CONTROL SYSTEMS FOR RADIOGRAPHY AND CARGO INSPECTION RF ACCELERATORS

A.N. Ermakov, A.N. Kamanin, V.G. Sayapin, V.I. Shvedunov, D.S. Yurov,
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Laboratory of Electron Accelerators MSU, Ltd, 119992 Moscow, Russia
I.V. Shvedunov, Laboratory of Electron Accelerators MSU, Ltd, 119992 Moscow, Russia

Abstract

Based on "open technologies" approach to design of control systems for radiography and cargo inspection electron RF accelerators constructed at Laboratory of Electron Accelerators MSU is described. The control system consists of a number of specialized controllers each responsible for separate accelerator subsystem connected via Ethernet interface and Modbus/TCP protocol with control computer which in turn is connected with control panel computer, modulator, power supplies etc. each having its own digital interface. Each controller contains one or several special boards conditioning external analogue and discrete signals and universal microcontroller part providing controller operation and network connection. Both control computer and control panel computer are based on BlueShark SOM (System on a Module) amd run Linux operating system. Custom SCADA-like system has been developed to provide proper accelerator operation and operator interface with support for different levels of access to accelerator parameters.

INTRODUCTION

The radiography accelerator UELR-8-2D with beam energy regulated in the range 3-8 MeV and dose rate from 0.5 to 15 Gy/min and cargo inspection accelerator UELR-6-1-D-4-01 with pulse to pulse energy switching between 3.5 and 6 MeV, with repetition rate 400 Hz and dose rate 4 Gy/min were developed and put into operation with the participation of Lomonosov Moscow State University and "Research and Production Enterprise "Toriy" stuff [1]. A compact control system located in the X-ray head cabinet in the vicinity of controlled objects is necessary for proper operation. The control system is built on the hierarchical principle (fig. 1). The top-level computer is connected by Ethernet network and RS232 interface to the operator panel and several subsystem controllers. Subsystem controllers are custom devices implemented using microcontrollers except for klystron modulator which is ready-made device. The control application running on the top-level control computer uses Modbus/TCP protocol to communicate with subsystem controllers that perform data acquisition, actuation and real-time critical tasks. The control application also communicates with the klystron modulator using modulator's own proprietary serial line protocol [2]. The system relies on hardware interlocks to ensure safe operation. The top level computer can query interlocks via Accelerator Controller and other controllers. Accelerator Controller also uses klystron modulator's hardware interlock inputs to prevent klystron failure in situations such as vacuum loss or cooling system malfunction.

CS STRUCTURE AND OPERATION

All the accelerator systems (fig. 1) are combined into several subsystems: interlocks and alarm signal processing system and synchronization controller (accelerator controller); RF system and cooling system sensors; klystron and accelerating structure ion pumps; sulfur hexafluoride gas delivery system; electron gun supply control; dose rate with ion chamber measurements; cooling module and accelerator power supply control.

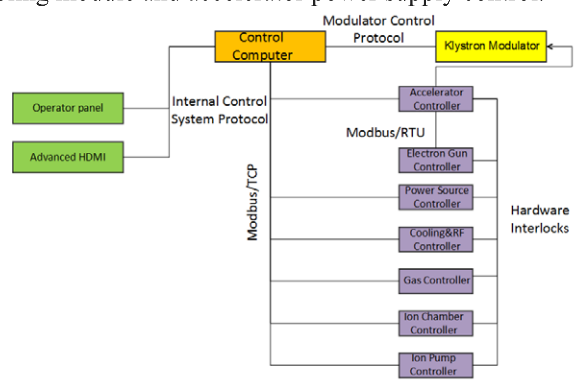

Figure 1: Control system structure.

Each subsystem contains a programmable controller which has the functions of receiving the primary sensor signals, transmitting control signals to actuators, controlling the system operation by incorporated algorithms and communicating with the host computer. The control system also includes a control computer, a network switch and the power source for its own needs.

Operator communicates to the monitor and control system using the control panel located in the control room and connected to the host computer via Ethernet interface. The accelerator network is also connected to the local enterprise network via a router. It can also be connected to a PC running the advanced HMI client program, which provides full access to the host computer and controllers. Local network provides access to the host computer and the individual controllers by the remote terminal over the Internet or private network.

