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A KLYSTRON-MODULATOR INTERLOCK AND FAULT ACQUISITION SYSTEM USING G-64, VME, AND MIL-1553-B STANDARDS

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Abstract

A new microprocessor controlled protection system has been integrated with the control and data acquisition scheme of the 35 MW, 100 Hz klystron-modulators for the pre-injector (LPI) of the Large Electron Positron (LEP) at the European Laboratory for Particle Physics (CERN), near Geneva. This equipment replaces the original relay logic hardware and is designed to improve the reliability and functionality of the modulators without compromising any safety aspects. Further, it acts as a base for the recently implemented data acquisition scheme which collects and stores modulator fault information.

In this paper we describe the G-64 hardware design and the firmware program structure that assures continuous, and fast surveillance of all interlock signals. This firmware program also prepares and stores any fault data acquisition by a real time task, written in C language, and operating within a VME hardware environment. A collector program will access this data and transfer it to the main ORACLE data base for use by high level maintenance and operator programs. The communication interface used between the G-64 and VME systems is the MIL-1553-B standard.

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A KLYSTRON-MODULATOR INTERLOCK AND FAULT ACQUISITION SYSTEM USING G-64, VME, AND MIL-1553-B STANDARDS

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Introduction

The LPI pre-injector is the first machine in a series chain of four accelerators that provides e-e+ beams for the Large Electron Positron Collider (LEP) at the European Laboratory for Particle Physics (CERN) near Geneva. The klystron-modulators in the LPI pre-injector operate at 100Hz rate and each provides up to 35 MW of peak RF power for the acceleration of the electron beams. Over a period of time, and with continuous system usage, components, active elements and sub-systems in the klystron-modulators start to age and have caused the overall reliability and availability of the process to degrade. The reliability of the total process and the availability of each accelerator in this series production chain is dependent on the reliability of every individual subsystem in each of the four accelerators. The overall process reliability R_s is given by an iterative product rule that uses the reliability of all elements R_i in this series chain, regardless of the particular failure distributions of components used.

The reliability iterative product rule is given by

$$R_s = \prod_{i=1}^n R_i.$$

The greater the number of series elements in the chain, the lower will be the process reliability. More importantly, the overall reliability of the total system becomes lower than that of the weakest system or sub-system.

The interlock relay protection sub-systems used in each of the LPI klystron-modulators, and part of the chain, were found to be increasingly contributing to the downtime and unreliability of the lepton production process. This paper describes the reliability problem and the design of a new replacement interlock protection system. The new design uses a micro-processor that has greatly improved modulator reliability and has added extra functionality to the protection system.

Interlock system problems

Each modulator interlock system is designed to protect the hardware from excessive damage if a fault occurs, and so must have an inherent high level of reliability to function correctly. Up to 120 input signals, coming from semi-static and real time operational sub-assemblies within each modulator are being continuously processed. In the original scheme the input signals operate 120 separate d.c. relays in each interlock unit. The output relay contacts are organised into four separate interlock chains, corresponding to the four output control levels (Off, Heater, Standby, Pulsing). A d.c current of about 20mA flows through every contact in each of the series chains of contacts, enabling the four output protection conditions.

During normal production operation the modulator system works continuously for many months at a time. Throughout this period many intermittent faults have occurred, mainly due to contact oxidation since the relays stay in an activated closed position. This intermittent oxidation build-up increased the system downtime in a random fashion. In addition, because most individual interlocks are not memorised the fault finding and separation of true external faults from

internal contact problems was difficult.

To overcome these difficulties a more reliable system has been designed using commercial solid state G64 micro-processor and opto-coupled interface board technology to replace the relay logic system. The new scheme, apart from improving modulator reliability can store up to eight complete fault sequences in local memory, in a fully time ordered presentation. Within each sequence the first eight faulty interlocks are memorised together with a date and time tag to give maximum fault finding information.

