THE CONTROL SYSTEM OF THE FERMI@Elettra FREE ELECTRON LASER

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Abstract

FERMI@Elettra is a new 4th-generation light source currently under construction at the Elettra laboratory. It is based on a single-pass free electron laser consisting in a 1.5-GeV normal-conducting linac and two chains of undulators where the photon beams are produced with a seeded laser multistage mechanism.

The control system interfaces to and controls all devices and systems of the facility. The hardware architecture has been designed using commercial components and open standards, and a software environment based on GNU/Linux and the Tango control system is deployed on all computers. The safety and protection systems rely on a well established technology based on PLCs. A real-time infrastructure based on a dedicated Ethernet network and a real-time implementation of Linux provides centralized shot-by-shot data acquisition at the linac repetition rate, as well as synchronized setting of the controlled variables required to implement feedback loops.

INTRODUCTION

FERMI@Elettra is the first user facility based on seeded harmonic cascade Free Electron Laser (FEL) providing controlled, high peak-power photon pulses [1]. The accelerator complex comprises a high-brightness RF photocathode gun and a 1.5 GeV S-band linac made of 18 accelerating sections powered by 15 RF plants. The produced electron beam has a single-bunch structure with a repetition rate of 50 Hz. Two FEL cascades with laser-seeded harmonic generation provide the beamlines with tunable output over a range from ~100 nm to ~4 nm, pulse duration of ~100 fs and peak power in the GW range. The generated radiation is spatially and temporally coherent, with fully variable output polarization. Four laser systems drive the photocathode gun, the laser heater, the FEL seeding and pump-and-probe experiments on the beamlines.

CONTROL SYSTEM REQUIREMENTS

The accelerator complex includes a considerable number of conventional systems and devices to be controlled requiring standard control system interfaces and functionalities. In addition to them, several special needs and challenges that arise from the complexity of the facility and the required performance must be addressed.

In order to meet the demand of reliability and availability, special care has been taken in the design of the architecture, in the choice of the technologies and in the selection of the components of the control system. Open standards and off-the-shelf hardware and software components have been adopted whenever possible. Remote monitoring and fixing capabilities have been added to the systems with out-of-band paths to detect faults and malfunctions and minimize the recovery time.

Synchronization and trigger signals at different level of precision have to be distributed throughout the facility from the photo injector laser to the beamline experiments. Shot-by-shot data acquisition and time stamping capabilities are also required to precisely characterize each electron bunch during its run throughout the accelerator and the corresponding photon pulse generated in the undulator chains.

A number of feedback loops, some of them working on a shot-by-shot basis, will be necessary to stabilize the crucial parameters of laser and electron beams. For this purpose, a generalized and integrated framework is required to flexibly and easily implement feedback loops using several monitoring and control variables.

CONTROL SYSTEM IMPLEMENTATION

Data Network

The backbone of the control system is a Gigabit Ethernet network where several types of devices are connected. A multi-mode fibre optics infrastructure, designed to allow for future upgrades to 10 Gigabit Ethernet, connects a central switch to ~50 peripheral switches. The central switch is made of two units working in high availability redundant configuration, each connected by fibres to all of the peripheral switches. The data network has been logically subdivided in a number of VLANs each dedicated to a homogeneous typology of devices: control system Linux computers, windows computers (including several instruments), wireless access points, diagnostics equipment, etc.

Equipment Controllers

The front-end computers (Equipment Controllers - EC) are VME systems equipped with Emerson MVME-7100 PowerPC boards running the Linux operating system. The crates feature a 16-slot VME64x backplane, two redundant hot-swappable power supplies and an embedded control unit with Ethernet interface for remote monitoring and control of the crate. Intel-based PCs are also used as front-end computers when required by proprietary software or special interface hardware.

All the cabinets containing control system computers have been equipped with intelligent Power Distribution Units (PDU) with Ethernet interface, providing remote current adsorption measurements and switching off/on capabilities on each power socket.

Hardware interfaces

A variety of interfaces are used to control the equipment. They are mainly direct I/O (ADC, DAC, digital I/O), serial lines (RS-232/485) and Ethernet connections. Direct I/O and serial lines are usually interfaced to the EC via VME boards, IP and PMC modules.

