A NEW PSS FOR THE ELBE ACCELERATOR FACILITY

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Abstract

The ELBE facility (**E**lectron **L**inear accelerator with high **B**rightness and low **E**mittance) is being upgraded towards a Center for High Power Radiation Sources in conjunction with Terawatt & Petawatt femtosecond lasers. The topological facility expansion and an increased number of radiation sources made a replacement of the former personnel safety system (PSS) necessary. The new system based on failsafe PLCs was designed to fulfil the requirements of radiation protection according to effective law, where it combines both laser and radiation safety for the new laser based particle sources. Conceptual design and general specification was done in-house, while detailed design and installation were carried out in close cooperation with an outside firm.

The article describes architecture, functions and some technical features of the new ELBE PSS. Special focus is on the implementation of IEC 61508 and the project track. The system was integrated in an existing (and mostly running) facility and is liable to third party approval. Operational experience after one year of run-time is also given.

FACILITY OVERVIEW

ELBE is an electron beam user facility in 24/7 operation. It has been largely upgraded over the last three years [1] and now consists of a 40 MeV 1.6 mA c.w. LINAC with the following secondary beam options:

- two infrared FELs (5…280 µm)
- a low current electron irradiation site
- a 17 MeV Bremsstrahlung facility
- redesigned targets for the generation of 0.1…10 MeV neutrons and 30 keV positrons.
- a new THz facility TELBE [2]

Upgrades in diagnostics, bunch compression and multi-user beam options are about to be implemented in the near future. The 150 TW laser DRACO [3] for laser – electron beam combined experiments (Thomson backscattering [4], laser driven electron acceleration) as well as purely laser driven particle acceleration is about to receive a second power option of 500 TW. In parallel, the PW scale laser system PENELOPE [3] is in development.

RADIATION PROTECTION CONCEPT

All accelerator and experimental sites are inside caves with 2.4 m shielding walls. The linac itself is separated from the secondary beam caves (see Fig.1). This concept was kept for the laser facilities. The walls are designed to protect against radiation caused by beam loss up to the diagnostic mode limit (10 µA average current) at any beam line location.

