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Personnel protection during the operation of Thomson scattering laser system on COMPASS tokamak

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ABSTRACT

A recently installed Thomson scattering diagnostic on COMPASS tokamak uses two high power lasers. The presented protection system ensures laser safety of the personnel. Protection covers three areas–laser laboratory, spectrometer laboratory and tokamak hall. Laser protection system inputs are controlling the covering of the laser beam path, the entrance doors, the beam shutters and the laser cooling. Six regimes are defined for the protection system, covering all operation of the laser system, including laser service and low power beam alignment. Hardware implementation of the protection is based on PLC. The system is controlled via PCs with a touch screen. Connection to the COMPASS personnel protection system is described.

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1. Introduction

Thomson scattering diagnostic (TS), i.e. diagnostic based on the phenomena of Thomson scattering of photons on the plasma electrons [1], is being installed on the COMPASS tokamak [2,3] currently. The system is focused on characterisation of edge plasma profiles with spatial resolution of up to 3 mm, with complementary 1 cm resolution in the core of the plasma. The Thomson scattering effect has very small cross-section, i.e. high power lasers are needed to obtain measurable scattered light. The COMPASS laser system for TS [4] comprises of two Nd:YAG (Nd:yttrium aluminium garnet) lasers, 1.5 J pulse energy and 30 Hz repetition rate each. Laser wavelength is 1064 nm, in the invisible infra-red region of spectra. Therefore, the parameters of the laser system necessitate appropriate safety precautions.

The Thomson scattering lasers are located in a separated laboratory. The laser beam is guided from the laser laboratory through the wall into the experimental hall and to the tokamak itself. Moreover, a test path in the laboratory is used for the laser alignment. The test path is located in the laser laboratory and a laboratory with the TS spectrometers. Therefore, a dedicated safety system was designed to ensure the personnel safety in all the areas during the high power laser operation. Several regimes of the safety system had to be defined to cover the alignment of the line using a HeNe laser (class 2 [5,6]) as well as the operation of the high power Thomson scattering Nd:YAG laser (class 4) in case of

(a) standard measurements during the experiments,
(b) beam alignment in the test path,
(c) beam alignment in the experimental hall, etc.

The safety system is based on a PLC (Programmable Logical Controller) which handles the inputs from the laser path covers, doors, tokamak hall shutters, etc. and which allows the high power laser operation at given conditions. The operator interface is built using a touch panel where the operating personnel can request individual regimes of the operation. In this contribution, there are described details of the laser system operation procedure and the design, implementation, and function of its safety system. Finally, the connection of the laser safety system with the COMPASS personnel safety system [7] is described.

2. Protected system and areas

2.1. High-power laser for the Thomson scattering diagnostic

A schematic overview of the TS laser system and Thomson scattering protection system (TSP) is shown in Figs. 1 and 2. The system

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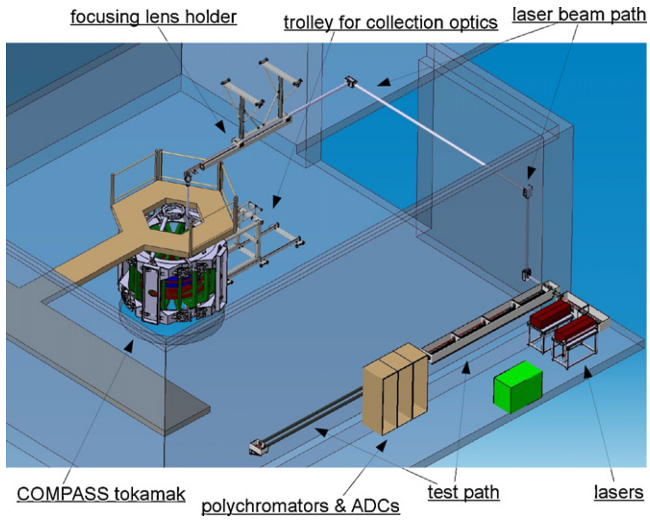

Fig. 1. Path of the laser beam in the laser and spectroscopy laboratory and in the tokamak hall. Picture from [4].

impinges three areas: laser laboratory (where are placed the lasers and their accessories), tokamak hall (where is the laser light scattered on the plasma inside the tokamak vessel), and spectrometer laboratory (where laser test path passes). The aim of the personnel protection system is to provide safety for the staff in all of these areas without necessitating laser safety training. This leads to a request of making the laser system a class 1 laser, i.e. the beam is fully covered, there is no possibility of its contact with the personnel [6]. To ensure this, beam covers and beam dumps are installed. Opening the beam enclosures must result in switching off of the laser system. This is provided by the further described electronic system.