Among the many interfaces the most used is Ethernet, which is becoming a standard for devices and instrumentation featuring an embedded controller. Ethernet devices are usually connected to the EC through an Ethernet switch, which aggregates a number of neighbor devices. Examples where Ethernet is used as a "fieldbus" are the interfaces to magnet power supplies and Gigabit Ethernet CCD cameras.

A special case of integration into the control system is the Libera Brilliance Single Pass BPM detector. This device has a 100 Mb/s Ethernet port managed by an internal Single Board Computer running Linux and the Tango software, which is directly connected to the controls network. A second Gigabit Ethernet port managed by an internal Virtex-II FPGA is in charge of the real-time transmission of beam position measurements at the bunch repetition frequency (up to 50 Hz) using UDP packets. Data from a number of neighbor detectors are transmitted synchronously to the EC via an Ethernet switch.

Control room consoles and servers

The control room consoles are low-consumption quad-core PCs with solid state hard disks running the Ubuntu/Linux operating system and the KDE desktop.

For the control system servers a hot backup configuration with two physical servers (each with four Intel Xeon quad-core processors and 64 GB of RAM) each running a number of virtual machines has been adopted. Xen has been chosen for the virtualization. In case of fault of one server, its virtual machines can be transferred to the other server transparently to the operation of the control system. Presently there are four virtual machines running in the servers, in charge of the following tasks: file system and boot support for diskless machines, general network services (DHCP, DNS, NFS, etc.), Tango servers and database, and historical archiving system.

PLC systems

PLCs are widely adopted in the control system. The PLC Siemens S7 series 300 has been chosen for all the applications. Extensive use of Profibus is made to connect distributed peripherals to the CPUs, which communicate with the control system via Ethernet interfaces using the TCP/IP Send/Receive protocol and a dedicated Tango server.

The Equipment Protection System manages the protection of vacuum chambers and magnets. In addition, a dedicated interlock system protects the linac RF plants: it consists of one PLC for each of the modulators and a master PLC that acquires cooling water and vacuum alarms from the accelerating sections. The PLCs communicate with each other via Profibus.

The Machine Protection System is in charge of protecting undulator permanent magnets from radiation damage. It relies on various detectors (beam loss monitors, ion chambers, dosimeters, current monitors, etc.) and inhibits the beam by acting on the photo-injector laser and on the linac RF.

The Personnel Safety System is based on a fail-safe version of the Siemens PLC. It controls access to the linac tunnel, the undulator hall and the hutch containing the beamline switching and deflecting mirrors.

Bunch trigger distribution

The bunch trigger is distributed all through the machine to synchronize the diagnostics electronics and to trigger the generation of laser and linac RF pulses. This task is carried out by the Event System, consisting in a set of VME boards manufactured by Micro-Research. The master of the system is the Event Generator, which distributes digital events to the Event Receivers, hosted in the ECs, through an infrastructure or fibre optics. The Event Receiver can generate software interrupts on the VME bus and electrical/optical signals with a maximum jitter of 20 ps.

Stepper motor controllers

Stepper motors are extensively used in the facility in a wide range of applications. In order to standardize the controls of the motors, a new in-house design has been made based on commercial components. The project, called YAMS (Yet Another Motor Sub-rack), consists in a 3U chassis containing the stepper motor controller, up to eight motor drivers and all the necessary auxiliary systems. The adopted motor controller is the Galil DMC2183, while the drivers are Intelligent Motion Systems (IMS) hybrid modules. The motors can be controlled locally with an operator panel or remotely through a TCP/IP Ethernet interface and a dedicated Tango device server.

CONTROL ROOM SOFTWARE

A set of generic applications is deployed in the control room: browser/launcher, alarm system, historical archiving, save/restore, generic tool, etc.

The control room graphical applications are based on the *Qt* toolkit (by Trolltech) and *QTango*, a C++ library of Tango-aware components handling the most common functionalities for building control panels, such as device proxy, event subscription, polling threads, error logs, etc. [2]. The *QTango* library has been integrated in the standard *QtDesigner*. In order to use this tool to also build synoptic panels, new functionalities have been added for drawing graphical components, managing layers and importing images.

