The Argus/Cerberus interlock system used throughout the CLF

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Introduction

The history of interlock systems at the CLF and a description of this system can be found elsewhere[1]. This system had been designed to work towards IEC 61508[2] and replace an older system which had obsolete components. At that time, the component parts of this system had been tested individually and it was awaiting installation and commissioning on Vulcan.

The system consists of three parts, the Argus control system using a PLC controlling one or more rooms, the Argus safety system in each room applied to the control system, using a safety PLC conforming to EN61508 and the Cerberus information display system, coded in Delphi running under XP.

The Argus control system specification

Each room may have one or more *Magelis Human Machine Interface* (HMI) control panels to control & give status for lasers, shutters, authorisations, faults, advice etc. The panel containing the HMI may have limited as well as master authorisation key switches. The *master authorisation* switch can authorise any task. The *limited authorisation* switch, intended for users, can be programmed, from the HMI by an operator with a master authorisation key to authorise particular tasks.

The *Room Interlock function* will turn off all unenclosed lasers & shut all shutters, wall shutters, enclosure shutters and virtual shutters, if unhealthy. The Room Interlock is healthy when:

- The entrance door to the room is shut or overridden for 10 seconds (the entrance door to the room will have an internal push button switch request door override & an external key switch or keypad request door override).
- All other doors to the room are shut.
- All maintenance keys are in their panel switches.
- There are no request switch faults detected.
- There are no shutter faults detected.
- The emergency stop is healthy.

The *Unenclosed Laser function* controls the on/off state of a laser in a room. For a laser to be permitted to turn on then the Room Interlock must be healthy. A laser may not be turned on unless the request to turn on is operated & the room authorisation key switch is operated simultaneously. If a wall shutter is open to a neighboring room then that room's authorisation key switch must also be operated simultaneously unless the room is searched & empty. The laser must trip if:

- The request 'turn off' switch is pressed;
- The Room Interlock becomes unhealthy.

A 5-second audible warning must sound before the laser turns on. Whenever a laser is on, a 'Laser Energised' lamp must be on outside every entrance door of the room, and if a wall shutter is open to a neighbouring room then a 'Laser Energised' lamp must be on outside every entrance door to that room as well.

The *Enclosed Laser function* controls the on/off state of a laser in an enclosure. A laser may not be turned on unless:

- The enclosure door is shut,
- The 'request to turn on' & the room authorisation key switch are operated simultaneously;
- If the enclosure shutter is open & a wall shutter is open to a neighbouring room, then that room's authorisation key switch must also be operated simultaneously unless the room is searched & empty.

A 5-second audible warning must sound before the laser turns on. The laser must trip if:

- The 'request off' switch is pressed;
- The enclosure door is opened;
- Shutter or switch faults are detected.

If the enclosure door is opened, then the laser will turn off but may be turned on again if the enclosure override is pulled on and the Room Interlock is healthy, the laser must now trip if the Room Interlock becomes unhealthy. (This is alignment mode; the Cerberus layout system will display a suitable message, including the nature of any additional hazards that are present).

Whenever a laser is on, a 'Laser Energised' lamp must be on outside every entrance door of the room the enclosed laser is in.

If a laser is on & the enclosure shutter is open and a wall shutter is open to a neighbouring room then a 'Laser Energised' lamp must be on outside every entrance door to that room as well.

The *Laser Auto Turn On* - Provided the room has been searched and described as empty at the end of the day, a laser may be automatically turned on at a predefined time (e.g. at 7 a.m.) to allow it to stabilise before operations begin. Should anyone enter the room from the time of the search to the time the laser is due to turn on, then it will fail.

The *Equipment slide function* controls a shutter or slide inside the room. It is used for shot mode setup or equipment protection, is not affected by room or enclosure interlocks and can be operated by operational mode selection.

The Enclosure Shutter function controls a shutter between an enclosure and a room. An enclosure shutter may not be opened unless both the 'request to open' & the room

authorisation key switch are operated simultaneously. If a wall shutter is open to a neighbouring room then that room's authorisation key switch must also be operated unless the room is searched & empty.

