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MACHINE PROTECTION SYSTEM UPGRADE FOR A NEW TIMING SYSTEM AT ELBE

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Abstract

Running a C.W. electron accelerator as a user facility for more than two decades necessitates upgrades or even complete redesign of subsystems at some point. At ELBE, the outdated timing system needed a replacement due to obsolete components and functional limitations. Starting in 2019, with Cosylab as contractor and using hardware by Micro Research Finland, the new timing system has been developed and tested and is about to become operational. Besides the ability to generate a broader variety of beam patterns from single pulse mode to 26 MHz C.W. beams for the two electron sources, one of the benefits of the new system is improved machine safety. The ELBE control systems is mainly based on PLCs and industrial SCADA tools. This contribution depicts how the timing system implementation to the existing machine entailed extensions and modifications of the ELBE machine protection system, i.e. a new MPS PLC, and how they are being realized.

ELBE TIMING SYSTEM UPGRADE

The electron accelerator at the ELBE Center for High Power Radiation Sources at HZDR [1] has provided beamtime as a user facility for more than two decades. Its unique feature is a 1 mA 35 MeV C.W. mode electron beam driven by a 235 kV thermal gun and SRF LINACs. It serves different sources of secondary radiation, i.e. infrared FELs (FELBE), THz sources (TELBE), a Bremsstrahlung facility (gELBE), as well as neutron (nELBE) and positron (pELBE) sources (Fig. 1). Having started as a one source one user facility, we could recently parallel beam options by a kicker, a scattering wire and reuse of the THz beam, but all of them only with limited range of beam power and pulse patterns. Over the past five years the ELBE SRF gun has become the standard electron source for THz and neutron beams [2]. It allows beam energies up to 40 MeV along with higher bunch charge and brightness, which implies further options of parallel beams.

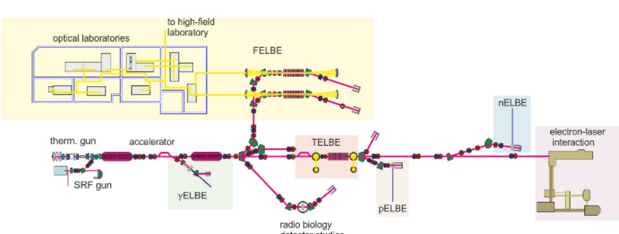

Figure 1: ELBE facility layout.

The existing (hardware based) timing system for the thermal gun (injector 1) consists of a master oscillator at 13 MHz, a 26 MHz PLL, a gun clock pulse divider (ratio 1:2^n, n = 0…8), and a single pulse generator to directly gate the gun from single bunches up to seconds long bunch trains at MHz down to mHz repetition rates (Fig. 2). A magnetic macro pulse generator in the 235 keV injector beamline gates the initial beam with repetition rates of 1 to 25 Hz. The distribution of pulses and triggers is done with hardware modules (PLLs, fanouts, fiber transceivers, ...). All components are managed by a beam control PLC that has the MPS master functionality. The SRF gun (IN2) timing patterns are currently generated by commercial off-the-shelf trigger sources in the range of 25 to 500 kHz.

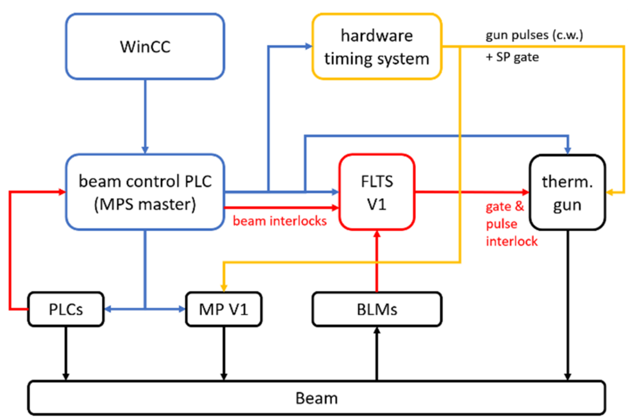

Figure 2: Existing timing system implementation with ELBE MPS for thermal injector.