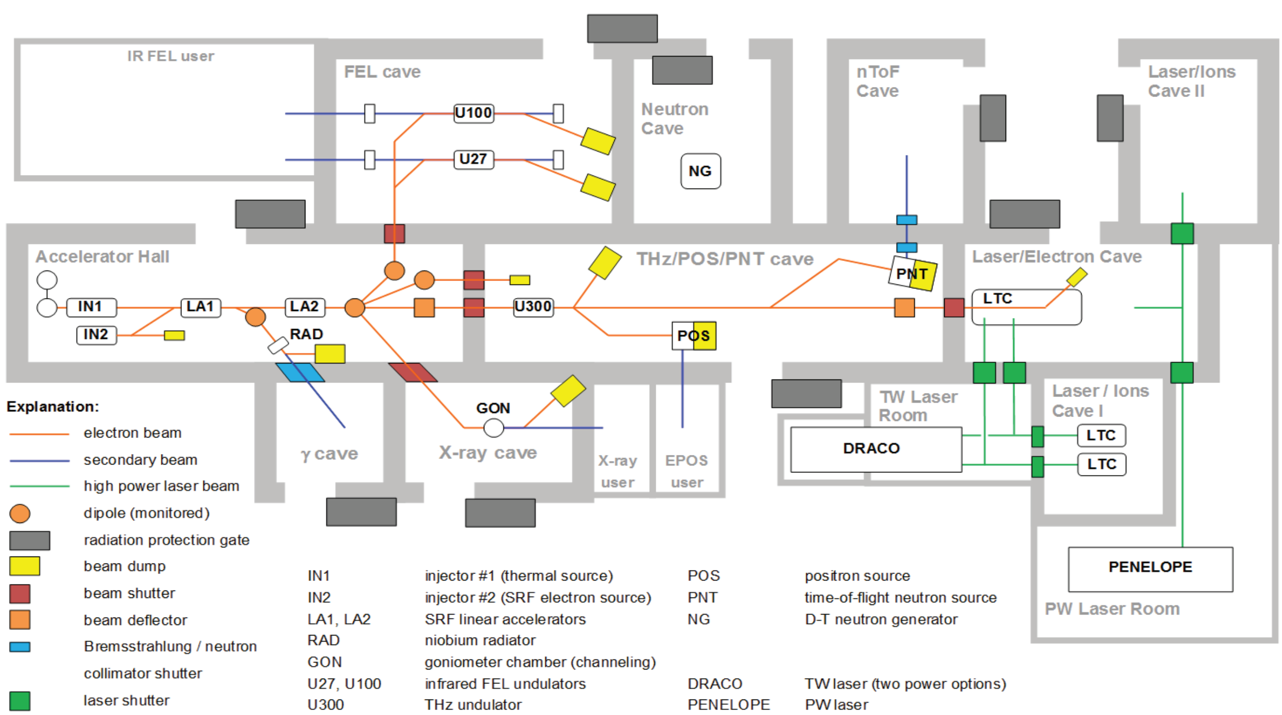

Figure 1: Overview of the ELBE Center for High Power Radiation Sources.

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Access to the caves is through shielding gates. In case of laser rooms, this is combined with clean room air locks and individual access control using badge readers. Before closing a cave, one has to search this area following a defined procedure, which is guided by acknowledgement buttons and accompanied by alarm signals and an announcement to leave.

The electron beam transport between two caves requires opening a beam shutter and powering a dipole magnet in the dogleg-shaped beam guide. As a new concept, a permanent-magnetic beam deflector has to be moved out of the beam line area. This deflector can dump and shield a full energy beam up to the diagnostic mode current limit. Figure 2 shows the design and radiation calculation. The neutron beam goes through a collimator that is otherwise closed by a pair of tungsten blocks which resemble the wall shielding effect. Laser beams use subsurface chicanes and can be blocked by two shutters.

During beam uptime, the restricted areas (except of cave classified as clean rooms) have a small low-pressure (circa 50 Pa) with respect to the outside hall to prevent activated particles from migrating out of the caves.

Dose rates are continuously measured within the building by circa 20 dose rate monitors. We use Berthold LB112 with counter tubes, ionization chambers and neutron detectors inside and outside the caves. For monitored areas, a permanent dose rate limit of 2.5 µSv/h applies, while in controlled areas up to 10 µSv/h may not be exceeded permanently.

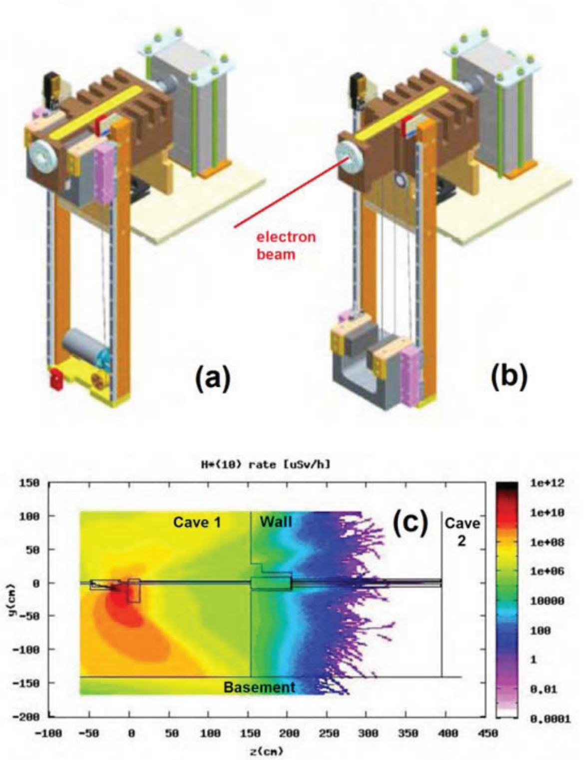

Figure 2: beam deflector for straight forward beam lines: (a) IN position (b) OUT position (c) radiation distribution from maximum beam power to be dumped.

SAFETY FUNCTIONS AND SAFETY REQUIREMENTS

The PSS has been built primarily to prevent people within the building from dangerous levels of radiation exposure caused by the electron beam, secondary beams, RF field emission or laser driven particle acceleration, as well as laser exposure in the TW and PW experiments. Possible hazardous events have been formulated together with safety functions for their prevention. According to IEC 61508 Part 5 [5] their required safety integrity level (SIL) was determined (see Table 1) considering

- the severity of health damage of person(s),
- the frequency of stay in the dangerous areas,
- the possibility of preventing the event otherwise,
- the overall probability of the dangerous event (where also organizational measures are taken into account)

The PSS as a whole is part of the safety concept required to obtain admission to operate the radiation sources from the appropriate federal state authority, and is thus liable to third party approval (i.e. TÜV) according to effective radiation protection law and regulations. Both hardware and software used for safety functions with SIL1 and above is in addition reviewed by an official expert for control systems. Laser safety (event 9) is by strict interpretation not subject to this review, but can hardly be separated from the PSS as it also requires access control and interlocks for the laser sources.