Micro-processor interlock system

The design requirements for the new interlock protection system were:

- Complete electrical compatibility with old system
- A fail-safe design approach
- High reliability
- An ordered fault memorisation
- Interfacing to control system and Oracle database
- Conforming to CERN personnel security requirements

Hardware design

A stand-alone protection system [1] has been developed that uses the MC6809, 8 bit micro-processor within a G-64 data bus crate. This system handles the 120 input signals via purpose-designed 32-way input buffer cards. Each input interlock signal generates three output signals. These are used for the following purposes:

- 1) A direct interlock connection to the 32 way input card for modulator protection
- 2) An opto-isolated output for the existing CAMAC data acquisition system
- 3) A TTL level output for on-board testing purposes

The new micro-processor interlock protection system is shown in Figure 1.

Figure 1 Micro-processor controlled interlock hardware scheme

The 32 way input card handles the interlocks in groups of eight and any one of these groups can generate a hardware interrupt for the processor.

The failed interlocks are then collected in groups of eight by the program and stored in a local memory. Any interrupt is processed immediately by an interrupt service routine (ISR), which changes the output status as required.

The MC6809 micro-processor has sixteen address lines so that a total of 64Kbytes of memory can be addressed. The actual program is stored in EPROM which holds a maximum of 28Kbytes. The same EPROM also stores the interrupt and start vector addresses. The 16 way output board connects the G-64 system with the modulator via opto-coupled links and a buffer card. There are four output levels that react directly with the modulators power circuits and control its status. A fifth output level is used as a watchdog and monitors the functioning of the processor via a status line that is toggled by the software. If this line stops toggling, the program has stopped running and the protection system is no longer working. Under these conditions the modulator is immediately put to the OFF state. The machine access control and HV protection doors also provide interlock contacts that are connected in series with the output control levels to give additional personnel security.

EPROM software development

The main interlock management program is a loop that includes the acquisition and treatment of the 120 input signals and has been written in Pascal. The flow diagram of this program is given in Figure 2. The program 'display' variable is used to make sure that the display screen information is written without interruption from any other keyboard action that occurs during this operation. The initialisation, start-up and interrupt routines have been written in assembler micro-code.

Figure 2 Main program flow diagram

There are two sources of system interrupt that can occur. One that is generated by a faulty interlock and a second by a key on the units display panel. However, the interlock generated interrupts have priority over any display requests. The response time to an interlock generated interrupt is shown in Figure 3.

The delay between the switching of the input interlock and the response of the NOR gate is caused by the opto-coupler. The overall response time between the change of input and the $\overline{\text{IRQA}}$ line on the G-64 bus is about 14 μs .

The four channels represent the following signals:

- CH1 (A): Input interlock signal.
- CH2 (B): Output of a group of eight interlocks
- CH3 (C): Interrupt flag
- CH4 (D): G64 interrupt request line ($\overline{\text{IRQA}}$).

Figure 3 Interlock acquisition response time.

When a fault occurs the interrupt service routine is executed and any subsequent new interrupts are disabled whilst the input group that caused the first interrupt is traced by means of a polling routine. The output status of the protection system is switched to the assigned operating level and so protecting the modulator. Finally the interrupt flag is cleared and the faulty interlock is stored along with the date and time tags.

The display screen on each interlock unit allows the following display modes to be selected :

- Mode 1 Checks system memory and is automatically activated when pulsing.
- Mode 2 Displays current status of interlocks.
- Mode 3 Changes the date and time.
- Mode 4 Displays information and error messages.

Each of the four display modes have their own software driver module containing special functions and procedures.

Figure 4 System Hardware Schematic Diagram

The new interlock system

The new interlock system design [2] uses three different layers of hardware and software. This enables the fault data to be available at the three basic system levels which are:

- 1) Stand-alone modulator interlock protection level
- 2) Front-end processor (Device Stub Controller) level
- 3) Operational user level

The system hardware scheme based on these three levels is shown in Figure 4.