Aged out electronics and insufficient flexibility of the existing timing system have led to the development of a new timing system for ELBE [3, 4]. It utilizes Micro Research Finland hardware based on the MTCA standard [5]. It is a modular, distributed system using event master modules (EVMs) to generate and send out events at a rate of 130 MHz and event receivers (EVRs) to build physical output signals from the received timing events. The gun pulse patterns become more variable, while SP and MP gating is preserved with enlarged parameter ranges. EVRs can be equipped with different universal output modules providing a variety of optical and electrical logic outputs for RF, beam diagnostics and user instrumentation. In future, the timing system shall support parallel user operation with very different beam patterns by use of RF kickers and parallel operation of two beam sources.

MACHINE PROTECTION SYSTEM UPGRADE

We define the ELBE MPS as a set of functionalities, realized by different technical sub-systems (or parts of them), which are orchestrated by a central logic unit and system

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intercommunication. It is a key part of the ELBE control system [6], which is based on industrial PLC controllers and uses Siemens WinCC V7.5 as its SCADA system [7]. The MPS main components are (Fig. 3):

- beam loss monitoring (BLM) with fast logic tripping system (FLTS) to shut off electron beams
- RF monitoring system with fast interlocks to shut down RF sources
- vacuum monitoring system with fast closing shutters to protect RF cavities
- a distributed system of machine control PLCs for standard MPS logics
- integration of PSS interlocks and vacuum monitoring system

The core MPS component is a superior beam control PLC that holds the central beam mode information, and distributes this information to the subsystems (Fig. 3). This can be channel activation for beam loss monitors or communication to subordinate PLCs. Sum interlocks from fast detection systems as well as from standards controls are collected by the FLTS or handled by PLC interrupts to shut off the appropriate electron or RF source. A more detailed description of the sub systems has been published [8].

Taking a more functional perspective, machine safety is a five-layer approach according to Table 1, where the MPS entails all electronic and programmable systems that cover levels 2, 3 and 4:

Table 1: Machine Safety Implementation Layers

Level	Safety Measures	Technology
5	procedures, instructions, training	organizational
4	authorization, operation permissions, procedures	GUI, user administration
3	parameter monitoring, permissions, soft interlocks	PLC field controller
2	automated safety systems interlock systems	hardware, CPLD/FPGA safety PLC
1	intrinsically safe design	engineering

