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UPGRADE OF THE MACHINE INTERLOCK SYSTEM FOR THE ELBE ACCELERATOR FACILITY

M. Justus, M. Freitag, B. Lange, P. Michel, W. Sorge, R. Steinbrück, H. Tietze
Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Abstract

The ELBE facility with its 40 MeV C.W. LINAC has recently received an upgrade in terms of new secondary radiation sources and beam lines, while advancing the accelerator infrastructure towards 1.6 mA C.W. operation (1.0 mA before). Therefore, the machine interlock system (MIS) was redesigned in parts to meet the new timing requirements resulting from the increased overall beam power. It comprises fast beam loss detection and a PLC based beam line equipment protection system (EPS), both tripping the key components of the electron sources. The former tripping system using PLC interrupts was replaced by an in-house developed staggered CPLD based system with optical transmission and a PROFINET IO interface for control system integration. The EPS is distributed on several PLCs and has been improved in terms of M2M communication. Further, the vacuum inrush protection was completely renewed using brought-in equipment. This contribution depicts the technical features and performance of the MIS subsystems, as well as the actual status within the upgrade project.

ELBE OVERVIEW

The ELBE Center for High-Power Radiation Sources combines an electron-beam multiple user facility with high power laser installations (see Fig. 1). The superconducting electron accelerator (40 MeV LINAC using TESLA cavities) works in 24/7 operation and is worldwide unique to accelerate beams from a thermionic electron source or superconducting RF source (SRF Gun) in c.w. mode. More information about ELBE, secondary beam options and the upgrade status are given in [1].

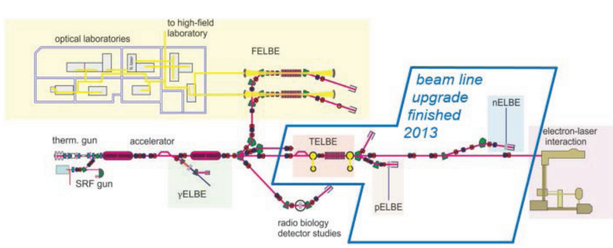

Figure 1: The ELBE facility overview.

MACHINE INTERLOCK SYSTEM REQUIREMENTS

Superconducting accelerators involve highest technological demands, especially in vacuum and cleaning technology. Damaging the machine`s critical equipment by improper beam characteristics or technical failure will usually result in long downtime and complicated repairs, at least in degraded beam parameters. Thus, a well-defined set of machine safety measures is needed to prevent from typical hazards:

- cathode damage or degrading
- damage to RF vacuum windows and amplifiers
- damage or contamination of the beam line
- contamination of the superconducting RF cavities
- damage to any beam instrumentation or beam guide components through thermal overload (coolant failure, radiation, direct electron deposition)

The ELBE machine interlock system has four major components (see Fig. 2):

- beam loss interlock system (BLIS)
- equipment protection system (EPS)
- RF interlock system (RFIS)
- Vacuum monitoring system (VMS)

The idea of this architecture is to have as far as possible independently working systems which, in parts, can compensate for malfunctions of each other, as some of the above mentioned damage scenarios occur connected. The EPS is mainly focused on inhibiting the beam if some equipment is not in the right operational condition, while the other systems are built for fast reaction to major malfunctions. However, all systems are connected or part of the PLC-based ELBE control system infrastructure [2] for alarming, monitoring and configuration. Uninterrupted power supply ensures functionality and backtracking even in case of power failure.

BEAM LOSS INTERLOCK SYSTEM

Beam Loss Detection

The most severe damage likely to happen to a SC LINAC is to melt a leak into the beam guide, whereupon melted material will be transported to the cavities by a shock wave, making them inoperative. To indicate such events, we use ionization chamber beam loss monitors (BLMs) and a system of strip line difference current monitors (DCM) at the frontend [3].

In general, a beam loss event has to trip the electron source by inhibiting the gating voltage and the pulse amplifier of the thermionic injector or, respectively, the cathode laser of the SRF Gun.

For 1 mA average beam current at 40 MeV, thermal calculations of a worst case scenario lead to a definition of the response time to be less than 2 ms, where 1 ms was assigned to the detector and 1 ms to signal processing. PLC interrupt technology fulfilled these requirements.

