonic Generation (HGHG). Unlike storage ring based synchrotron light sources that are well known machines, the commissioning of a new-concept FEL is a complex and time-consuming process consisting in thorough testing, understanding and optimization, in which a reliable and powerful control system is mandatory. In particular, integrated shot-by-shot beam manipulation capabilities and easy-to-use high level applications are crucial to allow an effective and smooth machine commissioning. This paper reports the status of the control system and the experience gained in two years of alternating construction and commissioning phases.

INTRODUCTION

FERMI@Elettra is a linac-based Free Electron Laser designed to supply photons in the soft X-ray spectral range. The 200 m long accelerator consists of a high brightness photo-cathode gun working at up to 50 Hz repetition rate, a 1.5 GeV normal conducting linac and two bunch compressors. The accelerated electron bunches, together with a tunable UV seed laser beam, are sent into a chain of undulators where they generate ultra short (<100 fs) and high peak power (~GW) coherent photon pulses with variable polarization. Two distinct undulator chains will be available, FEL-1 and FEL-2, covering the entire spectral range from 100 to 4 nm in the first harmonic.

Three beamlines have been designed so far, dedicated to different scientific areas: Low Density Matter (LDM), Elastic and Inelastic Scattering (EIS), and DIffraction and PROjection Imaging (DIPROI). The particular characteristics of the FEL photon beam enable time resolved experiments to study ultrafast dynamics and transient phenomena of matter under extreme irradiation conditions.

The FERMI@Elettra project has developed through several installation and commissioning periods and the achievement of intermediate milestones: first electrons from the photo-cathode gun in August 2009, linac energy at 1.2 GeV in September 2010, beam transported in the undulator hall in October 2010 and first free electron lasing in December 2010 [1].

Figure 1: Aerial view of the Elettra 2.4 GeV storage ring and the FERMI@Elettra Free Electron Laser.

OVERVIEW OF THE CONTROL SYSTEM

A complete description of the FERMI@Elettra control system is given in [2].

Fig. 2 shows the control system architecture. The low level computers are VME crates with PowerPC CPU boards or rack-mount Intel-based servers both running the GNU/Linux operating system with the Adeos/Xenomai real-time extension. Siemens S7 PLCs have been extensively employed in protection and safety systems, as well as for the low level control of undulators. In the control room, Linux PCs equipped with two or four monitors are used as operator workstations, while Intel-Xeon servers with a number of Xen virtual machines provide general common services such as network file system, remote boot, network services, database facilities, archiving system, etc.

The control system backbone is a pervasive Gigabit Ethernet network serving all of the machine tunnels and service areas of the facility. In addition, several isolated segments of data network are used to locally access Ethernet-enabled devices. The use of Ethernet as a fieldbus allowed us to reduce the number of low level computers (~70) necessary to interface a high number of devices.

A distributed real-time framework based on an in-house developed protocol called Network Reflective Memory (NRM) and a dedicated Ethernet network connecting all the low level computers, allows developing distributed

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real-time applications exchanging shot-by-shot data at the linac repetition frequency (10-50 Hz) [3].

The Tango toolkit has been adopted as control system software. Tango device servers are mostly written in C++ and Python, while graphical interfaces and control room applications are developed with QTango and Matlab. A high level software framework has been created to provide machine physicists with tools and methods to develop software applications for controlling the machine through its model.

The software development and deployment process relies on CVS. Bug reports and new requests are collected and managed using a ticketing system based on Bugzilla. Programmers develop the software using dedicated reference computers. The source code is then tagged on the repository, checked out and compiled on a clone of the field systems before being deployed in production. The system administrator hence performs the final installation keeping track of the details on an internal wiki page.

TWO YEARS OF MACHINE COMMISSIONING AND OPERATIONS: KEYS TO SUCCESS

The particular approach adopted in the project schedule, with alternating periods of installations and commissioning operations lasting in average five and nine weeks respectively, and the difficulties inherent in the commissioning of a novel machine, have set new challenges in the design and implementation of the control system. Since the beginning of each commissioning phase, physicists need to smoothly operate via the control system the machine components that have just been installed. Moreover, while performing the complex and time-consuming commissioning operations, the control system must effectively support them without inconvenience to their activities. For these reasons the control system must be flexible, high-performing and reliable: a service rather than a concern.

The experience gained in two years of installations and machine commissioning records several difficulties but emphasizes the importance of a few strategic factors that made it possible to meet the requirements mentioned above. They are in particular the standardization of hardware and software, the choice of Tango, the real-time framework and the use of Matlab.

