LASER FACILITY SAFETY CONTROL SYSTEM

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A Safety Laser Interlock System was required for the Laser Laboratories in the HiLASE Centre in Dolni Brezany. The goal of the work was to develop a universal Laser Interlock System, which would control all the laboratories and the interlocks of multiple lasers with different powers and wavelengths in the laser laboratories in compliance with ISO EN 13849-1, Safety Performance Level PLe. The Safety Control System was implemented using Safety PLCs, sensors, and other safety equipment certified for the PLe level. The HiLASE laser facility consists of nine laser laboratories interconnected by doors, some of them being walkthrough. The laboratories are additionally interconnected by two separate Laser Beam Distribution Systems, which enables the laser beams to be distributed among them. The Safety Control logic and key parts of the Personal Safety System as well as a laboratory Personal Access System and the Laser Beam Distribution System control logic are described in this article.

KEYWORDS

Safety, Control System, Interlock, Laser, Laser Beam Distribution, Programmable Logic Controller, PLC

1 INTRODUCTION

A Safety Laser Interlock System (further referred to as Interlock System) was required for the Laser Laboratories in the HiLASE Centre in Dolni Brezany. The goal of the work was to develop a universal Laser Interlock System, which would control all the laboratories and interlocks of multiple laser sources with different powers and wavelengths in the laser laboratories in compliance with ISO EN 13849-1: PLe (i.e. Safety Performance Level e) [ISO 2015]. The Laser Interlock System has to, among others, prevent the laboratories from any unauthorized access and unauthorized laser handling. The Safety Control System was implemented using Safety Programmable Logic Controllers (PLCs), sensors, and other safety equipment certified for the PLe level. The HiLASE laser facility consists of nine laser laboratories interconnected by doors, some of them being walkthrough. The laboratories are also interconnected by two separate Laser Beam Distribution Systems, which enables the laser beams to be distributed among them, which makes the control logic development a challenging task.

2 SAFETY LASER INTERLOCK CONTROL SYSTEM

As stated before, the Interlock System control logic is implemented using PLCs PSSuniversal from the Pilz Company. In our facility we have three safety control distribution cabinets (see one of them in Fig. 1), two of them control the ground floor laboratories, and the third one controls the Experimental laboratories on the first floor. All PLCs are interconnected by a dedicated SafetyNET® Ethernet network. A floorplan of one of the ground floor laboratory can be seen in Fig. 2.

Figure 1. One of the safety control distribution cabinets

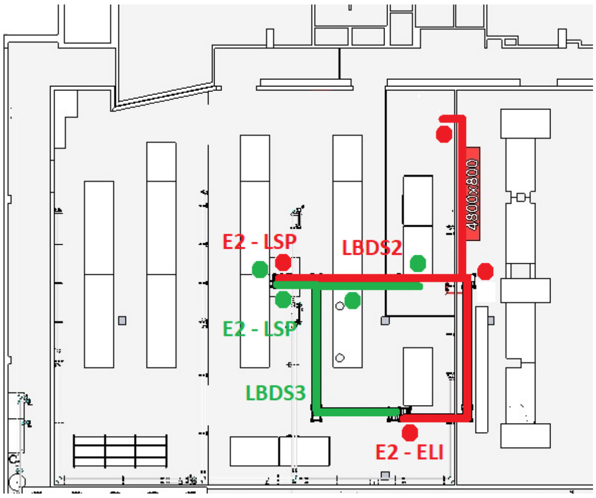


Figure 2. One of the ground floor laboratories with the LBDS system

Each laboratory has four Laser states depending on type of Lasers running in it:

1. S1 – (GREEN) No Laser Radiation in laboratory
2. S2 – (YELLOW) Laser ON
3. S3 – (RED) High Power Laser ON
4. S4 – (BLUE) UV, IR-B, or IR-C High Power Laser ON

The State S1 is intended for a safe state when all Laser Interlocks are disarmed. The State S2 is intended for Class 4 IR-A lasers with relatively low power, which are not equipped with a dedicated Interlock connection, e.g. lasers in development. The State S2 lasers are mainly Interlocked by a safety power supply contactors. The State S3 is intended for lasers of the same wavelength and class, but more powerful which are equipped with dedicated Interlock connections. The lasers in this state can damage the safety eyewear after 5 seconds of the direct beam exposure, the direct beam can ignite flammable materials, and a scattered light is also dangerous. Finally, the State S4 is intended for ≤ 532 nm and ≥ 1.5 um high-power lasers, which require a different protective eyewear. There is also one additional state S5, which is set automatically when the Interlock is tripped, and is indicated by a flashing GREEN color. This state is intended for service or maintenance related works, and no laser can be run. This State is also automatically set in case of any error, such as the SafetyNET® cable disconnection, etc. In addition, every higher laser State contains all of the lower laser States, so in the State S3 the S2 and S3 lasers can be run, and in the State S4 there could be any laser running.