To prevent contact of the staff with the beam in the laser and spectrometer laboratories, the beam is guided through metal pipes and boxes. The box covers are fitted with switches, for redundancy two switches per box. When the cover is closed, the circuit is closed. Open circuit signalises open box cover. Control over the beam is full, thus allowing the laser operation while people are working in the laboratories.

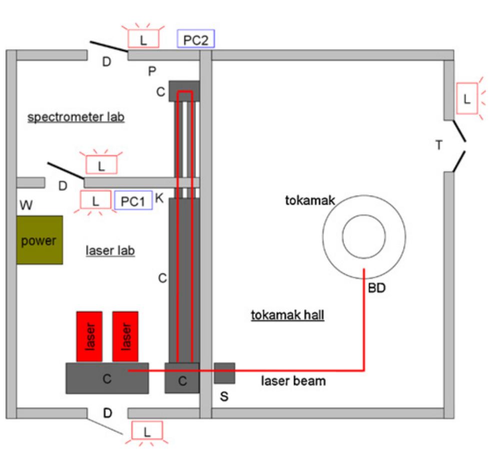

Fig. 2. Layout of key elements of the TSP system: C—box covers, D—door contacts, L—warning lights, PC1, 2—control PC, P—push button to confirm spectrometer laboratory check, W—cooling water flow, K—operators keys, S—beam shutter, BD—beam dump, T—tokamak hall door.

2.2. Tokamak hall

In contrary, in the tokamak hall, the beam cannot be fully covered. Therefore, it must be ensured that laser beam is let into the hall only when the area is clear of personnel. This can be controlled by connecting the TS safety system and the COMPASS personnel safety system [7], which controls the tokamak area access. Tokamak hall is isolated from the laser laboratory by an automatic shutter.

For beam alignment, HeNe laser at 632 nm wavelength (red visible light) is used. It is a class 2 laser, i.e. it is a safe laser, because of the human eye blink reflex. The contact with this beam is reduced by covering the beam path as much as possible and allowing the beam into the tokamak area only at a restricted access of personnel during the preparation and tests of the experiment. Covering the laser beam path also reduces dust accumulation on the optical elements.

3. Protection system

3.1. Thomson scattering laser protection system

The TSP blocks and allows the operation of the high-power laser system. The system is based on monitoring of sensors in the laser laboratory, spectrometer laboratory, and in the tokamak hall as well as on the information from the control elements (local control panel, key locks, push buttons).

The actual behaviour of the TSP depends on the input states and values from all the sensors and, in addition, takes into account current state of the experiment. Thus, the resulting state space and the monitored states are described in the states transition table (see Section 3.3).

Based on the above described information, the TSP controls: (a) the safety lock of the laser system, (b) closing of shutter between the laser laboratory and the tokamak hall, (c) the warning LED lights at the entrances to the touched areas.

3.2. Design

The design of the protection system is based on a modular PLC system Foxtrot made by Teco [8]. The protection system includes a central unit, supply source and 17 remote digital input and output modules. All remote modules communicate with central unit by proprietary Teco bus CIB which is a 2 wire bus for communication as well as for power supply for all remote nodes.

Central PLC includes a 32-bit RISC processor, Ethernet and CIB interface, several digital inputs and relay outputs on one board. All calculations of safeguarding algorithm are performed in this central unit. Input data from sensors are read and converted into the central unit by IM2 modules located in different places of the laser laboratory and tokamak hall. The logical inputs originate on switches which control the enclosure of the box covers, doors in the laboratories, locks, etc. (see Fig. 2).

The controller output is connected to a security lock of the high-power lasers. In such a way, the operation of the lasers is blocked as long as all the conditions are not fulfilled. Moreover, further outputs manage switching on the warning lights inside the laser laboratory as well as at entrances to all the related areas, including the tokamak hall. All warning lights have a self-test function which ensures reliable reaction to signalization error if the laser system is in the operation.

