MODERNIZATION OF CONTROL SYSTEM OF THE BEAM CRITICAL PARAMETERS AT A LU-10 INDUSTRIAL ELECTRON ACCELERATOR

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Continuous control and monitoring of critical parameters of radiation processing of products is one of the requirements of the international standard ISO 11137. The current system to monitoring the parameters of radiation treatment of products at the LU-10 accelerator is being in operation for more than 15 years. The life-time of the mayor part of measuring modules is over, and those modules are no longer produced. Modernization of monitoring system with the use of the multi-functional USB modules, single-board mini-computers and EPICS control system (Experimental Physics and Industrial Control System) is considered. The architecture and software for a new monitoring system have been developed. Debugging and operation of the system in a test mode is performed

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INTRODUCTION

International Standard ISO 11137-1: 2006 (Sterilization of health care products – Radiation – Part1: Requirements for development, validation and routine control of a sterilization process for medical devices) specifies, that all qualification procedures, processing, metrological performance, and other elements that affect the sterilization process must be properly ensured and documented [1].

The standard does not specify the structure and implementation of the control system of processing conditions. It denotes only, that any reliable system providing complete monitoring and control of critical parameters, and ones, that can be correlated with them, can be used.

One of the main conditions of the treatment is transfer of absorbed dose of radiation to product within specified limits. The dose distribution in the treated product depends on: the energy of electrons, the linear density of electron flux on the surface of the irradiated object (beam current, scanner parameters); the speed of a moving object through the irradiation zone (conveyor speed).

Such parameters are defined as critical. So their monitoring should be carried out with special attention – to ensure reliable transfer of specified sterilization dose to the product.

The control system to monitor the main parameters of the sterilization process at the radiation processing plant with an electron accelerator LU-10 are installed in accordance with the requirements of the standard [2].

The system for monitoring the parameters of radiation treatment of products at the LU-10 accelerator was developed more than 15 years ago on the basis of the CAMAC modules. The main part of the measuring modules of the system is out of its life and is no longer being produced. Therefore, the first priority is the modernization of existing measurement channels and the system as a whole.

In order to increase the reliability and quality of work on radiation processing of products at the LU-10 accelerator, the system for measuring and monitoring critical parameters of the accelerator beam is being modernized. Recently, a wide range of electronic modules and input/output devices for analog and digital signals with USB and/or Ethernet interface appeared, as well as single-board mini-computers that are successfully used in automated control systems. This article presents the structure of a new radiation process monitoring system based on the EPICS control system with using a multifunctional USB module and single-board mini-computers.

1. DEVELOPMENT OF A NEW CRITICAL PARAMETERS CONTROL SYSTEM OF RADIATION PROCESSING OF PRODUCTION

At the moment, the control and monitoring of parameters of radiation processing are carried out using a set of measuring channels located at the operator workplace and in the control room of the accelerator. In the latter case, the process parameters are sent to the operator workstation via the network. The structure of automated workplace (AWP) includes: control channel of scanner electromagnet; measuring channel of average beam current; measuring channel of conveyor speed; monitoring channel of electron energy and absorbed dose.

The block diagram of the existing measurement channels using modules in the CAMAC standard is shown in Fig. 1.

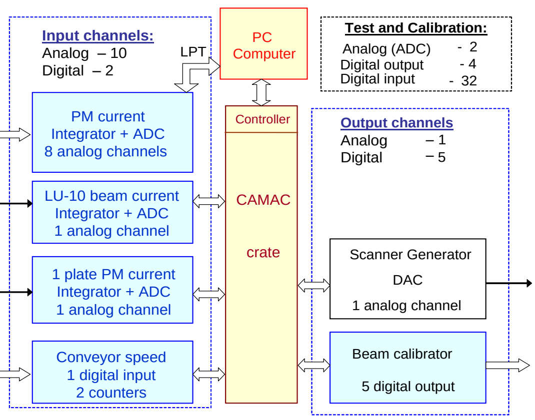

Fig. 1. The block diagram of measurement channels based on the CAMAC system

Current control system consist of next modules: 10 channels of analog-to-digital converter (ADC), 1 channel digital-to-analog converter (DAC) (scanner generator) and 7 digital channels (2 inputs, 5 outputs). For calibrations and tests, two more ADC channels and 31 digital input channels are used.