Standardization

Special care has been taken from the beginning of the project in order to possibly adopt the same hardware/software technologies as well as the same control system architecture throughout the whole facility, from the photo injector to the experimental stations. Standardization involves several aspects of the control system: hardware interfaces (mostly Ethernet and serial), low level computers (VME/PPC or Intel servers, depending on the required performance and hardware interfaces), system software (Linux and Tango) and graphical interfaces (QTango and Matlab). Forcing standardization has been sometimes hard and slightly more expensive, but the benefits in reducing the development and maintenance costs are evident. A particular case is the adoption of the YAMS motor controller, an in-house design using commercial components, utilized for most of the stepper motors of the facility [4]. Being a flexible system it fits to any motion application while maintaining a common interface to the control system. More than 400 axes will be eventually controlled by YAMS.

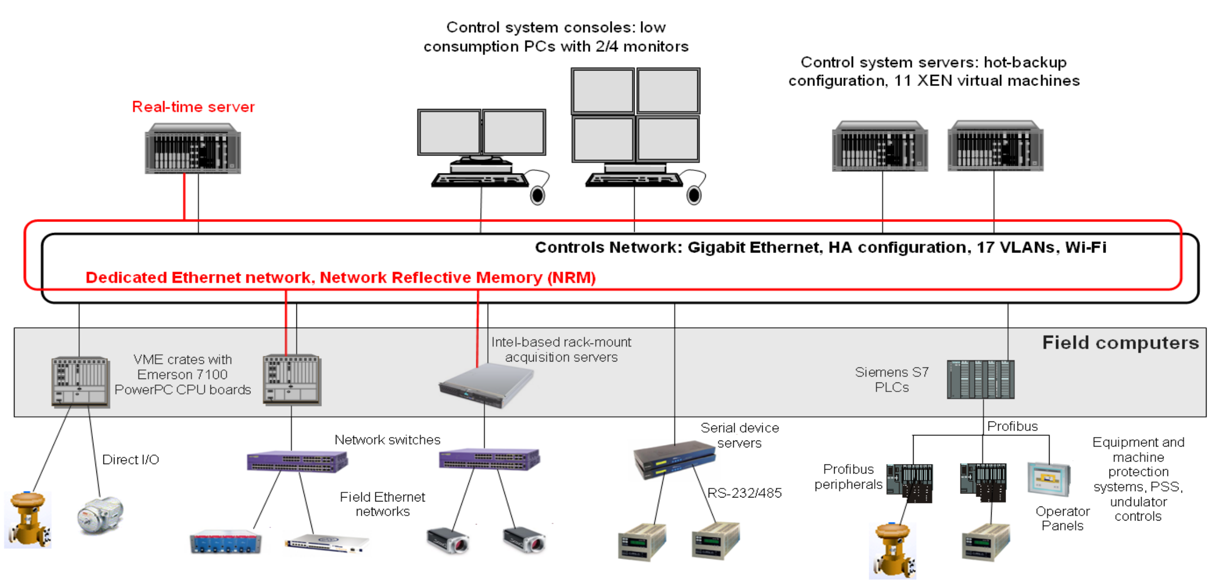

Figure 2: Architecture of the FERMI@Elettra control system.

Tango

The Tango toolkit is the real "glue" of the control system providing an effective integration of the controlled technical systems and the software controlling them. From the client point of view the machine components are seen through a uniform API interface regardless of the way they are connected to the control system.

The device model, which is the fundament of Tango, offers an object oriented approach to controls issues, with important benefits for the software development and maintenance. Each equipment or physical device connected to the control system is assigned a Tango device which exports an API with attributes and commands. Further hierarchical levels of Tango devices with a higher level of abstraction can then be developed to aggregate several devices, add more sophisticated functionalities or offer different views of the same device to the client level. This possibility has been widely utilized in FERMI@Elettra; following a general rule that we adopted, all of the coordination, processing and automation functionalities have been implemented in the device server level, leaving to the GUIs only display duties.

Tango is behaving as required in terms of reliability and performance, and confirmed to be mature and stable.

Real-time ramework

FERMI@Elettra is a pulsed machine with repetition rate up to 50 Hz. A distributed real-time framework well integrated into the control system provides the capability to measure and manipulate the laser, electron and photon beams, as well as to close synchronized feedback loops on a pulse-to-pulse basis.

All the relevant monitor points (e.g. electron and photon diagnostics) and control points (e.g. power supplies) are synchronized with the bunch trigger. Moreover, a real-time time-stamp called "bunch number" is distributed to all of the low level computers via the NRM.

