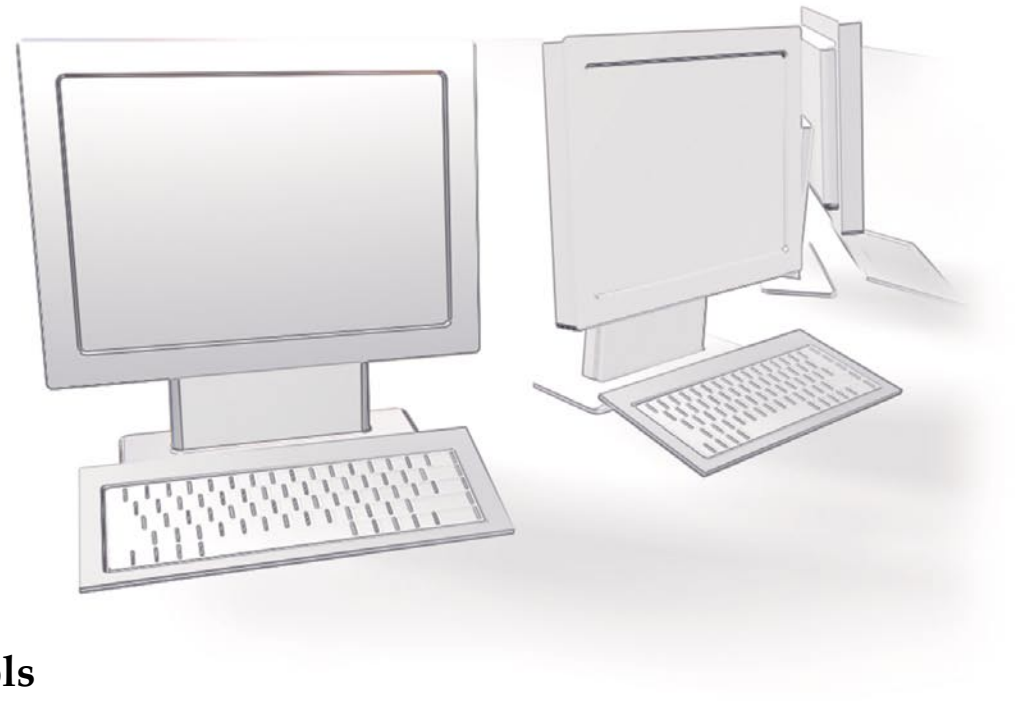

12 Controls

Synopsis

The control system provides operators, machine physicists and scientists with a comprehensive and easy-to-use set of tools to control machine components and experimental beam lines. It is designed to be robust and reliable in order to insure long periods of operation without failures or malfunctions. Diagnosis and possibly repair capabilities are implemented in order to allow for remote recovery from malfunctions of both the equipment and the control system itself, with minimum impact on the facility operation. In general, the control system design is flexible enough to accommodate the specific requirements of a large variety of both conventional and highly specialized devices that are installed and controlled on the accelerator, the beamlines and the experimental stations.

The control system consists of several computers distributed around the facility that interface with the different equipment and acquire data. A number of PC-based consoles allow to remotely operate the machine from the control room. Similar consoles in the experimental hall are used to control the experiments. A switched Ethernet network connects all the control system computers.

State-of-art software technologies are employed, based on open standards and free open-source packages. A uniform and homogeneous software environment using the GNU/Linux operating system and the Tango control system software is adopted for the whole control system. A high level software framework supports model based design of machine physics applications. General purpose control room applications (graphical panels, synoptics, alarms, archiving, logging, etc.) are implemented using the Tango package software tools.

Special attention is given to fast feedback loops, which are crucial to achieve the desired beam parameter accuracy and stability. They read sensors and set actuators on a shot-by-shot basis and are integrated in the general control system infrastructure.

Equipment protection systems, based on PLCs and on a number of distributed I/O peripherals connected via fieldbus, are designed to efficiently and reliably protect machine and beamline components.