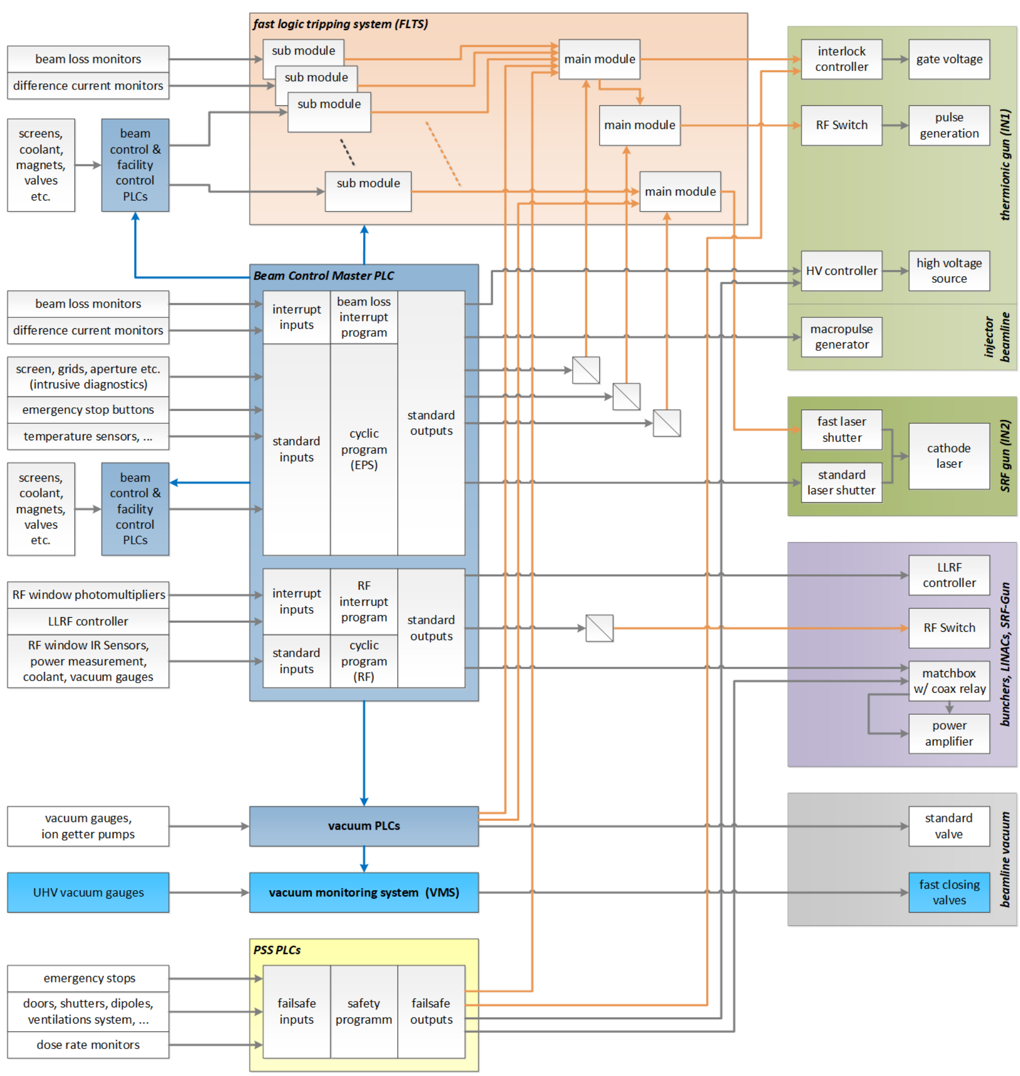

Figure 3: Current MPS architecture of ELBE.

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With the new timing system, the architecture described above is not obsolete at all, but its implementation has reached the limits of flexibility and safety:

1. Not all MPS machine safety measures are implemented end-to-end on levels 2 to 4. Some timing parameters relevant for beam generation (e.g. macro pulse parameters) are alterable until certain soft interlock thresholds are reached (i.e. average current for diagnostic mode, overall beam power) or protection systems reach their trigger thresholds (i.e. BLMs).
2. The CPLD based FLTS design from 2014 does not support parallel beam options efficiently.
3. The existing gun pulse and macro pulse generation does not support readback of the parameters before they are applied, thus logic malfunction of these systems will only be captured by layer 1 systems.
4. It is desirable to decouple the central MPS logics from equipment control as far as possible and implement critical parts of it in failsafe architecture, which is not the case right now.

Thus we have to establish a new MPS core controller (hereinafter "MPS PLC") and revise the fast tripping system as well as the macro pulse generator. Figure 4 shows the new system layout.

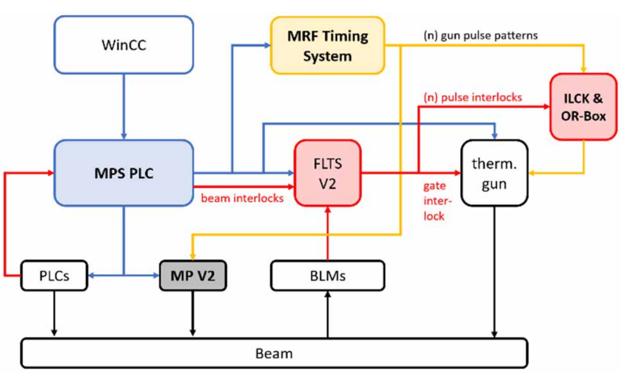

Figure 4: New timing system implementation with revised ELBE MPS for thermal injector.