During the development of the new control system, the following requirements and criteria were taken into account:

1. The cost of the system.
2. A standard control interface (USB, Ethernet, ...).
3. Reliability, a big “life cycle”.
4. Software support, the availability of libraries, drivers, ...
5. The possibility of expansion and modification.
6. Availability.

As already mentioned, at the present time a fairly wide choice of analog/digital input/output modules and whole data acquisition systems with USB/Ethernet interface is available, which allows using them in automation systems.

After market research of electronic devices for the modernization of the control system of the following modules have been chosen:

- NI USB-6341 Data Acquisition System: 16 channels of ADC, 2 channels of DAC, 24 input/output, 4 meters, USB;
- Functional generator SigLent SDG1010: 2 channels, 20 MHz, the given waveform, USB;
- Oscilloscope SigLent SDS1072: 2 channels, 70 MHz, USB, Ethernet;
- Multimeter SigLent SDM3055: 5+½ characters, current, voltage, resistance, temperature, frequency, USB, Ethernet;
- Single-board mini computer Raspberry Pi-3: 1 GHz processor, 1 GHz memory, 17 I/O, SPI, I2C, USB, Ethernet.

The following is a brief description and characteristics of these modules and devices.

1.1. MULTIFUNCTIONAL MODULE USB-6341

National Instruments is one of the leaders in the production of control and data acquisition systems and is well represented in the Ukrainian market. To replace most of the existing measuring channels, the multifunction USB-6341 module is selected. A distinctive feature of this module is a large number of analog input channels of ADC, digital input/output channels and high bandwidth up to 1 MB/s.

Fig. 2 shows the block diagram of measuring channels based on the USB-6341 module.

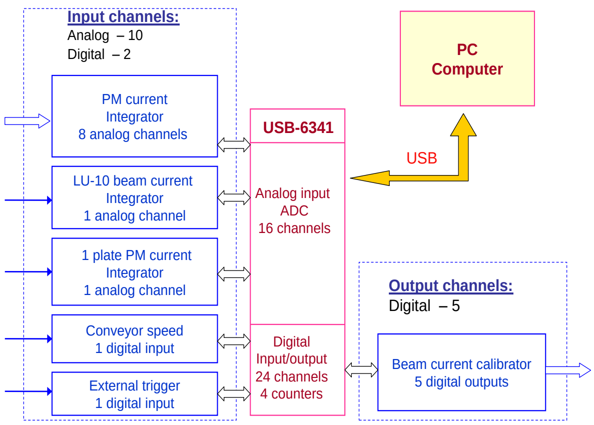

Fig. 2. The block diagram of measuring channels based on the USB-6341 module

The main parameters of the NI USB 6341:

- Number of analog input channels (ADC) 16;
- ADC bit depth, bit 16;
- ADC Digitization frequency, kHz 500 (1 channel);
- The size of the internal memory FIFO, kw 4000;
- Input range, V ±0,2; ±1; ±5; ±10;
- Number of analog output channels (DAC) 2;
- DAC resolution, bit 16;
- DAC sampling frequency, kHz 900;
- Output range, V ±10;
- Number of digital I/O channels 24;
- Counter / Timer 4 (100 MHz);
- Power external source, 11…30 V, 30 W;
- Size (length, width thickness), cm 26.4×17.3×3.6.

The modules are supplied with the NI-DAQmx and NI LabVIEW SignalExpress LE software. The NI-DAQmx driver allows you to develop own code both in the LabVIEW graphical environment and with traditional programming languages (ANSI C/C++, C#, Visual Basic.NET and Visual Basic 6.0).

1.2. FUNCTIONAL GENERATOR SIGLENT SDG1010

We use the functional generator model SDG1010 as a scanner sweep generator. Using such generator will allow the operator of AWP to set the scan parameters not only from the computer, but also in manual mode using the buttons on the front panel. This is an important argument in case of problems with the controlling computer. The special feature of the SDG1010 is the presence of flash memory, for storing predefined by the user waveforms.