The architecture of the access control system is similar to that of the equipment protection but, given the high degree of safety required, stricter procedures are adopted in its design, in conformity with the IEC 61508 European standard. Fail-safe versions of PLCs, fieldbus and I/O peripherals are utilized. Component redundancy and diversification are implemented whenever possible.

12.1 Introduction

The control system architecture and main hardware components are discussed in Section 12.2. Several computers are interfaced to the different pieces of equipment and perform data acquisition and control tasks. Personal computers are used as consoles in the machine control room and on the beamlines. A high speed data network connects all the control system computers.

The software framework is discussed in Section 12.3. Open standards and open-source software are adopted. A software environment based on Linux and the Tango control system is deployed on all computers.

The control system provides shot-by-shot synchronized acquisition and recording of accelerator and photon beams data for tuning and optimization purposes as well as for collection of user experiments data. Real-time processing capabilities and synchronized setting of the controlled variables are also required to implement feedback and feed-forward loops for the stabilization of beam parameters.

In Section 12.4 the main controlled devices are listed and briefly described.

A short description of the equipment protection system designed to automatically prevent accelerator and beamlines equipment from being damaged is given in Section 12.5. The system designed to implement regulations for controlled access of people to areas where radiation hazard exists, including active safety measures, is discussed in Section 12.6.

12.2 Control System Architecture

The control system architecture provides easy access to the equipment in a reliable and efficient way. It facilitates the development and maintenance of distributed applications, and the implementation of the required control schemes. It is designed to be modular and scalable in order to accommodate future changes and expansions.

The resulting system architecture, shown in Figure 12.2.1, includes various types of computers, distributed along the machine and the beamlines, all connected to the data network.