The communication of the PLC system to the operator interface is secured by Ethernet connection.

The control algorithm is fully given by the states transition table. The PLC has only 3 outputs (control of laser system, shutter, and warning lights). The relays are controlled by one of the CIB units.

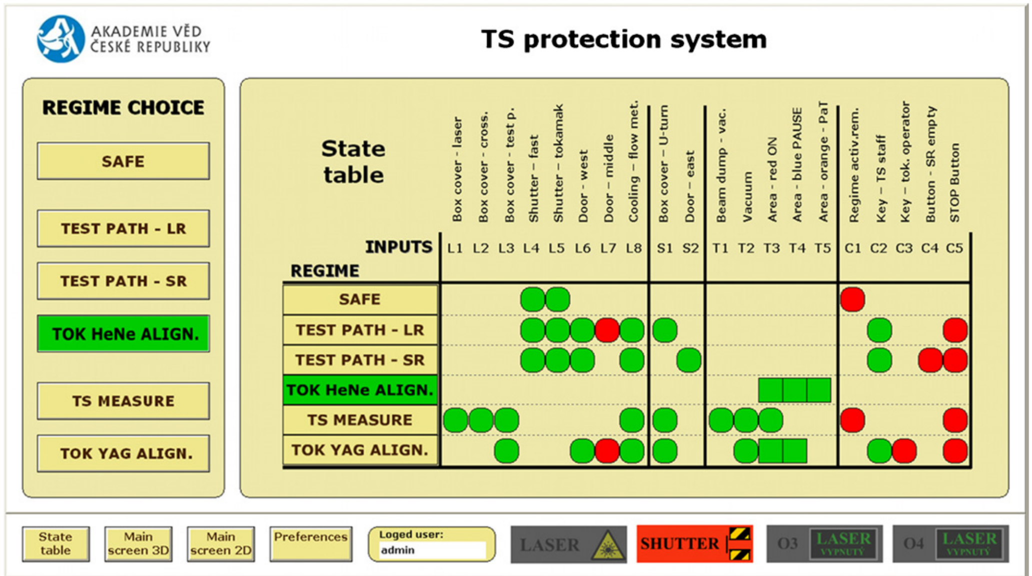

Fig. 3. Screen shot of the state transition table (in HeNe alignment regime) including the regimes of operation of the TSP. Depicted points mark conditions for the regimes, their fulfilment is distinguished by colour. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

The remaining CIB units manage the digital inputs: read-out the inputs states and connect the CIB bus with the PLC controller.

The PLC operates in a loop. After an initialisation, the PLC reads the inputs, performs the main code run, and sets the outputs, then returns to reading the inputs and so on. The cycle time is 100 ms.

3.3. *States and the state transition table*

The requirements for several regimes of operation of the laser system result into six states of TSP system to cover all situations during TS diagnostic operation. For each situation there is a unique regime of the TS system (Table 1).

Fig. 3 shows a screen shot of the state transition table from the visualization. For regular operation of the TS diagnostic, "TS

Table 1
Brief description of the TSP regimes, areas accesibility.

Regime	Description
Safe	laser off, all areas open
Test path – LR	laser allowed – laser room closed, spectr. room and tokamak area open
Test path – SR	laser allowed – laser room and spectr. room closed, tok area open
Tok HeNe align.	alignment HeNe laser (Class 2 laser)
TS measure	laser allowed – tok area closed, laser room and spectr. room open
Tok YAG align.	laser allowed – laser room and spectr. room closed, tok area limited access

