A MODULAR PERSONNEL SAFETY SYSTEM FOR VELA BASED ON COMMERCIAL SAFETY NETWORK CONTROLLERS

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Abstract

STFC Daresbury Laboratory has recently commissioned VELA (Versatile Electron Linear Accelerator), a high performance electron beam test facility. It will be used to deliver high quality, short pulse electron beams to industrial users to aid in the development of new products in the fields of health care, security, energy and waste processing and also to develop and test novel compact accelerator technologies. In the early stages of the design it was decided to use commercial Safety Network Controllers and I/O to implement the Personnel Safety System in place of the electro-mechanical relay-based system used on previous projects. This provides a high integrity, low cost solution while also allowing the design to be modular, programmable and easily expandable. This paper describes the design and realisation of the VELA Personnel Safety System and considers its future development. In addition, the application of the system to the protection of high-power laser systems and medical accelerators will also be discussed.

INTRODUCTION

The VELA photoinjector consists of a 2.5 cell S-band RF gun using a copper photocathode, driven by a sub-100fs UV laser, designed to provide low emittance, short pulses of electrons. VELA features a suite of diagnostics including YAG screens for transverse beam profiles, a variety of emmittance measurement devices, an energy spectrometer dipole and a transverse deflecting cavity for bunch length and longitudinal phase-space measurements [1]. The machine is housed inside a 2m thick concrete enclosure designed to provide shielding for future higher energy upgrades. The accelerator vault is split into 3 distinct areas; the accelerator room, beam area 1 and beam area 2 and is designed in such a way that set-up work can be carried out in either of the beam areas whilst the accelerator is operational. The basement area beneath the accelerator is also shielded. Construction of VELA began in September 2011 with first beam achieved in April 2013 and the first experimental users in September 2013. The general layout of VELA is shown in Fig. 1

PERSONNEL SAFETY SYSTEM OVERVIEW

The VELA Personnel Safety System (PSS) controls the generation of ionising radiation by enabling the operation of the electron gun and RF cavities. The gun and RF system may only be operated when the injector room and basement areas have been searched and interlocked. The PSS also controls the transmission of the electron beam to beam area 1 and beam area 2 by enabling the operation of radiation shutters and dipole magnets.

Search Procedure

A two-person search system is employed and each area (accelerator room, basement and beam areas) can be searched independently. A card reader is used to limit initiation of a search to those trained in the correct search procedure. Pairs of search buttons (which must be pressed in sequence) guide the search team along a pre-defined route which covers the entirety of the shielded area.

Warning Devices

'Secret until lit' warning signs and audible warning devices alert staff to the status of the accelerator. Illuminated signs use arrays of LEDs (light emitting diodes) which have a low failure rate (the manufacturers quote a MTBF of 100,000 hours which equates to >10 years continuous use). All warning devices are 'fail-safe' and this function is achieved by the use of current sensing circuits to detect current flowing through the devices and these circuits provide interlock inputs to the PSS . Sensors used for flashing signs and audible warning devices have a build-in time delay to allow for the variation in current. The sensors have an adjustable current threshold which gives an indication that the device is working when the current threshold is exceeded.

Safety Console

A 'safety console' located in the control room provides a number of PSS keys which enable individual accelerator functions. These are:

- Shielding key – removal prevents a search of the accelerator room and basement
- RF Mode Key – removal prevents operation of the RF system
- Run Key – removal prevents operation of the gun by disabling the photoinjector laser shutters
- BA1 Key – removal prevents a search of beam area 1
- BA2 Key - removal prevents a search of beam area 2

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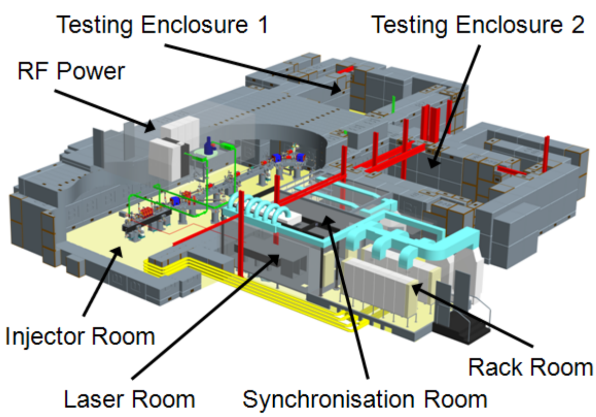

Figure 1: VELA layout.

Radiation Monitors

Gamma radiation measuring instruments are situated outside the shield wall. Readout of the radiation level is via a front panel analogue meter and 'trip' outputs are provided in the form of normally closed relay contacts. If the trip level is exceeded (> 25uS/hr), internal visual and audible alarms are activated and the trip relay contacts open. The PSS monitors the state of all radiation monitor trip outputs and takes appropriate action if the trip level is reached. Trip conditions are latched in the PSS and this latched state must be manually cleared before operation of the accelerator can recommence.