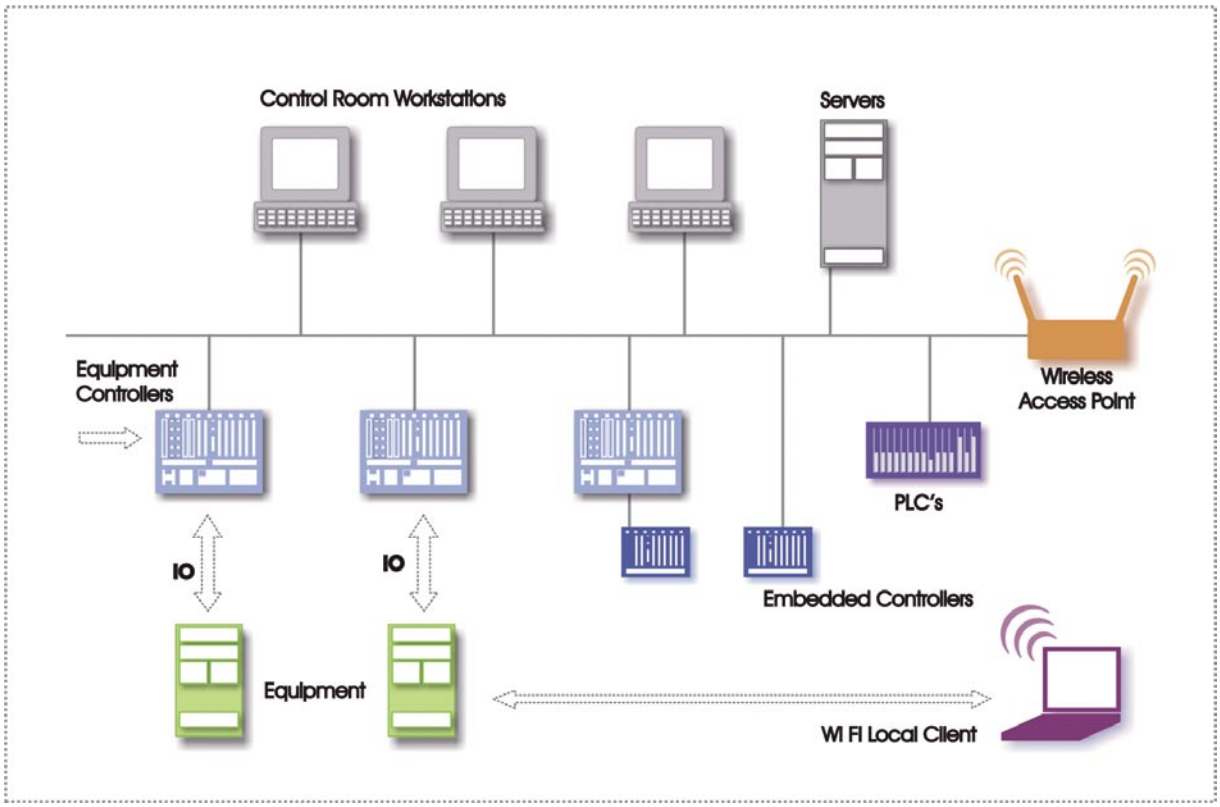

Figure 12.2.1:
Control system architecture.

12.2.1 Equipment Controllers

The Equipment Controllers (EC) are diskless computers interfaced to the controlled equipment. They acquire and process data from the field and execute control actions. Modular VME systems are adopted in order to tailor to any specific control requirements. Several Input/Outputs (I/O) types are used: analogue and digital signals, RS 232/422/485 serial lines, GPIB, fieldbuses, etc. The CPU boards have to provide good performance level together with excellent reliability and long life span.

12.2.2 Network Attached Controllers

Equipment embedded controllers featuring an Ethernet port as well as Programmable Logic Controllers (PLC), like those employed for the equipment protection and access control systems, are connected to the data network. A socket TCP/IP interface is normally used for the communication.

12.2.3 Servers

The servers are Linux computers providing common services for the control system such as remote boot, Network File System (NFS), database, alarms, historical archiving, experimental data storage, web servers, etc.

12.2.4 Consoles

The control room consoles consist of PCs (Personal Computer) running the Linux operating system. They execute client applications including graphical panels, machine physics programs, automatic procedures in support of the operations and data analysis software. Similar consoles in the experimental hall are used to control the experiments.

12.2.5 Data Network

The data network is based on Ethernet technology. A number of distributed switches connected via fiber optics up-links to the master switch provide Gigabit Ethernet connections to the control system computers. The control system data network is decoupled from the general on-site data network by means of a firewall to protect it from external intrusions or harmful traffic. The technical galleries are equipped with wireless networks to facilitate temporary connections of portable computers or electronic devices.

12.3 Software Framework

A uniform and homogeneous software environment based on the GNU/Linux operating system and the Tango control system software has been adopted for the whole control system. It is deployed on both PC and VME platforms and possibly also on the embedded computers.

12.3.1 Operating System

The open source GNU/Linux operating system is efficient, reliable, free of charge and runs on nearly all hardware platforms. Most of I/O hardware manufacturers support Linux and the device driver source code is usually available. Since the standard Linux kernel does not offer real-time characteristics, the real-time extension RTAI (Real-time Application Interface) [1] has been adopted and is used whenever a deterministic behavior of the control system is required.

12.3.2 Tango Control System Software

Tango is a fully object oriented CORBA-based control system software [2]. Born in the late '90s, Tango is now a well-established and mature project, used by a wide community of users especially in the field of synchrotron light sources. The ELETTRA controls group has first adopted Tango in 2004 for the controls of the ELETTRA injector booster and is currently a member of the international collaboration that is further developing it.

The “object model”, which is the fundamental paradigm of Tango, together with a set of useful tools

allows developing clear, efficient and maintainable code with reduced programming effort and facilitates re-using and sharing of software among different laboratories.

12.3.3 Control Room Applications

A number of generic applications are deployed such as alarm systems, historical archiving, databases, web servers, etc. Client control room applications including graphical panels, machine physics programs, applications for routine operations and specific data acquisition and analysis programs can be developed in C++, Python or Java, taking advantage of the graphical toolkits available in Tango. Commercial software packages for data analysis and presentation are also supported.