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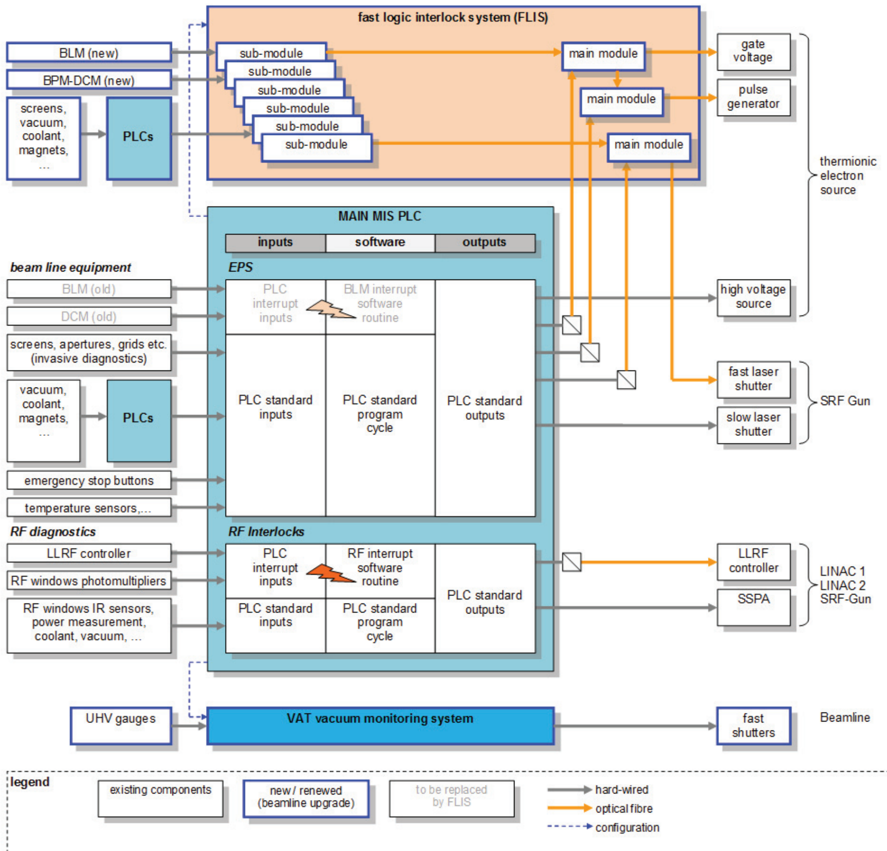

Figure 2: ELBE machine interlock system overview.

Fast Logic Interlock System (FLIS)

Upgrading ELBE to 1.6 mA c.w. beam current, we had to reduce the signal processing part to de facto zero to be able to go on with the installed BLM and DCM detectors. Also for reasons of decentralized instrumentation, a configurable, a staggered CPLD based fast logic interlock system was developed. Each module (Fig. 3 shows a front view) has 16 electrical or optical inputs and a threefold optical output. A Profinet interface enables configuration and control system integration of each module for alarms, GUI and data logging.

This configuration can cover all combinations of beam lines and sources by connecting sub and main modules over three levels. The total signal transit time of three modules plus the optical transmission to the electron source is now below 1 µs [4]. Thus, with the new system, the overall response time for a beam loss event could be reduced from 1,8 ms (±0,5) to 0,96 ms (±0,05). Figure 4 shows an exemplary performance measurement of the FLIS.

Figure 3: Fast logic interlock system, front view of sub module.

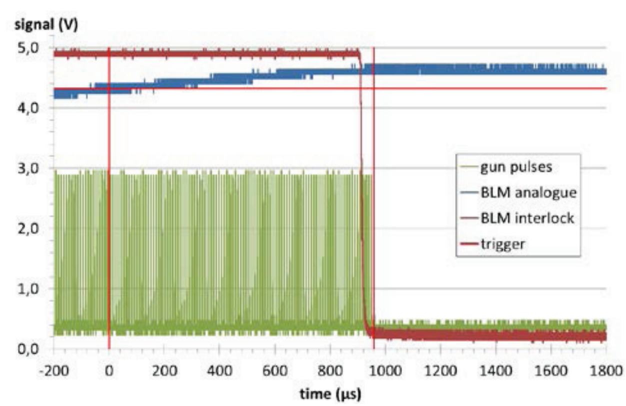

Figure 4: FLIS response time measurement of a beam loss event detected by ionization chamber.

