RADIATION AND LASER SAFETY SYSTEMS FOR THE FERMI FREE ELECTRON LASER*

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Abstract

FERMI is a Free Electron Laser (FEL) users facility based on a 1.5 GeV electron linac. The personnel safety systems allow entering the restricted areas of the facility only when safety conditions are fulfilled, and set the machine to a safe condition in case any dangerous situation is detected. Hazards are associated with accelerated electron beams and with an infrared laser used for pump-probe experiments. The safety systems are based on PLCs providing redundant logic in a fail-safe configuration. They make use of a distributed architecture based on fieldbus technology and communicate with the control system via Ethernet interfaces. The paper describes the architecture, the operation modalities and the procedures that have been implemented. The experience gained in the recent operation is also reported.

INTRODUCTION

In the FERMI free electron laser, the electron bunches accelerated at energies up to 1.5 GeV, together with a tunable UV seed laser beam, are sent into a chain of undulators where they generate ultra-short and high peak power coherent photon pulses with variable polarization in the soft X-ray spectral range. Two distinct undulator chains are available, FEL-1 and FEL-2, covering the entire spectral range from 4 to 100 nm [1].

Two safety systems are in charge of protecting people by denying access to dangerous areas and implementing the necessary interlocks to switch off the beams in case of danger. The first is the system for the protection from radiation hazards, also referred as Personnel Safety System (PSS); the second, referred as Laser Safety System (LSS), protects people from the user laser used for pump-probe experiments.

PERSONNEL SAFETY SYSTEM (PSS)

From the radiation safety point of view the FERMI facility is divided in three main areas: the linac tunnel, the undulator hall and the safety hutch. The three areas are entirely underground; a schematic representation is shown in Fig. 1.

The main radiation sources are the electron beam and the RF accelerating sections due to the high electromagnetic field generated inside them. The linac is made of several accelerating structures fed by 16 RF plants. The Cavity Test Facility (CTF), the photo cathode gun and the first two accelerating sections are connected to the first three plants (KS, K1 and K2) through a group of eight waveguide switches that can be set according to 12 possible configurations. This allows having for example one plant offline for maintenance purposes while the other two operate connected to the machine (Fig. 2). The waveguide switches are controlled by the PSS.

As the commissioning of the linac has been accomplished when the rest of the machine was still under construction, for operating reasons the PSS has been divided in two subsystems, each controlled by one PLC. The first is in charge of the linac, the other of the undulator hall and safety hutch.

Operation Modalities

Three machine operation modalities have been defined to access both the linac tunnel and the undulator hall: *Shutdown*, *Off* and *On*. A key panel placed in the control room and connected to the PSS allows defining the working modality.

In the *Machine Shutdown* modality, radiofrequency inside the tunnel is disabled and the following conditions must be fulfilled:

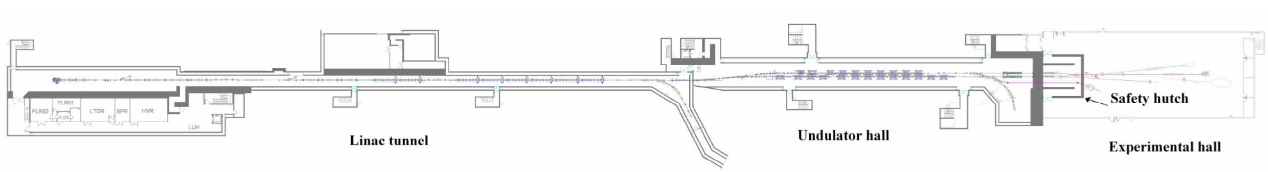

Figure 1: The three main areas of the FERMI facility.

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KS, K1 and K2 switched off or connected to loads, no RF detected by the six pickups installed along the waveguides of KS, K1 and K2, and RF plants from K3 to K15 switched off. If so, the PSS unlocks the doors and access into the tunnels is completely free.

When the machine is in *Off*, the radiofrequency inside the tunnel is disabled as in the *Shutdown* modality, but the access is restricted and personnel can enter the two areas following the controlled access procedure. With the machine set in this operation modality, operators can also perform the tunnel search to assure that no people are inside. At the end of a successful search, after a time during which an acoustic alarm is activated, the PSS permits switching on the RF and the machine passes in *On*.

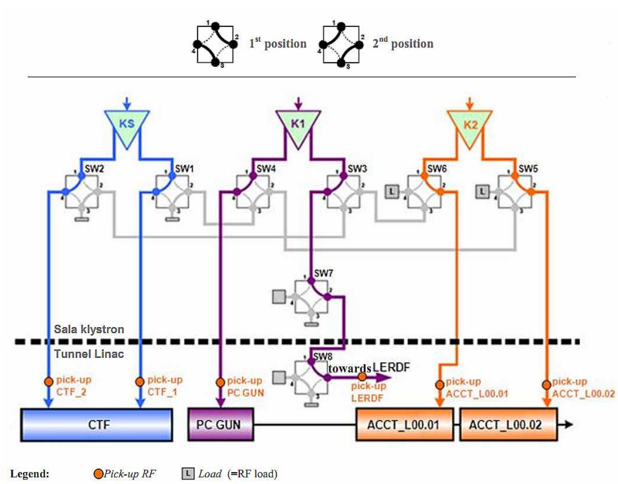

Figure 2: Layout of the waveguide switch system of the first part of the linac.