12.3.4 High Level Framework

A new High Level software Framework (HLF) [3] is being developed at ELETTRA to support model based design of machine physics applications. HLF is a set of software libraries, databases, configuration files and simulators that allow machine physics programs to control the machine through its model. HLF is fully object-oriented and uses a modular approach. A number of modules provide a set of different views or abstractions of the underlying machine.

12.3.5 Real-time Infrastructure for Feedback Systems

The stability of the electron and photon beam parameters is a crucial issue for FEL machines. Feedback loops are developed to stabilize charge, trajectory, length and energy of the electron bunches during long periods of operations. These loops operate on a shot-by-shot basis reading sensors and setting actuators at the linac repetition rate. Feedback loops are also foreseen for the laser systems to stabilize the beam trajectory and shape.

The control system provides the infrastructure necessary to synchronize the computers involved in the feedback and to exchange data in real-time. The computers use a separate port to connect to a dedicated Ethernet network that is set-up for this purpose. Specialized real-time drivers and tasks running in the RTAI kernel space provide communication and data processing with latency jitter of the order of a few micro seconds [4]. If necessary, dedicated centralized processing units can be added to execute and manage the feedback loops.

12.4 Controlled Devices and Equipment

12.4.1 Vacuum System Equipment

Vacuum equipment managed by the control system includes vacuum pumps with their high voltage power supplies, vacuum gauges and residual gas analyzers. These are interfaced to the control system through serial lines and Ethernet connections.

Vacuum valves and beam stoppers are controlled by the PLCs of the equipment protection and access control systems: status requests and open/close commands are sent to the PLCs via Ethernet TCP/IP interface.

12.4.2 Magnet Power Supplies

A large number of magnet power supplies are interfaced to the control system. They power solenoids, bending magnets, steerers, quadrupoles, phase shifters and undulator correction coils. Digital interfaces through high-speed serial links or Ethernet are privileged over direct analog/digital I/Os. High-speed low-latency interfaces are required to control the power supplies of the steerer magnets involved in trajectory feedbacks.

12.4.3 Diagnostics and Instrumentation

The control system interfaces several types of diagnostic equipment and instrumentation. It provides acquisition, processing and presentation of data, which can be immediately interpreted by machine operators and scientists. Real-time acquisition capabilities and fast data transfer allow for shot-by-shot measurements of the electron bunch characteristics, which can be displayed in real-time in the control room and on beamline consoles. Diagnostic systems include, among others, beam position monitors, current monitors, CSR diagnostics, electro optical sampling stations, profile monitors, YAG screens, collimators, beam loss monitors and various beamline diagnostics.

12.4.4 Timing and Synchronization

The timing and synchronization system generates and distributes optical and electrical signals to synchronize the machine operations and the beamline experiments.

One EC is dedicated to the timing central station, which is located close to the photoinjector laser room. It is in charge of hot swapping between a working Optical Master Oscillator (OMO) and a redundant one in case of fault of the former, to insure high availability of the timing system. Other controlled instrumentation includes oscilloscopes and an optical spectrum analyzer.

In the periphery of the timing system, standalone local units distribute timing signals with programmable delays to the end users. They are controlled via serial lines or Ethernet.

12.4.5 Linac

The existing ELETTRA linac control system will be completely replaced. The electro magnetically noisy environment and grounding issues in the linac klystron room require particular care in connecting the EC electronics to the linac equipment. Insulated I/O signals, shielded cables, fiber optics and digital interfaces are employed to reduce interferences and ground loops. RF shielded VME crates protect the I/O electronics from electromagnetic fields, while connections to the data network are done through fiber optics.

Each of the fifteen linac plants is controlled by a dedicated EC. Devices to be controlled include RF amplifiers, high voltage power supplies, thyratrons, klystrons and other auxiliary equipment and components.