Control computer functions are (1) providing the power supply accelerator on/off procedures and accelerator operation; (2) storing and loading operating parameters of

ISBN 978-3-95450-170-0

the subsystems; (3) maintaining the event lo and accumulation of statistical information related to accelerator operation; (4) to ensure operation in a remote location via the Internet

All controllers except the modulator controller communicate with the host computer via an Ethernet interface by the Modbus/TCP protocol. The RS-232 interface is used for communication with the modulator controller using proprietary ScandiNova protocol. The cooling module operates in standalone mode. To power on the cooling module the accelerator control system sends a signal of +24 V. The control computer and controllers are located in the X-ray head cabinet and connected via a network switch. The top level computer and operator panel are separate ARM-based machines running Debian GNU/Linux operating system. Optionally additional computers running Advanced HMI client software can be connected to the system. The control application is implemented using custom Lisp-based domain specific language (DSL) based on Hierarchical Finite State Machine (HFSM) formalism. The system has a number of states (fig. 2, on the left) that correspond to the states of klystron modulator (on the right). The control application's primary task is executing operator's commands by driving subsystems and the modulator in such way that they can function together correctly. Other tasks performed by the top level control application include maintaining the event log, support for maintenance tasks such as isolating gas replacement and relatively slow-running control tasks such as stabilization of acceleration section frequency. When an emergency situation is detected the system enters special "Fault" state which requires operator intervention.

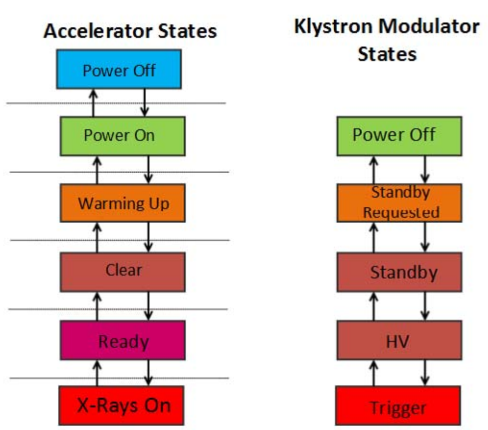

Figure 2: A diagram of control system states with corresponding modulator states.

The control computer provides the following three modes of the accelerator – operator interaction. (1) Production and maintenance works mode. (2) Single exposure beam energy, dose rate, integral dose settings, power on/off, X-ray on/off, emergency stop, the interlock status view. (3) Radiography operation mode, as well as shutdown and emergency shutdown of the accelerator.

The control panel allows the operator to perform all the necessary operations using keys and on-screen menu (fig. 3). The current state of the accelerator, energy and dose values, interlocks information is displayed on the console screen. The built-in speaker is used for sound notifications.

Figure 3: The control panel screen.

The controllers and control computer placement is shown on fig. 4.

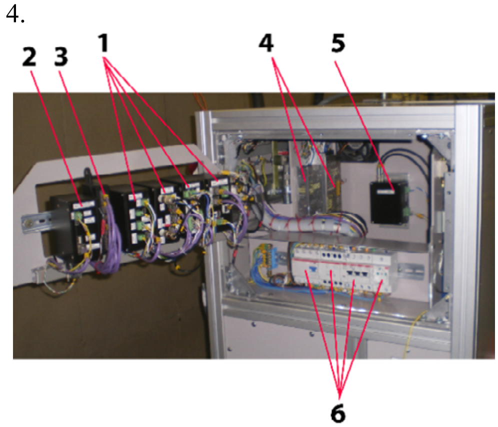

Figure 4: The controllers and control computer placement. 1 – controllers, 2 – control computer, 3 – network switch, 4 – power supplies 24 V, 5 - ion pumps power supply, 6 – switches and contactors.

SUBSYSTEMS CONTROLLERS

All controllers of the control system are based on LPC17xx series ARM microcontrollers [3]. It consists of three functional blocks implemented on a separate printed circuit boards (Fig. 5).