The Laser states are selected with a safety state selector Pilz PIT m3.2p (see middle right side of Fig. 3) using a personal RFID „Interlock" card with appropriate permission and pressing the appropriate State button. The current State of the laboratory is indicated outside of the laboratory by traffic lights (see upper right side of Fig. 3) and inside it by LED Information Panels, both controlled by the PSSu E F 4DO 0.5 Safety output I/O cards. The permitted State of the Interlock card, together with the Personal Access System described further ensures that only a person who is trained for working with particular lasers and is acquainted with the laboratory rules is able to enter the particular laboratory in particular State and run the laser. In addition, there are non-safety PC displays, which show a laboratory current State, information about a state of the door locks (i.e. whether the access is granted or denied) and a laboratory floorplan with a review currently running lasers (see Figures 3, 5.a, and 5.c). The PCs are connected to the PLCs via a non-safety MODBUS® Ethernet connection.

Finally, to warn the persons inside any laboratory a sound alarm is triggered every time the State is raised. The persons inside the laboratory have then one minute before the laser Interlocks are armed to either wear the appropriate safety eyewear or leave the room. The physical connections of the laser Interlocks and their control buttons (see Fig. 4) are located adjacent to all optical tables. The laser Interlock itself is implemented as a two-channel interlock connection and is connected to two safety PSSu E F 2DOR 8 Safety relay I/O cards from the Pilz.

Figure 3. Double-leaf door with motor lock

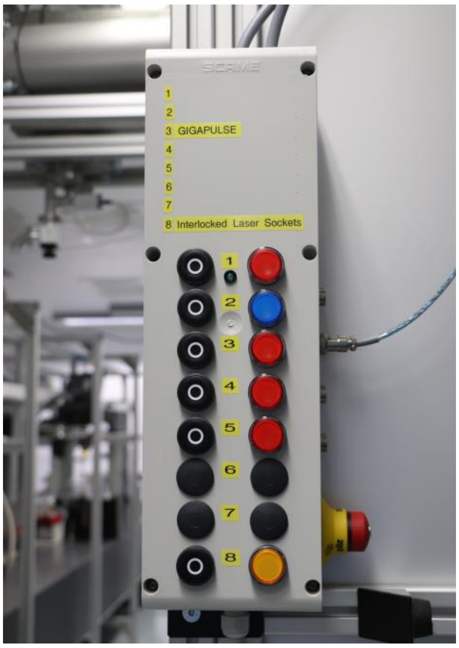


Figure 4. Laser Interlocks control box

We have three basic door types in the laboratories, sliding doors with magnetic guard (see Fig. 5.a), double-leaf doors with magnetic guard (see Fig. 5.b), and double-leaf doors with motor lock (see Fig. 3 and 5.c). An example of a typical sliding door safety equipment is shown in Fig. 6. All doors are equipped with a defeatable Interlock. The first two types, sliding doors and double-leaf doors, are both secured by the Pilz PSENmag magnetic locks. The magnetic lock can be defeated temporarily (to allow the person to get in) by inserting a permitted Interlock card into the card reader from the outside of the laboratory, or by pressing the „Exit" button from the inside. In the case of emergency, the „Emergency" button can be pressed, which physically disconnect the magnetic lock from the power supply. Third type are double-leaf doors with PLC controlled motorized locks from ABLOY company. The door mounting and the locks comply with EN 179: 2008 and EN 1125: 2008 standards for escape and panic exits, so they can be used in laboratories where no other escape route is possible. The motorized locks are remotely operated, similarly as in the case of last two door types, upon inserting a permitted Interlock card into the adjacent card reader. In cases where there is no magnetic lock (which has a position sensor embedded) on the door, its position is guarded by one PSEN cs3.1 RFID safety position sensor per a door leaf.

There are also two dedicated Emergency exit doors, three service doors, and one inspection window, which should be all closed during normal operation. The safety PSEN cs3.1 sensors guard all these doors and the window. In case of any of these are opened, the laboratory laser interlock is tripped (i.e. the S5 State is set in the current laboratory). This also ensures that any maintenance or inspection activities can be done during the S5 State only, when no laser is running.

a. b. c.