Controlled Access

The linac tunnel and the undulator hall have one entrance door each, which also works as emergency exit. The procedure for entering these areas requires the supervision of an operator from the control room who gives the final assent to unlock the doors. Once the conditions for the operation modality *Off* are all fulfilled, the person who wants to enter must:

- pass his magnetic badge in the badge reader placed next to the access door (Fig. 3);
- extract the baton which is unlocked by the PSS once the badge is recognized as "authorized" for the access;
- wait for the final assent given by the control room operator, who unlocks the door after recognizing the person through a video camera;
- open the door, enter, close the door and insert the baton into the internal panel.

Until at least one baton is missing in the external panel or a person is registered in the PLC access list, the PSS denies switching on the RF.

Figure 3: The badge reader and baton panel next to the linac door.

A time-out is defined for the execution of each step of the procedure described above: if the available time expires, an anomaly status is generated, which can only be reset by the control room operator by pressing the "Reset" button in the PSS graphical interface.

To get out of the tunnel, one must extract a baton from the internal panel, unlock the door by pressing a button, open the door and exit, close the door, insert the baton in the external panel and pass the magnetic badge in the reader. Two LCD displays placed next to the baton panel both inside and outside the tunnel help the person suggesting what to do next.

Search Procedure

The search procedure requires the presence of two operators, one executing the search and the other supervising the operation from the control room.

The operators must:

- press the "Start" button on the PSS graphical panel;
- use a special "search badge" to enter the tunnel following the entrance procedure described above;
- inspect the area, press all the search buttons installed along a predefined path and activate only once the optical barriers placed along the tunnels (the barriers guarantee that nobody is following the operator executing the search);
- get out of the tunnel following the exit procedure;
- press the "End" button in the PSS graphical interface.

There are a minimum and a maximum predefined time for each search: the timer starts when the operator opens the door and stops when the operator closes the door after pressing the search buttons.

FEL Interlocks

In FERMI, the FEL coherent radiation can be produced by two undulator chains called FEL-1 and FEL-2, working one at a time. In the spreader, the electron beam coming from the linac is forwarded to either FEL-1 or FEL-2 by means of a number of bending magnets and two transfer lines. At the end of each undulator chain, other bending magnets and transfer lines transport the electron

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beam to the beam dump, while the produced photon beam goes forward through the machine front-end towards the experimental hall. Two permanent magnets, located downstream the bending magnets, ensure that the electrons cannot exit the undulator hall even in the case of failure of the electromagnets power supply.

The PSS measures the currents of the bending magnets using DCCTs to verify that their values are in agreement with the electron energy. An energy mismatch, in fact, could produce electron losses and thus unwanted radiation. The reading of the currents also tells the PSS if FEL-1 or FEL-2 is used.

In addition, measurements of the electron beam current by means of current monitors are carried out by the PSS in five different positions in FEL-1, FEL-2 and before the dump. By comparing these measurements the electron beam losses can be estimated and the beam is disabled if they are above a given level.

In order to allow studies and optimization of the beam transport inside the undulator hall during the commissioning, a key panel has been provided in control room to temporarily disable the interlock based on the current monitors. When the interlock is disabled, the undulator hall beam stoppers are forced closed.

Safety Hutch

The safety hutch contains the front-end of the machine, where the photon beam is characterized and manipulated before delivery to the beamlines. One beam stopper at the end of the linac and four at the end of the undulators (two per chain) stop the electron beam and the secondary radiation, to allow safely entering the hutch.

The conditions to enter the hutch through its two doors are: linac and undulator hall beam stoppers closed, and beamline gamma monitors indicating "Normal Operation". The status "access allowed/forbidden" is reported on the PSS synoptic in control room as well as by a lamp on a panel placed aside the hutch doors. The same panel also contains two key locks connected to the PSS, each of them hosting one key. If the safety conditions are fulfilled it is possible to turn the first key and take out the second key. This disables the beam stoppers opening and allows entering the hutch by unlocking the doors.

Starting from a condition with free access in the hutch, a search procedure using the second key and a dedicated internal search button must be carried out before closing the doors. After the second key is replaced in the external panel, the first key can be turned and extracted, thus enabling the beam stoppers.

LASER SAFETY SYSTEM (LSS)

An infrared laser derived from the seed laser source is used for pump-probe experiments in the FERMI beamlines. The laser beam is transported through a 150-meter long vacuum pipe and some deflecting mirrors to the experimental area and then delivered to the selected experimental station using a switching deflecting mirror. This class-4 laser can produce serious damages to the eye retina, therefore the beam is fully shielded, the windows filtered and any removable part is interlocked to confine the beam and avoid any leakage in the experimental hall. An additional safety system with automatic interlock functionalities and the access control of the areas where the laser is used further improve the safety. A wall has been built to segregate the area around the experimental stations with controlled doors and access procedures. With this solution the experimental hall becomes a multi users area, people have to wear the safety eyeglasses for very short time.