An online modelling toolkit has been developed to provide machine physicists with tools and methods to easily and quickly develop machine physics applications. It is made by a set of software libraries, calibration databases, simulation programs and configuration files that allow machine physics applications to control the machine through its model. A complete description of this toolkit is given in [3].

Taking advantage of the availability of the Tango bindings, Matlab and its GUIs have been chosen to let the physicists develop their own machine physics applications and measurement procedures used during the accelerator commissioning.

REAL-TIME FRAMEWORK

FERMI@Elettra is a pulsed machine generating and accelerating electron bunches at 50 Hz repetition rate. The control system is required to implement built-in capabilities to measure, through the diagnostics, the characteristics of every single laser pulse, electron bunch and radiation pulse, and correlate them to each other. Moreover, a number of feedback loops are necessary to stabilize the laser and electron beams, some of them working at the bunch repetition rate. A real-time framework tightly integrated in the control system has been implemented for this purpose.

A dedicated Ethernet network reaching every control cabinet has been installed for this purpose. The computers involved in real-time activities (both Intel-PCs and PowerPC machines) run Linux plus the Xenomai real-time extension [4] and interface to it by means of an additional Ethernet port of the CPUs. The standard Ethernet device driver has been modified in order to be able to receive and transmit UDP packets in real-time. A network software application called Network Reflective Memory (NRM) has been developed to implement a real-time shared memory, where data can be transparently shared among computers. The communication architecture is centralized, i.e. a master is in charge of receiving UDP packets from each computer and re-transmitting them to the other machines with a broadcast message. The NRM engine works at up to 10 kHz repetition rate. However, being most of the job performed with DMA, the CPU load is negligible.

The architecture of the real-time framework is shown in Fig. 1. A real-time server is in charge of bunch number distribution (time stamp), data recording/archiving and feedback processing. In this machine multiple feedback loops can run in parallel reading sensors and setting actuators through the NRM at the bunch repetition frequency. The loops can be configured and monitored from the control room using GUIs and high level applications that take advantage of the on-line model and simulator to calculate the feedback parameters.

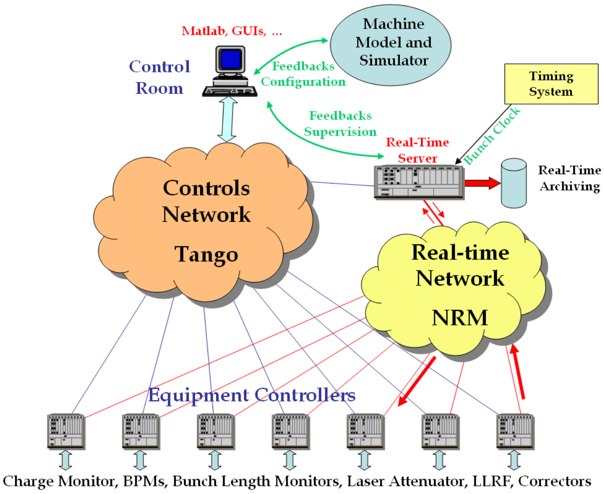

Figure 1: Architecture of the real-time framework.

STATUS AND OUTLOOK

The first part of the FERMI@Elettra linac has been installed and is currently under commissioning, while the installation of the rest of machine is proceeding in parallel thanks to a radioprotection wall placed in the linac tunnel.

The control system has met its requirements in terms of performance and availability. As a result the commissioning with beam is going along very smoothly. Further installation and commissioning phases will follow with the objective to perform the first experiment on the beamlines by the beginning of 2011.

While the main control system infrastructures and services (network backbone, servers, control room, etc.) have already been built and are currently operating, the challenge is represented now by the further installation and commissioning of a large number of devices and systems in a very short time. Due to the increase of the number and complexity of the installed systems, a set of new control room applications must be developed to better support future operations, such as synoptic global displays, applications oriented to high level operations (tuning and optimization) and tools for the automation of multiple complex actions.

In view of the first experiments, emphasis will be given to the design of control and data acquisition systems of beamlines and experimental stations. It will be crucial to provide scientists with efficient and integrated online processing tools, data storage systems and grid facilities.

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