Interlock protection level

At the interlock hardware level each G-64 interlock unit has a Remote Terminal Interface (RTI) card plugged into its data bus. The multi-drop MIL-1553-B field bus [3] connects this card up to the accelerator controls system. This enables the asynchronous exchange of data in response to commands from the Bus Controller (BC) in the front end processor (DSC). The two buffer memories on the RTI card are used as Receive and Transmit FIFO buffer stacks that hold control values, and the G-64 acquisition data. A Control and Status Register (CSR) bit (TB) indicates to the BC that interlock data has been loaded into the transmit buffer memory. The TB bit is only reset after the transmission is complete. A data transmission rate of 1 Mbits/s was selected for the MIL cable connection length used in the system.

The interlock protection micro-processor has a set of firmware assembler instructions that are used to load the faulty interlock data into the transmit buffer on the RTI card. This EPROM program is triggered into action by a hardware interrupt on the occurrence of the first faulty interlock. An internal delay ensures the capture and storage of up to a maximum of seven subsequent cascading interlocks before the RTI transmit buffer is loaded. The worst case acquisition time measured for a complete sequence of cascading interlocks was 116 ms. However, the measured average protection response time to put the modulator to a non-pulsing state, after a fault event occurs, is about 66 ms as shown in Figure 5.

CH1(A): The faulty interlock.
CH2(B): The change of output state.

18-May-93
13:21:48

A:M1
20 ms
1.0 V
B:M2
20 ms
1.0 V

Figure 5 Protection response time of modulator

Front-end processor level

At the DSC level a real-time software task has been written in C language and runs under the control of the Lynx (UNIX like) operating system. The RTI buffer cards are scanned every 20 seconds by this task to check for any new data. A representation of the real-time task software algorithm is shown in Figure 6.

If new data is available from the RTI card it is taken, the CSR bit is cleared and the data reformatted and stored. The reformatting process consists of removing any padding characters and decimal points from the fixed length 32 byte message.

The interlock numbers are then converted into corresponding 32 bit integer values and the UNIX system date and time is attached. Finally the position to store the fault message in the data table TBL is calculated and the data is stored. One table is used for each modulator. These tables are located within the specific software Equipment Module (EM) drivers [4] used for LPI modulator control and acquisition.

Figure 6 Real-time task algorithm representation

Operational user level

At the present moment a Windows driven user program exists on the controls network [5] that has been written in Visual Basic. This enables operations and maintenance staff to see equipment faults directly from a selected modulator, for a particular date and time. The displayed data is obtained either from the current contents of the selected modulators data table TBL, or from historical data stored in the Oracle database. The programs interactive display is shown in Figure 7.

Figure 7 Faulty interlock display

The part concerning historical fault data storage is presently being developed and uses a real-time task that must be scheduled to run daily. This collector process program will extract the fault data from the TBL data tables of each modulator, and reformat it before sending it to the Oracle database. The direct display windows program can then access the information as required.

In addition to this a statistical analysis program is being considered that will also access the same Oracle data and enable fault trends to be analysed and displayed. It is also thought that the alarm screen of the LPI process could handle usefully more detailed information on equipment faults. This data would come directly from the individual modulators data tables as faults occurred. The range of possible user software to be developed and linked to the acquisition and storage of fault data is given in Figure 8.

Figure 8. Range of user level software

Summary

The new interlock system has been installed in three of the CERN LPI modulator systems, since November 1993. The other six modulators will have the new interlock system installed during the course of 1994. The new equipment has performed reliably over this period with a noticeable reduction of downtime due to random faults in those modulators that have been equipped. There has also been a noticeable decrease in the fault diagnosis time since the local memories of each interlock unit hold time ordered historical data on the last eight fault sequences that have occurred. The interlock fault display program allows this information to be viewed from any PC terminal. This fault memorisation and display function allows a faster maintenance response time than in the previous relay system and improves the overall reliability and availability of the LEP process.

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