PROJECT TRACK

In 2010 the conceptual design and technical enquiry started along with the safety report for the whole facility upgrade. The detailed specification was then developed with a local outside company [*]. The implementation of the new system went on in three steps during shutdown periods:

- In September 2011 the aged out PLC controllers for the existing part of the ELBE facility were replaced by new controller hardware with minor changes in functionality, leaving most of the signalling hardware in operation.
- In 2012, the hazards and risk assessment was completed for the facility including laser based radiation sources. The second PLC system went in operation for the new options of the electron accelerator.
- In 2013, the dose rate monitoring was harmonized throughout the ELBE facility, Fig. 3.
- The safety functionality concerning DRACO and PENELOPE is about to be approved.

[*] SAAS Systemanalyse & Automatisierungsservice GmbH, Neues Leben 30, 01728 Bannewitz, Germany, www.saas-online.de

Table 1: Dangerous Events, Safety Functions and SIL Requirements of the PSS

	dangerous event: health damage to person(s)…	safety requirements	safety functions
1	… left in restricted area through direct radiation by electron beam or RF field emission	SIL 1	search room for person(s) inhibit closing gate emergency stop button inhibit accelerator
2	… working in controlled area through direct radiation by misguided electron beam	SIL 2	monitor beam shutter & dipole / beam deflector inhibit accelerator
3	… in monitored area through direct radiation by electron beam or RF field emission inside cave while gate is open	SIL 2	monitor gate (closed) inhibit accelerator
4	… in monitored area through radiation by insufficient wall shielding	SIL 2	monitor dose rate outside cave emergency stop button inhibit accelerator
5	… in controlled area through radiation by insufficient wall shielding, shutter irradiation or open shutter	SIL 1	monitor dose rate inside cave, monitor beam shutter & dipole / beam deflector emergency stop button inhibit accelerator
6	… outside the caves through activated air	no specific requirements	monitor low-pressure inside caves, inhibit accelerator
7	… entering the cave after experiments through activated air	no requirements	air exchange purging inhibit opening gate
8	… left in restricted area through direct radiation by laser particle acceleration	no specific requirements	personal access control switch laser to alignment mode inhibit opening shutters
9	… in laser rooms/caves through direct laser light exposure (eyesight damage)	no specific requirements	personal access control switch laser to alignment mode inhibit opening shutters