Figure 5. a. sliding door with magnetic guard, **b.** double-leaf door with magnetic guard, **c.** double-leaf door with motor lock

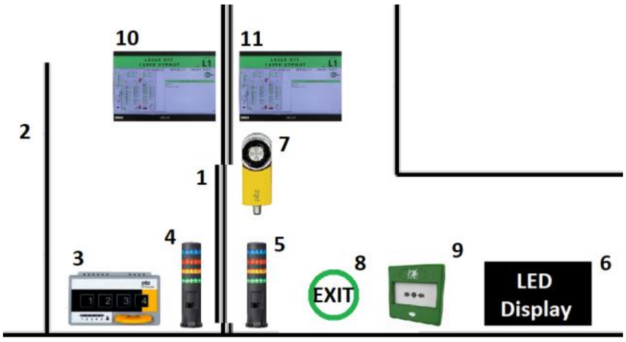


Figure 6. Sliding door safety equipment: 1. Sliding door, 2. Laser protective screen, 3. Card reader, 4., 5. Safety traffic lights, 6. LED Information panel, 7. Magnetic lock, 8. Exit button, 9. Emergency exit button, 10.,11. Non-safety PC displays

3 LASER BEAM DISTRIBUTION CONTROL SYSTEM

The Laser Beam Distribution System (see Fig. 7) was built to enable the delivery of laser beams between different laboratories. Basically, it is constructed from Steel pipes connected together, which are kept either evacuated or under atmospheric pressure. We have two separate LBDS Systems within our facility. Both systems interconnects several laboratories on the ground floor and one laboratory on the first floor.

Figure 7. Part of the Laser Beam Distribution System (LBDS)

The goals of the LBDS Control System were to safely interconnect the Interlock systems in laboratories, and to use our, in most cases already installed, safety equipment, to lower the price. The idea of the control logic is that initially the LBDS tube is sealed, this means that all beam input Shutters, output Shutters, and maintenance windows are closed, and the LBDS is in State „OFF“. When a first Shutter (including the maintenance windows) is opened by the staff, the LBDS adopts a laser State which is in the current laboratory and thus enters one of the „ON“ States S3, or S4. When the LBDS is in any of the „ON“ States, only in a laboratory which is in the same State as the LBDS any shutter can be opened. This ensures that only laboratories with the same laser States can be connected together. If the laboratories are connected, they virtually creates only one laboratory with interconnected laser Interlocks from the logical point of view. This means that any fault in any connected laboratory trips the Interlocks in all of them. All other laboratories with closed Shutters (i.e. disconnected from the LBDS) are not affected. Another advantage of this logic is that the Control System is not dependent on the path of the laser beams within the LBDS, nor on the number of opened laser Shutters, so it does not have to be reprogrammed frequently.

From the programming point of view, extreme care must be taken concerning the signaling of the Open and Closed states of the Shutters. The information about the state of the Shutters must be communicated via the SafetyNET®, in our case the Pilz PASConnect® secure Safety connection. Moreover, it must be ensured that when the PLC where the Shutter is physically connected is in a fault state, or physically disconnected, the Shutter must appear as „OPENED“ for remote control programs, as the real State of the Shutter cannot be discovered. The same rule applies for the signaling of the remote laboratory laser State. In case of any failure it must be indicated either that the laboratory is in a fault State or S5. The states of the Shutters, together with the States of the laboratories they are located in are signaled according to the Tab. 1 in our Control System. We are using only two bits of signaling logic OUT(S3) and OUT(S4). The logic is that the OUT(S3) = (!(S3) & (!(Shutter Closed))) which means that the Shutter is opened and the laboratory is in State S4 and similarly OUT(S4) = (!(S4) & (!(Shutter Closed))). Also, simple test can be done whether the LBDS is running. It is so if OUT(S3) xor OUT(S4) = 1.

LBDS Shutter Closed	Laboratory State	OUT(S3)	OUT(S4)	LOGIC State
0	<S3	0	0	LBDS ERROR/ Disconnected
1	<S3	1	1	Shutter closed
0	S3	0	1	Shutter opened in S3
1	S3	1	1	Shutter closed
0	S4	1	0	Shutter opened in S4
1	S4	1	1	Shutter closed

Table 1. LBDS Shutters Safety signaling

According to the Tab. 1, all logical States of the Shutters excluding the OUT(S3) = OUT(S4) = 0 means that the connection of the remote control system is without any error. It is also necessary that the error is indicated by the two zeros, because when the PASConnect® connection is interrupted, all variables are set to their default values, which are also zeros. The remaining five logical States (three on the output) indicate that the Shutter is either Closed in any State, or Opened in the State S3 or S4. Due to the relative complexity of the logic for the LBDS users, and because the opening of any shutter in laboratory, where a different State is set, causes triggering of the Interlock of all connected laboratories, the possibility of the opening of the current Shutter is indicated by a green LED light located on each of them (see Fig. 8). In addition, it is not permitted to change the State of any connected laboratory when the LBDS is running, because doing so would result in possibility of sending a different class of laser to a remote laboratory. So all Shutters in the current laboratory must be closed (i.e. the laboratory must be disconnected from LBDS) prior to changing its laser State.