The low level RF (LLRF) digital controllers feature an embedded computer connected to the control system through an Ethernet port.

12.4.6 Undulators

The FEL undulators (radiators and modulators of FEL-1 and FEL-2) variable gap segments allow for individual tuning to specific photon wavelengths. Elliptical undulators with variable polarization need additional phase control. Gap and phase of the segments of undulator are controlled with micrometric accuracy and reproducibility by a local control unit interfaced to the control system.

Feed-forward systems based on lookup tables correct trajectory and optics distortions due to the undulators by acting on correction coils and quadrupole magnets.

12.4.7 Quadrupole Movers

Mechanical movers remotely operated through the control system are foreseen for quadrupole magnets, both for initial alignment and for periodic beam based alignment procedures compensating for long term drifts. Quadrupoles are moved transversally along both the x and y axes with micrometric resolution.

12.4.8 Laser Systems

A number of laser systems are foreseen: photoinjector, laser heater, seed and pump lasers.
They include various pieces of equipment such as power meters, autocorrelators, oscilloscopes, photodiodes, shaping systems, mirrors and parametric amplifiers to measure and optimize beam parameters. They are interfaced to the control system through serial lines, Ethernet or direct I/O. Analysis and optimization software tools help the setting up of the laser systems, while feedback loops are foreseen to stabilize all relevant laser beam parameters.

12.4.9 Beamlines Optics

The beamline optics systems transport the photon beam from the FEL undulators to the experimental stations and shape it by means of a set of in-vacuum optical components such as mirrors and collimators [5]. Stepper motor movers, coupled with piezo ones, are used for mirror selection, translation and angular positioning, as well as for collimator slits adjustment.

Operations involving different “physical devices” that must be positioned and set–up according to complex rules (e.g. monochromators) are performed by higher level “logical devices”.

Hardware control parameters, photon beam parameters and data produced by different diagnostic elements are controlled, processed and displayed via the control system.

12.4.10 Experimental Stations

The control system software provides an efficient framework to develop photon beam optics and experimental station controls and to integrate them into the experiment application programs. Among others, it allows for shot-by-shot synchronized acquisition of both experimental data and photon beam pulse parameters for data normalization.

While the instrumentation set of a given experimental station is ever changing and growing in accordance with the experiment needs, basic systems to be controlled such as vacuum equipment (pumps, pressure

gauges), sample sources (pulsed supersonic jet source, pulsed plasma cluster source, vapor sources) and detection systems (time of flight, mass spectrometers, wavelength resolved visible/UV fluorescence detectors, time resolving channel plate fluorescence detectors, hemispherical electron energy analyzers) can be considered as "standard" items of the set. The control system design is flexible enough to allow for a particular subset of such devices to be installed and controlled on any given experimental station according to the experiment specific requirements.

12.5 Equipment Protection System

12.5.1 Requirements and Architecture

The equipment protection system is designed to efficiently and reliably protect machine and beamline components from damage. It is based on PLCs, in charge of executing control programs, and on a number of distributed I/O peripherals connected via fieldbus. Interlock actions implying simple logic rules but involving severe risks are implemented as hard-wired circuits.

Control room applications for the operator consoles (graphical panels, synoptics, alarms, archiving, logging, etc.) are implemented using the Tango package software tools. PLCs communicate with the control system through their Ethernet interface using the TCP/IP protocol. In addition, small consoles equipped with keyboard and LCD display for local control are installed in the machine technical gallery and in the experimental hall, wherever necessary.

12.5.2 Interlocks Description

12.5.2.1 Cooling Systems

Several sensors measuring temperatures, cooling water fluxes and pressures monitor the machine and beamline components and their cooling systems in order to prevent temperatures from drifting outside the specified ranges.

12.5.2.2 Vacuum

The gas pressure in the vacuum chamber is continuously monitored by vacuum gauges and by measuring the ion pump high-voltage power supplies current. An interlock closes the proper vacuum valves in case of anomalous pressure rises.