The New MPS PLC

We use a Siemens S7-1500F PLC [9] with the option to run failsafe code. Standard code is written OOP-like in SCL (structured text). State machines can be written in a special graphic language.

The MPS PLC tasks are:

- administration of all beam modes, parameters and thresholds for two electron sources and about ten beam destinations
- configuration fast tripping system and subordinate PLCs for slow MPS functions
- control of beam sources and macro pulse generator
- interfacing the operator GUIs in terms of gun clock or beam parameters with timing system parameter sets
- on-change check for the timing system configuration parameters with actual or target bunch charge and beam energy to permit or deny appliance
- on-change check for the timing system actual parameters with actual bunch charge and beam energy to interlock beams in case of MPS condition violations
- ensure safe beam mode changeover

The timing system software has two operation modes: the EPICS mode is an expert mode for testing and parameter setup, while the WinCC mode is for regular operation. Figure 5 shows the data flow for WinCC control mode. Depending on the type of parameter, a value change (1) will be possible during beam operation, or only in beam off state. All set parameters are checked against certain thresholds for beam current and power, which can be depending from the beam selected path and beam mode (2). Valid settings will result in an OK signal to the timing system (3). After passing the timing system parameter check for timing plausibility, i.e. counter limits (4), the parameters will be applied to the MRF system (5) and sent back as effective parameters (6). In addition, the actual parameters are checked by the MPS PLC as well (7). Threshold violations and communication failure will trigger an interlock to the FLTS system (8) and stop emission by the timing system software (9). This applies analogously to the EPICS operation mode.

Redesign of the Fast Logic Tripping System

The FLTS has is a cascaded, fast tripping system to collect interlock from single sensors or PLCs, mask them and trigger sum interlocks to the electron sources [8]. Figure 3 shows the current CPLD based modules with 16 electrical or optical inputs, that trigger one threefold logic output (three transmitters). All modules are configured and monitored by the MPS master PLC via Profinet IO according to the actual beam mode.

We currently work on a complete redesign of this system, keeping the form factors and interfaces, but enhancing the logic capabilities by use of an FPGAs. With the new modules, 4 outputs can be triggered by up to 16 inputs completely independent from each other. For multiple beam operation, the key component is the so called ILCK&OR-Box. It combines multiple pulse patterns from the gun clock EVR into one pulse train that is sent to the gun pulse shaper. Each of the input signals can be switched off separately by optical outputs of the FLTS. For efficiency, we use the same hardware platform as for the FLTS V2.

It should be mentioned that the FLTS modules can be used for fast RF interlocks in the future as well. One module will collect all sensor signals for two RF cavities and interlock both their analog and digital LLRF drivers.