Main characteristics of the generator:

- Frequency band: 1 μHz ... 10 MHz;
- Sampling rate for arbitrary waveforms 125 Mb/s, 14 bit;
- Built-in memory of 16 thousand points;
- Amplitude of the output signal from ±5 V;
- For remote control from a personal computer, a USB interface is provided;
- Support for the commands Standard Commands for Programmable Instruments (SCPI).

1.3. DIGITAL MULTIMETER SIGLENT SDM3055

To measure the resistance of the temperature sensors of RISO calorimeters, it is suggested to use a standard digital multimeter with the USB/Ethernet interface SIGLENT model SDM3055. This will allow to carry out measurements directly under the control of the computer.

Main characteristics of SDM3055 module:

- Resolution – 5½ bits;
- Basic accuracy of voltage measurement up to 0.015%;
- A wide range of built-in functions (11);
- Measurement speed (up to 150 op/s);
- USB/Ethernet interface for use with SCPI commands.

1.4. SINGLEBOARD MINI-COMPUTER RASPBERRY PI

Today there is a wide choice of single-board mini-computers with a high enough efficiency and low cost [3]. Support for various interfaces allows them to be used in automated control and monitoring systems [4, 5].

As one of the options for the control system was chosen single-board mini-computer type Raspberry Pi-3 (Fig. 3).

The main characteristics of Raspberry Pi-3:

- The size: 86×57 mm;
- ARM 1GHz processor (4 cores, 64 bit) + GPU;
- Memory 1 GB, 900 MHz;
- Ports 4 USB, 1 Ethernet, microSD card slot;
- 17 digital input / output lines;
- Interfaces SPI, I2C, RS232;
- Video, audio output;
- LINUX operating system;
- The cost is 35…50$.

This mini-computer is to be used as an EPICS IOC to control the parameters of the scanner.

Fig. 3. The picture of a single-board mini computer Raspberry Pi-3

2. EPICS SYSTEM (OVERVIEW)

The open system Experimental Physics and Industrial Control System (EPICS) was chosen as the software environment for the radiation processing parameters monitoring system. EPICS is widely used to create distributed control systems in large scientific centers, laboratories and accelerators. The EPICS collaboration has more than 25 participants (http://www.aps.anl.gov/epics/). In addition, the advantage of this environment is a wide choice of client programs, libraries and drivers, as well as their support for various operating systems.

Overview of the EPICS system (Fig. 4):

- Experimental Physics and Industrial Control System – a set of software tools, applications, libraries and drivers that are developed and supported by an international collaboration;
- EPICS architecture – client-server model with network communication protocol Channel Access (CA);
- Servers – Input/Output Controller (IOC), access devices and devices through various interfaces, process and store the data received from them in Process Variables (PV) and provide this information to clients through the Channel Access;
- Each PV variable has a unique name and stores a set of data associated with a particular signal or device state. Process variables, their type and interaction are defined in the database, which is loaded into the IOC I/O controller when it starts. EPICS clients need to know only the name of the PV process variable to access the data set of a particular signal;
- EPICS clients are a variety of applications such as: graphical management interfaces – MEDM, Control System Studio (CSS, CS-Studio), StripTool; Alarm handlers (ALH), AlarmServer; data archivers (ChannelArchiver, ArchiverServer, Archiver Appliance), and many others.

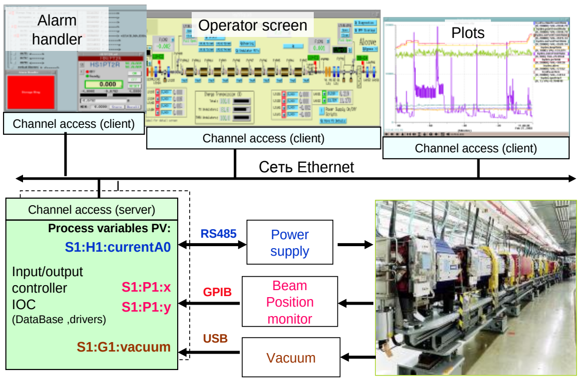

Fig. 4. The block diagram of the EPICS control system

The EPICS system has developed drivers for supporting a large set of basic protocols and interfaces (the main part is presented): CAMAC, CAN, Ethernet (Modbus), Firewire, GPIB, PCI, RS-232, 422, 485, USB.