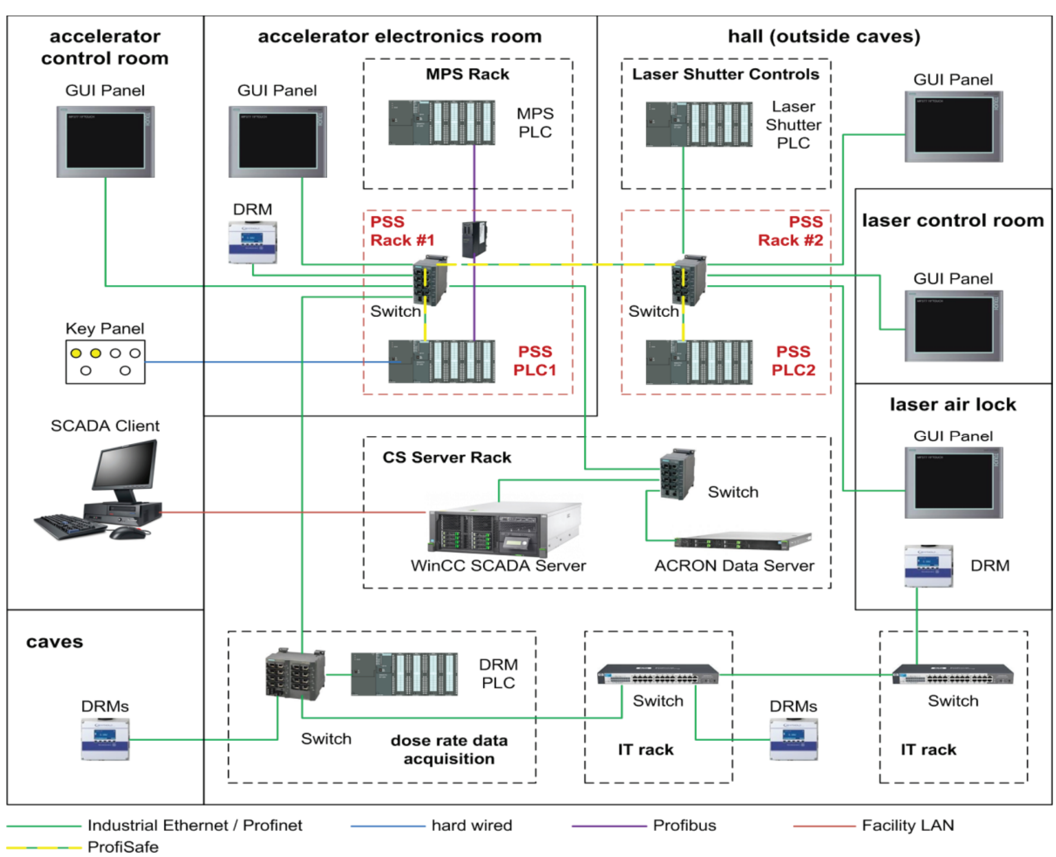

Figure 3: The ELBE PSS hardware overview.

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HARDWARE IMPLEMENTATION

Two interconnected failsafe PLCs are the PSS main components, ref. Figure 2. The basic PSS operating modes (PSS ON, Accelerator ON, PSS Override) are selected via key switches from the accelerator control room. All safety related I/O signals are binary and realized in closed-circuit technology. Signalling instruments (i.e. position switches) use SIL3 certified or equivalent hardware and signals are connected to the I/O modules with a redundancy level according to their SIL requirement. Safety related outputs are in general isolated dry contacts using contactors. All hardware components utilize channel monitoring leading to interlocks in case of wire break, short, ground leak or discrepancy of redundant channels.

The electron accelerator is shut off in three parallel ways by inhibiting the cathode high voltage source, the gun grid voltage and the accelerator's RF amplifiers.

Lasers are switches to safe (alignment) mode using hard-wired signal exchange with the laser control system and a shutter control PLC.

Altogether five HMI panels in the control rooms or service areas using WinCC flexible [6] serve to monitor components status and handle alarms and events messages. In case of the electron accelerator, the PSS is also connected to the SCADA-System WinCC [6].

An additional standard-PLC is used to read the analogue dose rates for data display, integration, logging and long term archiving with WinCC and ACRON [7]. For communication within the PSS and with the accelerator controls, we use industrial field bus and Ethernet. The PSS PLCs also collect several data from building equipment such as oxygen monitors or the ventilating system, which is also an issue of personnel safety, but not directly related to the safety functions.

SOFTWARE IMPLEMENTATION

The safety PLCs (Simatic S7-317F [6] are configured and programmed using the Step7 V5.5 suite [6]. Safety and standard operation is separated by different code blocks and data blocks as well.

Table 2: PSS Software Main Components

Safety Program	Standard Program
PSS operational modes	ventilation monitoring
room search and status	oxygen monitoring
enable opening + closing doors	GUI / SCADA commands
enable accelerator & laser	alarm handling
interlocks detection	communication to MPS
purge mode handling	
failsafe communication	
hardware monitoring	

The safety code is executed in fixed cycle (100 ms) and is monitored for data falsification during execution. The standard code handles alarm generation and data collection from building equipment as mentioned above and is running in free cycle. Table 2 shows the main software objects of both types. GUI applications can write to the safety application only via standard data arrays, which are then handed over to the safety program.

Unauthorized software or configuration changes will lead to invalid CRC and loss of the approval of operation.

CONCLUSION AND OUTLOOK

The ELBE PSS upgrade is nearly finished and will be completely approved in terms of safety functionality by end of 2013, although some experimental sites will require one or two more years to become reality. The necessity of third party approval demands a high level of foresight during conceptual design, as any major functional changes will require a new test series of assessment and tests, which takes time and, of course, money. A special organizational challenge was the step-wise installation during very short periods of shutdown including deconstruction of old infrastructure, tests and approval.

Concerning the first two years of operation, we experienced no hardware malfunctions, but had to change few functions for reasons of machine availability.

With the new PSS, designed to fit well with in the ELBE control system landscape [8], we expect to be prepared for all planned facility options to be commissioned until 2015.

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