The shutter must shut if:

The request 'shut' switch is pressed;

The Room Interlock becomes unhealthy.

A 5 second warning must sound before the shutter opens.

The *Virtual shutters* (used in Astra Gemini & Ultrafast) are imaginary shutters which may be associated with a wall shutter to prevent it opening. These are used in laser rooms during alignment and set up to prevent target areas opening wall shutters.

The *Wall shutter function* controls a wall shutter between two rooms. A wall shutter may not be opened unless both rooms' Room Interlocks are healthy. A wall shutter, which is not associated with a virtual shutter, must have authorisation from both rooms. A wall shutter, which is associated with a virtual shutter that is open, only needs authorisation from the room the virtual shutter is not in, provided there are no hazards on in that room. If a wall shutter in either room is open to another neighbouring room then that room's authorisation key switch must also be operated unless the room is searched & empty.

The wall shutter must shut if:

The request 'shut' switch is pressed;

If either rooms' Room Interlock becomes unhealthy;

It is associated with a virtual shutter which closes.

A 5 second warning must sound in both rooms before the shutter opens.

The *Related shutter function* (used in Vulcan) is a shutter, related to other shutters, which will close whenever the related shutters close. The related shutter may then be re-opened. Whenever a Target area wall shutter is closed then the safety beam stops in the Laser room also close.

The *Search function* - Search switches must be sited so that all parts of the room are searched. The search is started by clearing the room of people and then operating the first search key which will cause -

An intermittent audible alarm to sound;

A timer to start, during which time the complete search must be completed;

A message 'search in progress' to be displayed on the warning system.

When all the rest of the search keys have been operated, the searcher exits the room by operating the internal door override & completes the search by operating the 'external search completed' key switch or keypad.

The search procedure will fail if:

Any door opens during the search, apart from internally overridden exit door;

The search time is exceeded.

The intermittent audible alarm will stop if the search procedure fails or is completed. Once the search procedure has been completed the room status will revert to occupied if any door opens (even if overridden).

The *Fault detection function* - All shutters are monitored for faults. The Room Interlock becomes unhealthy immediately if a shutter is forced open, and within 5 seconds if it does not respond to a command. All request switches, such as authorisation switches, are monitored and if 'on' for longer than 30 seconds will make the room interlock unhealthy.

The *Mode selection function* (used in Astra Gemini) - The operational mode will be selected from either the TA3 Magelis HMI, or the TA3 control room Magelis HMI, which must be operated simultaneously with the authorisation key switch.

The LA3/TA3 wall shutters must be shut in order to change modes. Only one mode can be on at one time except for CW 532nm, which can be on with any other mode. There will be six mode selects in TA3 (CW 532nm / CW 800nm operations, Low, Medium or High-power operation, Gemini full shot operation).

Gemini Full Power Mode (1 of 6 modes) - Single pulses from LA2 amplified in LA3 and either used in LA3 or propagated to TA3. This mode requires one or both Quantel pump lasers to be fired. For Gemini Full power operation into TA3 to be permitted:

TA3 needs to be searched;

LA3 needs to be searched;

The service area needs to be searched;

The shield door needs to be closed and secured;

The wall shutter between LA2 & LA3 needs to be open;

One or both of the wall shutters between LA3 & TA3 needs to be open;

Gemini Full power needs to be selected on TA3 Magelis;

Quantel pump laser interlock needs to be made;

TA3, LA3 and service area castell keys need to be in their panel switch locks.