If necessary, it is possible to develop drivers for new devices and interfaces using EPICS libraries.

The IOC I/O controller can be either a special hardware controller (VME, PC-104, ...) or a personal computer (PC) with a Linux, OS-X or Windows operating system. In the case of a PC, "soft" IOC is used.

3. CONTROL SYSTEM OF RADIATION PROCESSING PARAMETERS ON THE EPICS

The monitoring system for radiation processing parameters consists of the following elements (Fig. 5): database server based on PC (Linux OS); the local network; automated workplace of the operator on the basis of the PC (OS "Windows") with the operator's screen (CS-Studio); multifunctional module NI USB-6341; measuring instruments connected to a local network (oscilloscopes, multimeter, generator); EPICS I/O Controllers running on single-board mini-computers (OS "Linux").

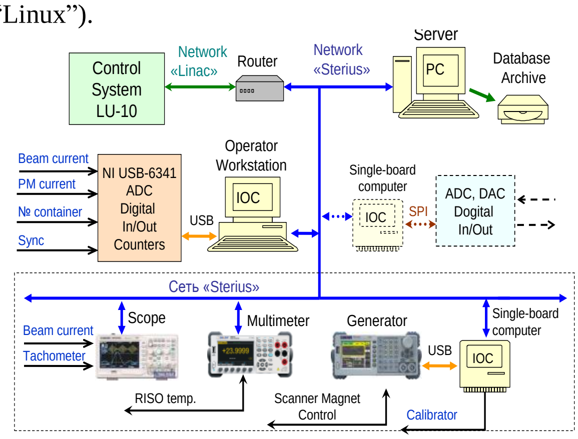

Fig. 5. The block diagram of the new control system

3.1. INPUT/OUTPUT CONTROLLERS (IOC)

The data acquisition system (Fig. 6) based on the USB-6341 module provides the measurement of the beam current of the accelerator from the magnetic induction sensor (MIP), signals (currents) from the plates of the plate monitor, the speed of the conveyor. To operate the module in the EPICS system, an “IOC-1” I/O controller and a PV process variable database are designed. During the measurement of analog signals, they are averaged (1000 points per 1 s) and the resulting values are placed in the corresponding PV variables. Scanning of variables is performed at a frequency of 2 Hz. The average energy of the beam and the absorbed dose in the object measured from the plate monitor, are calculated in the I/O controller also [7]. The “IOC-1” controller is developed using the “nidaqmx”, “pcaspy” libraries and Python-2.7 and runs on the Windows system. The programming language Python is widely used in the EPICS system for writing scripts and programs.

The signal for the scanner magnet is formed from the SDG1010 function generator. The operation of the generator is controlled by the I/O Controller “IOC-2” through the USB bus. The controller operates on a single-board mini-computer Raspberry Pi-3 running Linux.

The I/O controller “IOC-2” is designed using EPICS “asyn” and “stream” libraries to work with serial interfaces and supports the SCPI protocol (commands). Scanner parameters (sweep width and offset) are specified by the operator and placed in the corresponding process variables. The controller processes these variables and sends commands to the function generator. Thus, the generator produces a sweep signal for the scanner with the specified parameters.

The I/O controller “IOC-3” has developed to obtain the parameters of the LU-10 accelerator into the EPICS system. The parameters of the LU-10 accelerator (energy, average current, scan width and offset, scanner magnet current) are stored locally in a file on the accelerator's computer. Scripts have developed for monitoring changes in the LU-10 parameter file. When the file is updated, it is read, and the updated parameters are placed in the corresponding process variables of the I/O controller using the CA protocol. The “IOC-3” controller and scripts run on the single-board mini-computer Raspberry Pi-3.