Figure 8. One of the manually operated LBDS Shutters equipped with LED indicator and PSEN cs3.1 safety sensor

The LBDS Shutters are guarded by one, or in some cases, two PSEN cs3.1 sensors, which detect the „Shutter Closed“ state. The „Shutter Closed“ state is the only Safety information which is required from the laser safety point of view. The Shutters are also uniquely shaped, so when the PSEN sensor is closed there is no possibility that the LBDS is left physically open.

4 PERSONAL ACCESS SYSTEM

The Personal Access System is used to control and record accesses of workers in all laboratories. The individual person is allowed to enter the room only if listed in a database, i.e. has a training for current laboratory. It is also possible to permit the person to enter the laboratory only in particular laser State, which is useful i.e. for cleaner or technical persons, which should not be in the laboratory when the laser is running.

The System runs on a decentralized Computer because the required frequent changes in the access rights would complicate the program implementation to the PLCs, but a computer program can be easily changed anytime. The Identification Number (ID) of the RFID Interlock Card is firstly read and stored as a variable in the adjacent PLC according to the scheme in Fig. 9. The PLC then sends the ID, along with the Card Reader position and the Laboratory State via the MODBUS® connection to a decentralized computer where it is compared with the access database. After verifying the access to the location for a particular person, an information whether the door could be opened is sent back to the PLC. The entire event is then stored to a text log.

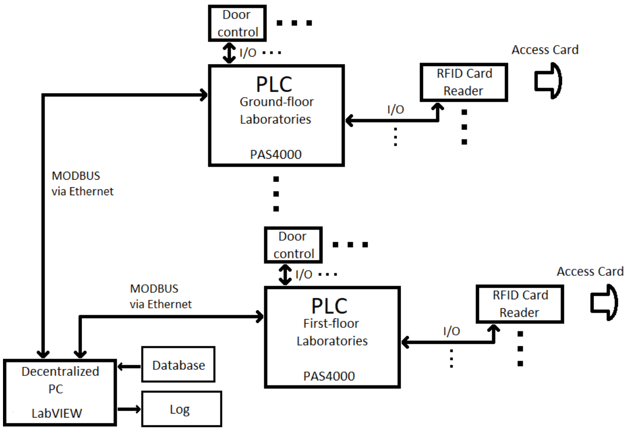
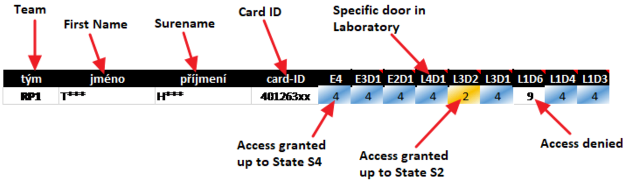


Figure 9. Personal Access System scheme

The whole Personal Access System processing, both in PLC and in decentralized PC, works fully in parallel, with each access point (Card Reader) assigned to its dedicated communication channel (i.e. MODBUS® variable). Thus, the speed of the ID processing is not dependent on the number of IDs currently being processed and the system cannot be overloaded.

A file on a decentralized computer (see Fig. 10) is used to set the access rights. The Access System program, which is written in LabVIEW®, is made so that it is capable of making changes in the rights without the need of its interruption or restart. The program also has the capacity to increase the number of Card Readers and to increase the number of laser States (up to eight) without any modification.



tým	jméno	příjmení	card-ID	E4	E3D1	E2D1	L4D1	L3D2	L3D1	L1D6	L1D4	L1D3
RP1	T***	H***	401263xx	4	4	4	4	2	4	9	4	4

Figure 10. Structure of the access rights file

In addition, because the LabVIEW® program, as well as the decentralized PC it is running on, are not Safety, the Safety system is equipped with two possibilities of the program bypassing in case of any error. First means of the bypass is a physical switch located inside each distribution cabinet, and the second is a classic key, which can always open the door. However, opening the door by the classic key trips the Interlock inside the laboratory.

5 CONCLUSIONS

Laboratory Control System was built in our laser facility. It is made in compliance with ISO EN 13849-1 Safety Performance Level PLe and incorporates nine laser laboratories and two separate Laser Beam Distribution Systems. It also incorporates a non-safety fully parallel Personal Access System which controls and registers personnel activities within the laboratories.

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