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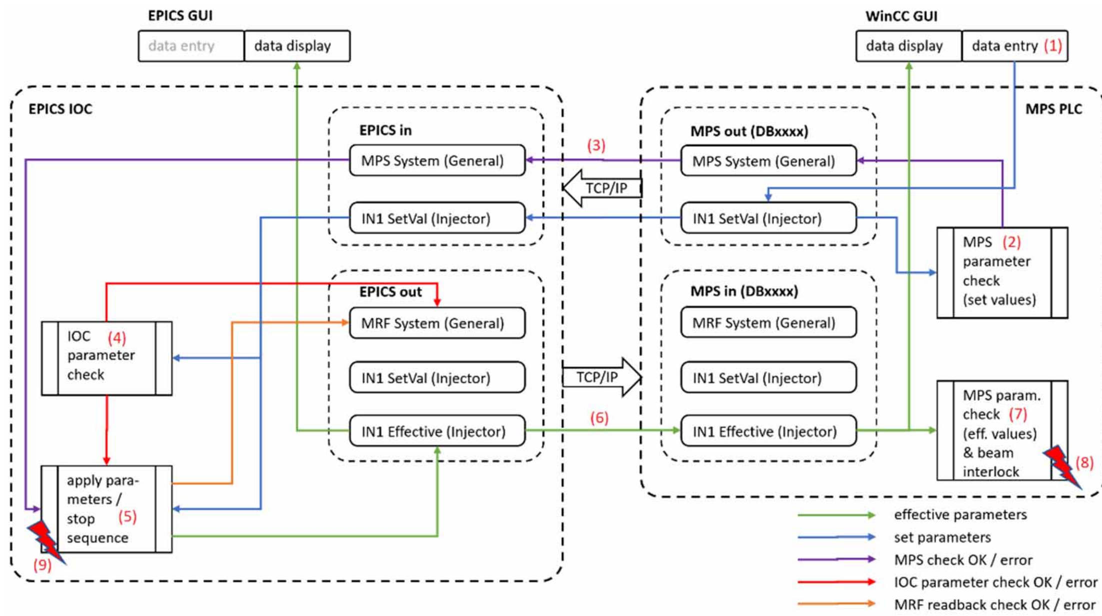

Figure 5: Data flow for MPS related timing parameter check in WinCC control mode.

Table 2: Project Steps of MPS Implementation of the New Timing System

Project Phase	Steps	Milestone / Outcome
system design	define systems architecture and data interfaces to MRF system, WinCC and existing MPS (PLCs, FLTS)	MPS part of timing system specification
MPSPLC data modeling	define data model of timing parameters, guns, beams, beamlines and operation modes	data model & PLC configuration
MPS PLC im-plementation	define parameter ranges and validity check logics	
	implement provisional interfaces to existing MPS	
	code MPS PLC timing part for injector 1	
	test interfaces and logics for current beam options	proof of principle
	develop WinCC GUI and interface	
	implement new macro pulse generator to MPS PLC	
	test with injector 1 and new macro pulse generator	pilot operation IN1
	code MPS PLC timing part for injector 2	
	test with injector 2	pilot operation IN2
FLTS redesign	design, build and test FLTS V2 modules	MPS ready for parallel beam options
	design, build and test ILCK&OR-Box	
	implement FLTS V2 drivers to MPS PLC	
	replace FLTS	
MPS revision	implement gun, kicker and FLTS controls to MPS PLC	
	revise PLC intercommunication	
	implement beam mode state machine to MPS PLC	
	revise beam diagnostics	
	test parallel user options	parallel user beams
	test parallel gun options	parallel gun operation

PROJECT STATE AND OUTLOOK

Since the timing system implementation at ELBE is heavily interfering with the existing accelerator instrumentation hardware, as well as with routine operation, the MPS upgrade is schedule in different project phases (see Table 2). The most challenging aspect are:

- not all foreseen timing options can be tested at the current machine (i.e. there is no beam kicker yet for all desired switching rates)
- not all beam diagnostics systems are ready for bunch to bunch measurement (which is mandatory for multiple beam operation)
- as long as stable timing of the existing machine with the new timing system is not proven, the option to

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switch back to the old system for user operation is mandatory

The development of the timing system is in the final test bench phase [4], where the MPS PLC is resembled by a soft PLC which just simulates the permission signal for sequence emission. On the MPS side, we recently performed MPS PLC logic tests with actual ELBE instrumentation. Here, the MPS PLC acts as an interface between the existing MPS hardware and the timing system. Injector 1 timing parameter checks and interlocks were successfully tested. The FLTS redesign and the new macro pulse generator are work in progress. With their commissioning, the MPS PLC is to take over beam mode management and serve as the main MPS controller for guns, FLTS and subordinate PLCs. This will allow operating parallel beam modes in a broader variety of beam options than ever before. With view on the DALI project (Dresden Advanced Light Infrastructure [10]), the possible successor facility of ELBE, the MRF timing system and MPS implementation is a significant and valuable piece of preparatory work.

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