The diagnostic electronics provide shot-to-shot data to the low level computers through real-time interfaces; data are tagged with the bunch number and stored in local circular buffers that can be easily read by high-level applications through specific Tango servers. The same data can also be placed in the NRM and shared in real-time with the other control system computers (see Fig. 3).

Most of the power supplies allow synchronized current settings. The values can be generated, sent to the low level computers through the NRM and set on the power supply shot by shot in real-time. Alternatively, an arbitrary waveform can be loaded into a local buffer through a Tango server and then used to set the power supply shot by shot after a trigger command.

The above described capabilities have been widely used during the machine commissioning. Relevant examples are FEL jitter studies carried out by correlating shot-to-shot data provided by photon and electron diagnostics, and fast emittance measurements using synchronized quadrupole power supplies and fluorescent screen CCDs.

A centralized real-time server can run synchronized feedback loops by reading sensors and setting actuators through the NRM at the linac repetition frequency. For now a fast trajectory feedback has been developed to correct the electron beam position in various locations of the machine [5].

Matlab

Thanks to the availability of effective Tango bindings, Matlab has been chosen to easily develop scripting procedures and GUIs interacting with the machine through the control system. Matlab has also been interfaced to simulation codes like Elegant [6], thus opening the way to the physicists for the development of their own machine physics applications and measurement procedures employed during the accelerator commissioning.

Matlab GUIs are also useful for graphical panels prototyping carried out by non-professional programmers such as physicists or specialists of technical systems. The GUIs are developed, used and modified several times, and eventually translated to QTango by controls people once they are stable.

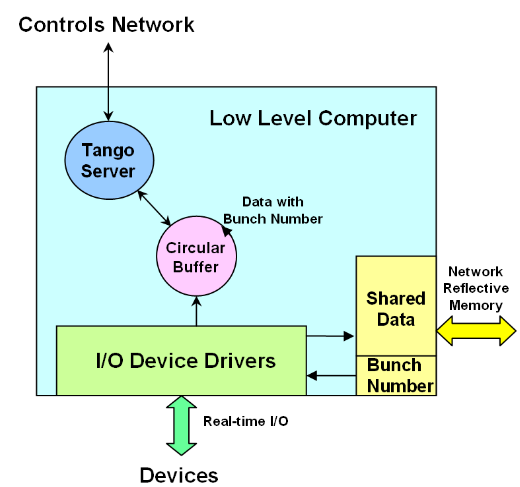

Figure 3: Software architecture of a low level computer acquiring real-time data.

EXPERIMENTAL STATIONS CONTROL AND DATA ACQUISITION SYSTEMS

Experiment controls are an extension of the machine control system and employ the same technology and architecture [7]. For practical reasons the control system of the experimental stations is logically separated from the machine: each of the stations has its own Tango database running on a dedicated virtual machine and separated VLANs in the controls data network. Access to the machine control system from the experimental stations is realized by providing a restricted view of the machine devices through special Tango servers acting as bridges.

Data acquisition and online processing applications are developed using Tango on Linux machines. High-level applications can be developed both on Linux and Windows platforms using C/C++, Python, LabView, IDL or Matlab.

The NRM provides the experimental stations with the bunch number and pulse-to-pulse data from the upstream electron and photon diagnostics. This allows associating to the data acquired in each shot from the experiment detectors the characteristics of the corresponding FEL photon pulse, such as position, intensity, wavelength and bandwidth.

A scientific data storage system featuring a capacity of several hundreds of terabytes is being designed to accommodate the considerable amount of data that will be generated by the detectors with sustained data rate up to 400 MB/s. Dedicated acquisition servers will receive data from the detectors through high-speed real-time interfaces and will directly send them via dedicated 10 Gb/s Ethernet links to an online processing server, which will reduce data and eventually transfer them to a centralized storage system.

CONCLUSION AND OUTLOOK

After the commissioning of the machine and optimization of the FEL process in the first line of undulators (FEL-1), in July 2011 a coherent photon beam having the expected intensity and stability in a tunable wavelength range from 52 to 20 nm has been obtained, allowing the first rudimental experiments in the beamlines. In the next months, further optimizations will be carried out after the commissioning of the second bunch compressor and of the X-band RF cavity devoted to the linearization of the longitudinal phase space. In 2012 FEL-2 will be commissioned and more time will be gradually dedicated to the experiments, accomplishing the transition of the facility from commissioning to users operation.

The control system will evolve according to the new requirements. In particular, a number of additional feedback loops will be provided to stabilize the main beam parameters, such as charge, energy, bunch length and time of arrival. Moreover, further high-level applications will be developed to let the operators run the machine effectively and autonomously during users shifts.

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