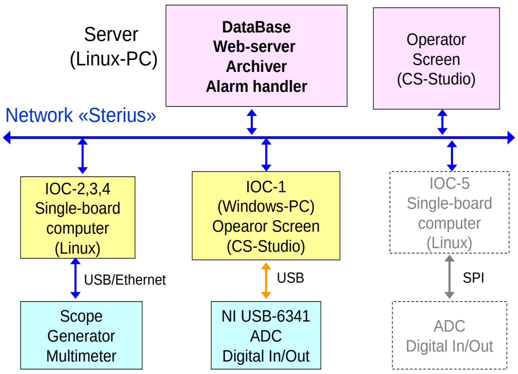

Fig. 6. Functional diagram of the radiation treatment parameters monitoring system

The SDG1010 oscilloscope connected to the local network is used to monitor additional parameters about beam current (pulse shape), scanner magnet current. The input/output controller “IOC-4” has been designed to receive data from the oscilloscope. The controller is created using the EPICS “asyn” and “stream” libraries and runs on the single-board mini-computer Raspberry Pi-3 also.

3.2. THE OPERATOR GRAPHIC INTERFACE

Control system studio is a software complex based on Eclipse, which is designed to build control systems in scientific experiments and accelerators and is the result of collaborations between different laboratories and universities [8, 9]. Control system studio is an integrated system with a set of tools, such as: alarm handler, subsystem for archiving in the database (archive engine), graphical operator interfaces and system diagnostics tools.

CSS requests the PV process variables from the IOC input/output controllers using the Channel Access protocol. Process variable includes value of variable, timestamp, information about the emergency state of variable, units of measurement, and so on. The resulting variables are processed in CSS: represented in a graphical form, stored in a database, checked for a signal, etc. A key feature of CSS is the integration of these tools into one system. CS-Studio runs on various operating systems and allows creating operator interfaces of different complexity.

The graphic interfaces (“operator screens”): “Parameters LU-10” and “Energy and absorbed dose monitoring” have been developed to display the monitored parameters of the radiation process.

The following parameters are displayed as text and graphical form on the operator's screen “Parameters LU-10” (Fig. 7): beam energy; average beam current; the specified and measured parameters of the scanner: scan width; scan offset; the magnet current of the scanner; conveyor speed.

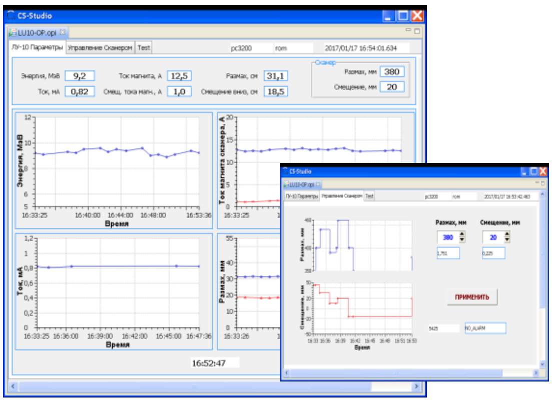

Fig. 7. Operator screen "Parameters LU-10"

The beam energy and the absorbed dose in the processed object are displayed on the screen of the operator "Monitoring energy and absorbed dose" in graphic and text form (Fig. 8): beam energy; average accelerator current, current from the monitor plates, conveyor speed; current value of the absorbed dose and averaged over the container; fields for entering the parameters of the irradiated object (weight, dimensions); distribution of measured current values from absorber plates; distribution of the sum of all currents from the plates in time;

distribution of absorbed dose in the object along the length of the transport container.