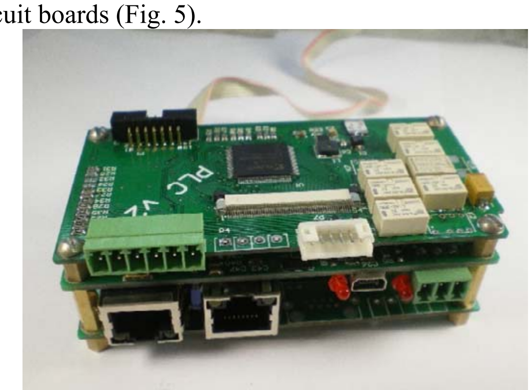

Figure 5: The accelerator controller without a box.

ISBN 978-3-95450-170-0

The controller consists of a CPU board, a synchronization board and an instrumental board. The CPU board function is receiving and transmitting data and commands from/to the control computer, communicating with DACs and ADCs located on the instrumental board via SPI and I2C interface, receiving and transmitting digital and analogue normalized signals from/to the instrumental board. The Ethernet controller is located on the CPU board and allows to communicate with control computer by Modbus/TCP protocol. A flash memory chip is also located on the CPU board. It allows to store the parameters required for controller operation. For example, there are amplifier normalizing factors, controlled device settings and so on. The instrumental board function is to normalize, receive and transmit signals from/to external sensors and devices. For example, the RF and cooling system controller structural diagram is shown on fig. 6. Figure 7 shows the placement of a controller of the RF and cooling system in the X-ray head cabinet.

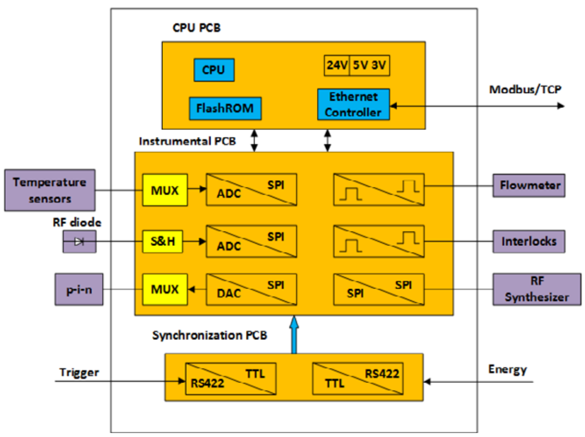

Figure 6: RF and cooling system controller structure.

In this case the sample-and-hold circuit used measure the RF field envelope amplitude, the p-i-n attenuator control circuit, the flow relays circuit, the circuit of flowmeter, temperature sensors signal processing, the interlock and RF pre-amplifier control optically isolated circuit are located on the instrumental board. The synchronization board is used to receive the trigger signal from accelerator controller via optically isolated RS-422 interface and to convert it to TTL. This signal synchronizes operation of the above-mentioned sample-and-hold and RF amplifier control circuits. The accelerator controller treats the hardware level interlock signals from the accelerator hall safety system, the modulator, the electronic key, subsystem controllers and from accelerator cabinet switches. In order to provide the interlock signal to the modulator and RF system the accelerator controller communicates with external safety system via standard +24V signals and open/close "dry" contacts.

The controller software utilizes a common Modbus/TCP stack based on uIP and FreeModbus library [4]. Each controller has its own IP address and supports several simultaneous Modbus/TCP connections. This can be used to debug the controllers without stopping the main control program. Coil and holding register values that represent controller settings are stored in controller EEPROMs. A special protocol used for coils (writable single-bit registers) that represent interlocks so that interlock signals are never missed by the control program. The control application maintains a database that maps controlled device parameters to Modbus registers. In case of communication problems with subsystem controllers the control system enters the fault state with corresponding operator notification.

Figure 7: RF and cooling system controller.

CONCLUSION

We have designed and manufactured the control system of accelerators for radiography and cargo inspection. The authors are grateful to Mr. A.V. Nalivaev for support of this work.

REFERENCES

[1] A.N.Ermakov et al., in these Proc.
[2] www.sc-nova.com
[3] www.nxp.com
[4] http://www.freemodbus.org

ISBN 978-3-95450-170-0