12.5.2.3 Linac RF Transmitter Plants

A series of interlocks are implemented on all RF plants to ensure safe operation of the linac. They inhibit switching on or switch-off the various subsystems in case of anomalous situations. Signals from cooling water and oil systems, from thyratron grid and filament, from the klystron vacuum, filament, pulse transformer, focalization system and from the sulfur hexafluoride gas system are continuously monitored at each plant. A number of additional plant parameters, such as klystron anodic current, modulator inverse current and reflected RF power at the klystron output are measured on a pulse-to-pulse basis. Additional checks related to personnel safety are also performed.

The accelerating sections vacuum level is also continuously monitored so that the RF and the photoinjector are switched-off in case of pressure increases above a given threshold. Other photoinjector protections,

continuously monitoring the gun vacuum pressure as well as the grid filaments voltage and current, enable/disable operation of the photoinjector sub-systems.

12.5.2.4 Beam Trajectory

A protection interlock based on continuous monitoring of the electron beam position in the FEL undulators prevents the beam from accidentally hitting the vacuum chamber and damage the undulator permanent magnets. Radiation beam loss monitors and additional monitors measuring bunch current differentials at several locations are also deployed and integrated into the protection system. In case of alarm the interlock trips the photoinjector.

12.6 Access Control System

The access control system protects personnel from radiation hazards by controlling access to potentially dangerous areas. Whenever an anomalous or dangerous situation is detected it switches off the electron beam and prevents it from being restarted until the danger has been removed.

The access control system architecture is similar to that of the equipment protection system but, given the extremely high degree of safety required, stricter procedures are adopted in its design in conformity with the IEC 61508 European standard [6]. Fail-safe versions of PLCs, fieldbus and I/O peripherals are utilized. Component redundancy and diversification is implemented whenever possible.

The access control system monitors the linac gallery, the undulator hall and the hutch containing the beamlines switching and deflecting mirrors.

From the access control point of view the linac gallery and the undulator hall are considered as a single area. A door between them facilitates the search procedure prior to switching on the accelerator. Both the photoinjector and the linac RF drive must be inhibited to access the linac gallery and the undulator hall. The two doors and six emergency exits of the controlled area are all interlocked. Individual access through the doors for temporary internal activities is only allowed using personal badges and safety keys, after having been granted permission by a control room operator.

Bending magnets located downstream of the FEL undulators deflect the spent electron beams into an appropriate beam dump. The bending magnet currents are continuously monitored to guarantee a correct electron beam deflection. Moreover, in order to ensure that all electrons are correctly dumped, current monitors are installed to check that no significant particle loss occurs in between the magnets and the dump.

The beamline hutch has two controlled doors that can be opened only with special keys. As done for the ELETTRA beamlines, the access policy foresees searching the hutch before the beam is turned on. Beam stoppers located at the end of the linac and behind each FEL undulator chain must be closed before access into the hutch can be granted.

The experimental hall is equipped with several radiation monitors that are part of the access control system.

Further details concerning the logics and working modalities of the access control system are given in Chapter 15 - Radiation Protection.

12.7 References

[1] http://www.aero.polimi.it/~rtai/index.html

[2] A. Goetz et al., "TANGO a CORBA Based Control System", ICALEPCS2003, Gyeongju, October 2003.

[3] C. Scafuri et al., "ELETTRA New Full Energy Injector High Level Software", EPAC2006, Edinburgh, June 2006.

[4] M. Lonza et. al., "Design of a Fast Global Orbit Feedback System for the ELETTRA Storage Ring", ICALEPCS 2005, Geneva, October 2005.

[5] "ULiSSE – Ultrabright Light Source Spectroscopy Experiments – project", http://www.elettra.trieste.it/FERMI/index.php?n=Main.UliSse

[6] http://www.iec.ch/zone/fsafety/fsafety_entry.htm

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