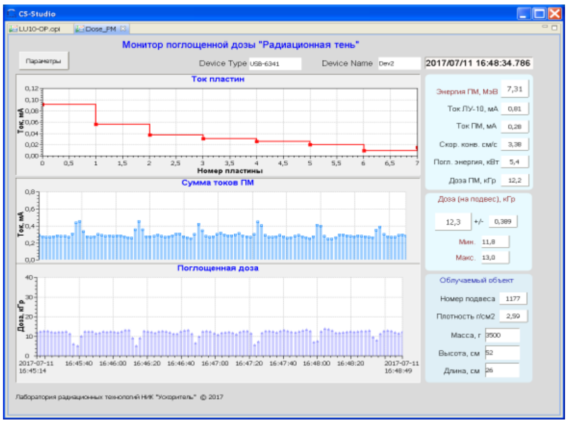

Fig. 8. The operator screen "Monitoring energy and absorbed dose"

3.3. THE ARCHIEVER OF PARAMETERS

The software package "The EPICS Archiver Appliance" – the implementation of the archiver for EPICS control systems is planned to use as the archiver of parameters of radiation processing. The main features of the package [10]:

- Ability to cluster appliances and to scale by adding appliances to the cluster;
- Multiple stages and an inbuilt process to move data between the stages;

A management interface giving you the ability to manage and monitor the system using a browser;

- Ability to script the business processes in the appliances using an external process in a language like Python;
- Ability to configure various archiving parameters on a per PV basis;
- Support for retrieval of data using CS-Studio, the ArchiveViewer and Matlab;
- Configuring and retrieving data using JSON/HTTP requests.

The archiver uses "ProtocolBuffers" (a mechanism for serializing structured data) developed by Google (https://developers.google.com/protocol-buffers) to record data.

The archiver is launched on the server (Fig. 6) as a web application running the "Apache Tomcat" program. The expected amount of archived data about 5 GB per year, which is acceptable for existing storage devices (hard disks, flash memory, etc.).

CONCLUSIONS

In order to improve the reliability and quality of radiation processing of products at the LU-10 accelerator, the system for measuring and monitoring critical parameters of the accelerator beam based on the EPICS system and electronic devices with standard control interfaces is being modernized.

The use of modules and devices with a standard control interface made it possible to provide information, electrical and structural compatibility of these elements.

The introduction of the EPICS system allows unifying the monitoring system for radiation treatment parameters, it makes it possible to modify and integrate new devices quite quickly, which reduces the time for software development and increases the reliability of the system as a whole.

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МОДЕРНИЗАЦИЯ СИСТЕМЫ КОНТРОЛЯ КРИТИЧЕСКИХ ПАРАМЕТРОВ ПУЧКА ПРОМЫШЛЕННОГО УСКОРИТЕЛЯ ЭЛЕКТРОНОВ ЛУ-10

Р.И. Помацалюк, В.Л. Уваров, В.А. Шевченко, И.Н. Шляхов

Непрерывный контроль и мониторинг критических параметров радиационной обработки продукции является одним из требований Международного стандарта ISO 11137. Действующая система контроля параметров радиационной обработки продукции на ускорителе ЛУ-10 работает более 15 лет. Большая часть измерительных модулей системы выработала свой ресурс и больше не производится. Рассмотрена модернизация системы контроля с использованием многофункциональных USB-модулей, одноплатных мини-компьютеров и системы управления EPICS (Experimental Physics and Industrial Control System). Разработана архитектура и программное обеспечение для новой системы контроля параметров радиационной обработки. Проводится отладка и работа системы в тестовом режиме.

МОДЕРНІЗАЦІЯ СИСТЕМИ КОНТРОЛЮ КРИТИЧНИХ ПАРАМЕТРІВ ПУЧКА ПРОМИСЛОВОГО ПРИСКОРЮВАЧА ЕЛЕКТРОНІВ ЛП-10

Р.І. Помацалюк, В.Л. Уваров, В.А. Шевченко, І.Н. Шляхов

Безперервний контроль і моніторинг критичних параметрів радіаційної обробки продукції є одним з вимог Міжнародного стандарту ISO 11137. Діюча система контролю параметрів радіаційної обробки продукції на прискорювачі ЛП-10 працює більше 15 років. Велика частина вимірювальних модулів системи виробила свій ресурс і більше не виробляється. Розглянуто модернізацію системи контролю з використанням багатофункціональних USB-модулів, одноплатних міні-комп'ютерів та системи управління EPICS (Experimental Physics and Industrial Control System). Розроблена архітектура та програмне забезпечення для нової системи контролю параметрів радіаційної обробки. Проводиться налагодження і робота системи в тестовому режимі.