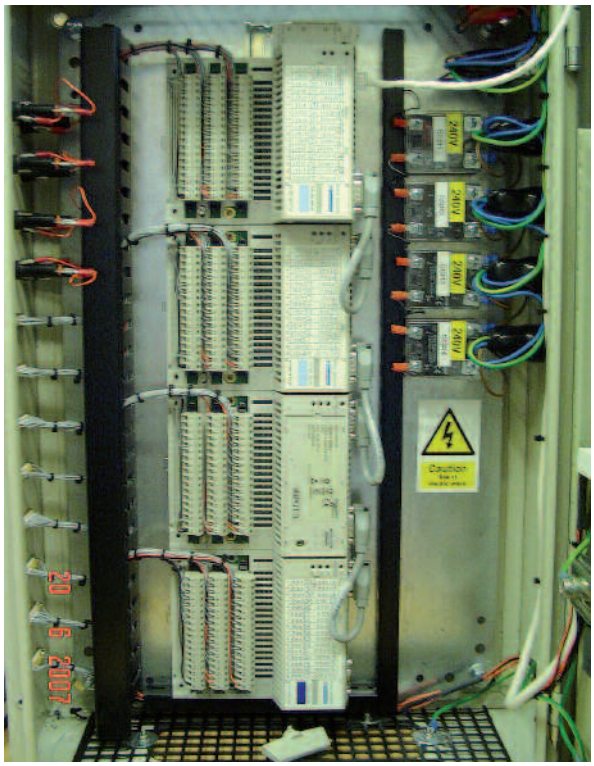

Figure 1. The Ultrafast control PLC panel.

The Argus safety system specification

The *Room function* - The safety system will monitor doors, door overrides, maintenance keys & emergency stops and will turn off or shut, if illegal entry to a laser designated room occurs, all unenclosed lasers, shutters & wall shutters independently of the laser control system by removing power to the laser control system outputs.

The *Enclosure function* - The safety system will monitor enclosure doors and enclosure overrides, & will turn off enclosed lasers if an enclosure door opens. The enclosed laser may be turned on again if the enclosure override is activated & the authorisation key activated.

The Cerberus information display system specification

The Cerberus system requests information about the state of the interlocks from Argus as a bit pattern and uses it to generate a layout room display showing the whole laser system and door / room information displays for a single room for the people using the laser. The layout of the room / door display is defined by an internal document [3]. Cerberus does make some consistency checks on the information but does not influence the state of the PLCs or the safety system.

The operation of Cerberus on a particular facility is completely defined by a text file. Setting up the text file that defines the layout of the system in Cerberus has proved to be time consuming for large (e.g. the seven rooms in Vulcan) systems and, as a substantial amount of cutting, pasting and editing is involved, errors can creep in. Most of the critical errors are detected as syntax errors as the text file is read into the program and the rest come to light during testing. However, as Cerberus only generates the information displays, this does not impact on the safety of a room. For operational reasons it was decided to eliminate these errors before reading into a live system and a stand alone program was written to read the text file and analyse it for syntax errors and inconsistencies (e.g. bits in the bit pattern that were either multiply defined or not defined, missing information etc.). This has increased the efficiency of bringing systems on line.

From the start of the project, it was always known that a system to record all changes to the data in the interlock system with a date and time stamp was a desirable feature. This was duly added. Each time the record system is turned on (which only needs to be done on one computer, usually the control room on Vulcan, as all computers monitor the whole interlock system) the initial state on the system is recorded (i.e. the bit patterns and the room states 'off') and then all changes, all with a date and time stamp are recorded into a text file. A new text file is started for each day at midnight and re-initialised. These files are kept with the associated layout text file as a record of what has happened.

A playback facility allows the operation of the interlock system to be viewed retrospectively. This is ideally done on a stand alone system away from the laser. The associated layout file is read into the code and a start day and time is requested. The system is then initialized to the initial state at midnight on that day, brought up to the state at the time requested and then plays back. As it reaches the end of that day, it will search for subsequent day's files and continue playing back until it runs out of data. The method of playback can be switched dynamically between 100 Hz., single step and real time. In the case of real time play back a 'nudge' facility has been provided to jump over long periods of inactivity (e.g. overnight or at weekends when there is no change to the interlock system for many hours). This has proved invaluable for investigating problems (e.g. component failures) and unexpected events (e.g. unexpected activity in the early hours of the morning).

The playback system was informative, but it was easy to miss the event of interest. The recorded text files consist of a date and time stamp and the room, word position and word value of the bit pattern that was set (during initialization) or had changed (during operation) so was not straightforward to read. It was decided to write a stand alone analysis program that would interpret the recorded file and the layout file for a single day and produce a narrative text file of what was happening (e.g. at a particular date and time a particular door opened and at a future date and time the door closed etc.). Two versions of the narrative are generated, a simple one and a more complex one that includes the actual values of the bit patterns from Argus. This has made the interpretation of what has happened and the investigation of faults and unusual events much easier to follow.