System Hardware

Omron NE1A Safety Network Controllers and DST1 series Safety I/O Terminals [2] enable the construction of a safety control network that meets the requirements for Safety Integrity Level (SIL) 3 according to IEC61508 (Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems) [3] and the requirements for Safety Category 4 according to EN 954-1 [4]. The NE1A series controller provides safety logic operations, safety I/O control and a DeviceNet safety protocol. DST1 series safety I/O Terminals support the DeviceNet safety protocol and interface directly to I/O devices. A master-slave relationship is established for each connection on the DeviceNet Safety Network and the status of the safety I/O data can be monitored in a standard Omron CJ2M PLC on the same DeviceNet network using standard I/O communications. This I/O data is transferred over Ethernet to the VELA control system which runs within an EPICS (Experimental Physics and Industrial Control System) environment [5].

Dual channel mode can be set for pairs of related local inputs. When dual channel mode is selected input data patterns can be evaluated and the time discrepancy between input signals can be analysed. Output data patterns can also be analysed.

Test pulses are used to check the NE1A's internal circuits, external circuits and external wiring – enabling the immediate detection of short circuits. To protect external circuits, outputs are cut off when an overcurrent condition is detected.

Data stored in the NE1A-series Controller can be locked to protect the data after it has been downloaded and a password can be set to prevent unintended or unauthorized access to the NE1A-series Controller.

DeviceNet

DeviceNet is an open-field, multi-vendor, multi-bit network which enables the easy connection of Safety Network Controllers, PLCs, sensors and actuators. DeviceNet supports message communications as well as remote I/O communications. A baud rate of 500kbs can be achieved with a maximum of 64 connected nodes.

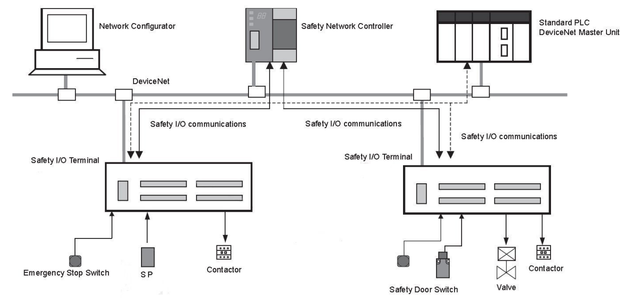

Figure 2: DeviceNet schematic.

Programming

Network Configurator (running on a windows based PC) is the software package that is used to create the complex logic designs required to implement the PSS. Standard logic operations such as AND, OR, NOT are provided along with dedicated function blocks such as emergency stop and safety gate monitoring. The completed program can then be downloaded to the NE1A via a standard USB connection. The state of each safety input/output channel can then be monitored via the same USB connection. Up to 254 logic function blocks can be used in each program and a program password can be set to prevent unintended or unauthorized access to the NE1A-series Controller.

Program Debugging

The NE1A *Logic Simulator* software is an offline debugging tool that can be used to test logic designs before downloading to the NE1A. Any combination of input conditions can be set and all output states can be monitored. Program execution can be started, paused and stopped at any point and timing charts can be created.

Physical Layout

The Safety Network Controllers, standard PLC and 24VDC power supplies mounted in 19" racks located in the VELA instrumentation room. I/O modules, wired directly to sensors and actuators, are mounted in *node boxes*, situated inside the shielded areas. A single *thick* DeviceNet cable links all the I/O modules and safety network controllers.

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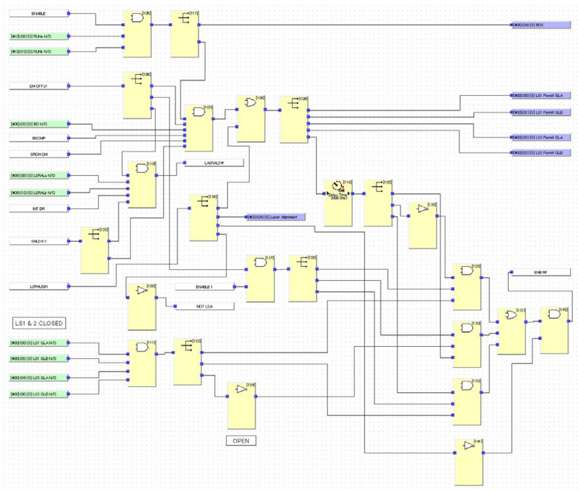

Figure 3: Example of logic design.

System Performance

During the first phase of VELA operations the PSS has proved to be highly reliable. The ability to make logic changes and carry out program simulations in an offline environment has saved a considerable amount of commissioning time and provided the high level of flexibility required as the accelerator design has evolved.

Complex systems can be designed using only 2 types of I/O modules, thus reducing the number of spares required, resulting in a significant cost saving for the project.

Figure 4: Typical node box layout.

FUTURE DEVELOPMENMTS

Following the successful implementation of the VELA PSS, the safety network controller based system has now become the standard solution for all future PSS applications at Daresbury. Over the last 12 months, the same basic design philosophy has been used to design and commission safety systems for a number of other projects including:

- VELA laser room – which houses the class 4 low emittance sub-100fs UV photoinjector laser.
- Linac Test Facility – this area is being used to test a compact 1MeV Linac with the aim of producing a mobile shipping container scanner.
- Medical Teaching and Research Laboratory (MTRL) – this is a partnership between STFC, the University of Liverpool and the Royal Liverpool Hospital. The MTRL houses a SPECT/CT scanner which provides hand-on training for MSc students.

Safety network controllers will also be used as the basis of the PSS for the new X-ray Free Electron Laser prototype, CLARA (Compact Liner Accelerator for Research Applications) with construction due to begin in early 2015.

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