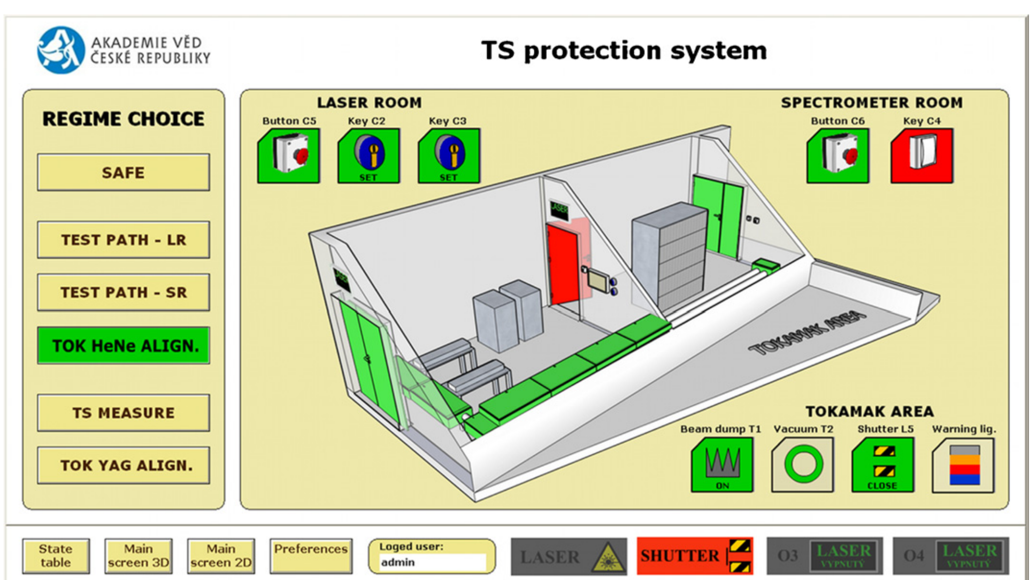

Fig. 4. Visualization screen for the operator interface—example for the HeNe laser alignment.

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measure" regime ensures that the lasers firing is allowed only when the tokamak hall is closed, shutter between laser laboratory and tokamak hall is open and all covers in laser and spectrometer laboratories are closed. For safety of the tokamak machine, all vacuum valves in the laser beam path must be open and a beam dump bellow the tokamak must be in position to absorb the beam. During the TS measurements, laser and spectrometer laboratories are fully accessible.

The Nd:YAG lasers can be aligned and serviced under regime "test path – laser room (LR)", keeping the spectrometer laboratory accessible. If longer optical distance is requested for the alignment, regime "test path–spectrometer room (SR)" prevents unauthorized staff from entering the both laboratories. Checking the spectrometer laboratory is confirmed by pressing the button (P in Fig. 2).

To align the lasers into the tokamak vessel using the class 2 HeNe lasers regime "tok HeNe align" is used. Although because of possibility of using the test path it should not be necessary, an alignment of high power Nd:YAG lasers in the tokamak hall can be realized with regime "tok YAG align". The regime can be activated under strict safety measures–tokamak operator unlocking the safety system with a key and access to the tokamak hall limited only to the selected authorized persons.

Between TS measurement and laser alignment, regime "safe" is always active. Under this regime Nd:YAG lasers cannot be switched on and HeNe lasers cannot be let into the tokamak hall, not to distract the personnel.

3.4. Visualization and operation

The visualization runs on two PCs with a touch screen and Windows XP operating system. First PC is located in the laser laboratory (PC1 in Fig. 2) and in addition to visualization allows the operator to change the system state. Second PC is located outside of laser laboratory and only reports the states.

The PCs visualize the states of the system and its individual components. The transition between each two states is based on information obtained from sensors connected to the PLC. Information from sensors is used to compare the actual state of physical elements (shutter, doors, laser cover etc.) with the requirements for the transition between states. If conditions are not fulfilled, the operator is informed about the conflict between the requirement and the current state of the system and also about the subsystems that caused the conflict and how to remove it.

Visualization software is written in Reliance [9], which is one of the developmental environments for PLC programming according to current standards in the industry. Fig. 4 shows a screen shot for case of the HeNe laser alignment as an example.

4. Conclusion

The protection system for the Thomson scattering diagnostic was designed and is being tested presently. The system automatically ensures safety of transitions between different regimes of the laser system operation. Laser safety is controlled in three areas–tokamak hall, laser laboratory and spectrometer laboratory. The protection system allows laser alignment to be performed with controlled accessibility of affected areas. The system was designed to cover all situations with as easy user interface as possible, while maintaining its efficiency and reliability.

Consequently, the TSP became subsystem of the COMPASS personnel protection system [7] by linking the tokamak hall access in both systems and by including the TSP outputs to the overall personnel protection system.

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