EQUIPMENT PROTECTION SYSTEM

Several PLCs evaluate the status of coolant, vacuum or beam instrumentation, always depending on the chosen electron source and secondary beam target, as well as on the actual beam mode. To share these and other parameters throughout the control system and ensure safe and consistent data, we revised the M2M communication. Every PLC has a set of status or setup information that is passed to all or some of the other PLCs via S7

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communication on Profinet and Profibus technology. Loss of connection or data will be treated as an interlock both by source and recipient.

Impermissible machine conditions cause the same reaction on the electron source as beam loss interlocks do, but with a response time of 2 seconds. Therefore, the tripping outputs of the EPS main PLC are handled by the FLIS, see Fig. 2. We use one main MIS PLC to trip the electron sources, while subsequent PLCs give a hard-wired sum interlock to the main PLC or use a peripheral FLIS sub module.

RF INTERLOCK SYSTEM

The accelerator cavities are driven by an in-house developed analogue low-level RF (LLRF) controller and two matched solid state power amplifiers (SSPA) [5]. Cooling and vacuum insulation of the cryostats necessitate two matched RF windows per cavity.

Figure 2 shows these parts of the RFIS that are covered by PLC technology. Two PLC interrupt based interlocks are used for fast shutdown of the LLRF output signal in the few ms range:

- local discharges detected by photomultiplier tubes
- mismatch or overload in the RF system is detected by the amplitude loop limiter of the RF controller

Additional conditions trip the SSPA directly using their interlock inputs:

- RF windows over-temperature (IR sensors)
- wave guide and cryostat vacuum degradation
- mismatch or self-excitation of the amplifiers, loss of coolant, etc.

VACUUM MONITORING SYSTEM

We recently replaced the former in-house built VMS by a commercial system delivered by VAT [6]. It comprises a set of UHV gauges installed at dedicated locations of the beam line and fast shutter valves (Fig. 5). The overall response time of the system to a massive inrush is around 10 ms, which protects the cavities if the event occurs at a distance of at least 20 m.

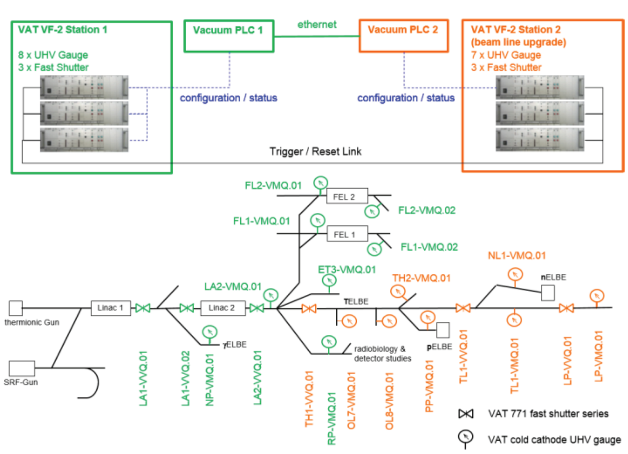

Figure 5: ELBE vacuum monitoring system.

A general principle of ELBE is to close off vacuum sections from the accelerator vacuum if they are not part of the actual beam path. UHV gauges in closed sections are disabled from triggering the fast shutters, while fast shutters in these areas will not trip to enlarge their lifetime.

CURRENT STATUS AND SUMMARY

The former RF Interlock system for klystron amplifiers has been successfully adapted to the SSPA technology. Also, all beam lines are by now equipped with the new vacuum monitoring system.

The implementation of all MIS related system into the control system enable us to configure them as the actual beam option requires, so maintenance work in closed-off beam line sections will cause a beam shutdown. Further, redundancy could be realized for certain scenarios. For example, an RF interlock, beam loss interlock or vacuum inrush event will always lead to shutting off the electron sources by the EPS.

A new fast logic interlock system was implemented at ELBE, which reduced and stabilized the response time for BLM interlocks as expected. The system can easily be used for other than beam loss related signals that need a fast reaction. Although beam line installations within the ELBE upgrade project have been completed in late 2013, older parts of the machine (i.e. the FEL sections) still use the PLC interrupt technology for beam loss related interlocks. We expect to fully change over to the new technology within 2014 to allow full beam parameters in all beam lines of ELBE. In this context, strip line DCM electronics will be replaced by new BPM electronics that are currently developed at HZDR [7].

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