Three laser operation modalities have been defined to access this area: *On*, *Off* and *Maintenance*. A key placed in seed laser room and connected to the LSS is used to select them.

When the laser is in *Off* the LSS inhibits opening the main beam shutter placed after the source at the beginning of the vacuum pipe; a redundant safety shutter placed immediately upstream is closed in case the first one fails. In this condition access to the segregated area is free.

When the key is in the *On* position, it is possible by means of graphical panel to open the shutter from the control room. In this condition access to the restricted area is controlled and the LSS closes immediately the shutter in case any potentially dangerous situation is detected, such as for example no vacuum in the pipe, protection covers removed, emergency doors open or emergency buttons pressed.

In *Laser Maintenance* the laser beam is allowed to go out of the vacuum pipe and of the protection devices in the restricted area but only trained and authorized people are allowed to enter it. This modality is typically used for alignment operations by laser specialists.

The procedure to enter the area when the laser is switched on is based on a magnetic badge reader and two sequential doors that cannot be open at the same time. In *Laser Maintenance* an additional authorization is required by the responsible of the laser operation, who must already be inside and can open the second door only after having verified that the safety conditions are fulfilled and the person is wearing the protection glasses. This solution maximizes the time of availability of the area for the users.

Pump-probe experiments using this laser can be carried out in the *Laser On* operation modality. The person responsible for the laser system consents using the laser by delivering a key to the responsible of the experiment who can eventually open the shutters using this key together with a second personal key.

SYSTEMS ARCHITECTURE AND TECHNOLOGIES

Given the extremely high degree of safety required, strict procedures have been adopted in the system design.

Fail-safe versions of PLCs (Siemens S7 315F [2]), fieldbus (Profisafe) and I/O peripherals have been

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employed. The general design philosophy has been to use fail-safe devices whenever possible and, if not, redundancy and diversification of sensors and actuators have been adopted (double door switches, double and different switches for each beam stopper, direct safety loops, etc.). The choice of software programmable devices has been driven by the complexity of the logics and procedures to implement.

The block diagram of a generic system is shown in Fig. 4: one or more CPUs are in charge of the execution of the control programs, while a number of distributed I/O peripherals connected through Profibus, interface all of the controlled devices. The PSS includes two CPUs and 25 Profibus peripherals with 474 digital I/Os and 12 analog inputs, while the LSS features one CPU and 7 peripherals with 137 digital I/Os.

The connection of the PLCs to the FERMI control system [3] is made via Ethernet TCP/IP interfaces. Graphical supervisors running in the control room consoles have been developed to monitor the state of the safety systems and allow operators to manage access and search procedures. They communicate with the PLCs through dedicated TANGO device servers, which are also in charge of logging into an archive database every event related to the systems. The supervisors are made of a main graphical synoptic and a number of specific panels. In order to guarantee quick resolution of anomalous situations the supervisors provide operators with comprehensive information on the state of the safety systems, including on-going accesses and search procedures, as well as with any significant detail of every controlled device and of the PLC internal state machine.

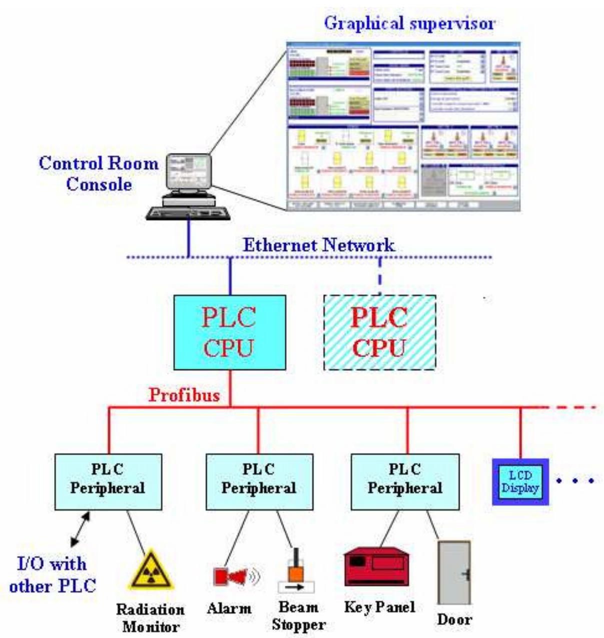

Figure 4: Block diagram of the safety systems architecture.

CONCLUSIONS

In the FERMI free electron laser facility, issues regarding personnel safety have been addressed by the adoption of fail-safe PLC systems. They provide the required safety level with the flexibility of software programmable devices. During the past four years of operation, they have proven robustness and a high level of reliability.

A recent upgrade of the PSS of the Elettra 2.4 GeV storage-ring using the same Siemens PLCs and devices, allows us to have a uniform hardware and software platform on all of the safety systems of the laboratory accelerators. This standardization facilitates the management of spare parts and reduces the manpower needed for new developments.

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