During operational periods it was found that the PCs running Cerberus drifted away from each other in time. Also great care had to be taken that all Cerberus systems were running the same version of the code and the layout text file. All these computers are in a Workgroup so it was decided to declare one machine as a 'server' (in the case of the Vulcan system, this was the PC in the control room). A simple time server was written for this machine using TCP IP sockets and client code was written for all other PCs requesting the time at predefined intervals and resetting their clocks. This has proved successful. Also a single version of the code and layout file is loaded on this PC and the disk shared to all other PCs in the system. As each system is run (with auto logon and Cerberus in the startup group), it attempts to load a copy of the code and layout file onto it's local disk from the server (taking a backup first) and then run from that latest version. If the down load fails, then it will run the latest copy it has. The date stamp of both files is displayed on all wall / door displays as a version number so it is trivial to check the correct versions are being run. Also available on the central machine is a bat file that will remotely log off all other machines and re-start them, thus forcing an update from the server and doing away with the need for an operator to visit all PCs and manually make changes. This has proved very popular.

Code has been included in Cerberus to detect the presence or absence of a bit from Argus and display a general purpose text box message (e.g. to state that auto turn on is enabled for a specific laser) on the layout screen.

This overall specification has been proved robust and sufficient during the installation and commissioning phase and has not been modified.

Installation and commissioning

During the Vulcan shutdown in October in 2006, two weeks were allocated as part of a scheduled shutdown for the removal of part the old system and the installation and commissioning of the new system. The main components

of the old system were left in place as a fall back in case of unforeseen problems with the new system. This option was not needed. The installation went according to plan. There were problems with transferring the data from the PLCs to the Vulcan control system via a gateway computer (i.e. a computer on the interlock and the control network) but these were solved and the system was fully working as scheduled ready for the next experimental period.

Operational experience

The system worked according to expectation with the one difficulty of Cerberus declaring a room to be 'off' when it lost connection to PLCs in that room. Each instance of Cerberus (on Vulcan this is one in each room, seven in all) interrogates each Argus PLC system (six on Vulcan) for the data at 5 Hz. Initially, if any transfer failed, that room was declared as 'off' and the layout screen and door display showed a suitable message with a black background. This was occurring regularly when it was clear by inspection that the PLC was controlling the safety in that room perfectly adequately. In the light of operational experience, this was modified such that the room was not declared 'off' until contact has been lost for one second or more. It is still not clear why this loss of connectivity is occurring and it is still under investigation.

Extending this system throughout the CLF

With the system working well, it was decided that any new interlock systems required in the CLF would follow this same scheme and there would be a program of replacing any old interlock systems. This has been done and is nearing completion. These systems are now in use in Astra Gemini, Breadboard, Confocal & Optical Tweezers, Ultra and Vulcan laboratories and will be installed in the Ultrafast and 10 Petawatt development laboratories during 2007.

Having a complete system in every room gives room independence and the system will continue running safely if connection is lost between rooms for any reason (power, networking etc). However it was decided that having a PLC and a computer system in every room was over complicated for simple (i.e. one or a few room) system so minor modifications were made to allow one system to control many rooms. This is at the expense of loosing room independence when, and only when, this is implemented.

There were very few modifications made to Cerberus. The layout diagram is the same for all rooms so that needed no modification and the only change was to allow Cerberus to create door and wall displays for rooms other than the one it occupied. The upper limit was eventually fixed by the number of video screens that can be easily driven from a PC display system which, in practice, currently stands at eight. Therefore one instance of Cerberus can generate the layout diagram and door / room displays for seven independent rooms.

Conclusion

The Argus / Cerberus system was successfully installed on Vulcan and worked as expected. The specification proved robust and sufficient. A number of extensions and additions were made and the whole interlock system has been well received by staff and users. The system has been installed in most new areas of the CLF and progress in replacing older interlock systems is well underway.

References

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2. 'Functional safety of electrical/electronic/programmable electronic safety-related systems', IEC 61508 / BS EN 61598 (7 parts).
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