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THE CONTROL SYSTEM OF THE LINAC-200 ELECTRON ACCELERATOR AT JINR

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Abstract

The linear accelerator Linac-200 at JINR is constructed to provide electron test beams with energy up to 200 MeV to carry out particle detector R&D, to perform studies of advanced methods of beam diagnostics, and to work as an irradiation facility for applied research. While the accelerator largely reuses refurbished parts of the MEA accelerator from NIKHEF, the accelerator control system is completely redesigned. A new distributed control system has been developed using the Tango toolkit. The key subsystems of the accelerator (including focusing and steering magnets control, vacuum control system, synchronization system, electron gun control system, precise temperature regulation system) were redesigned or deeply modernized. This report presents the design and the current status of the control system of the Linac-200 machine.

INTRODUCTION

Linear electron accelerator Linac-200 (Dzhelepov Laboratory of Nuclear Problems, JINR, Dubna, Russia) is a unique facility intended for scientific and methodological research in the field of accelerator physics and technology, elementary particles detectors research and development, as well as fundamental and applied research in the fields of materials science and radiobiology. It is based on the MEA linear electron accelerator which was transferred to JINR from NIKHEF in the end of 90s.

Main accelerator structure unit is a station. The injector station A00 includes the electron gun, chopper, prebuncher and buncher. First accelerator station A01 includes one accelerating section and a klystron, which also feeds the RF equipment of the A00 station. All the rest stations include two accelerating sections and a klystron each.

Current setup (Fig. 1) consists of 5 stations, A00–A04, and allows generation of the 200 MeV electron beam. In the future it is planned to increase the number of stations up to thirteen, and the energy will accordingly increase up to 800 MeV [1].

Almost all MEA equipment is in good condition and has reasonable operating resource. However, control systems hardware and software, as it is the most rapidly developing sphere, were mostly out-of-date already at the moment of accelerator transfer from NIKHEF to JINR. Therefore, two major accelerator control system upgrades took place. The first one was continuous, when necessary control subsystems were developed when they were needed [2]. The second one started in 2018 when development of the new global control system began [3].

The global control system automatically collects, processes, stores and displays information about the operation of the accelerator, as well as about the state of the technological equipment involved in the operation of the accelerator. Also, the global control system provides the ability to automatically control individual accelerator subsystems.

The main requirements for the Linac-200 global control system is high reliability, safety, simplicity of software development, and ease of technical support. There should be an opportunity for future modifications and extensions. The software of the global control system should use standard interfaces for interaction between components and be able to use existing developments of the world community.

Tango Controls allows to create control systems that meet these requirements. It is also worth mentioning that the control system for the NICA collider at JINR is being developed using Tango [4]. Therefore, it was decided to implement a new global control system for the Linac-200 accelerator based on Tango.

CONTROL SYSTEM CONCEPT

Tango Controls

Tango Controls is a free open source device-oriented controls toolkit for controlling any kind of hardware or software and building supervisory control and data acquisition (SCADA) systems. The fundamental unit of Tango is a device, which is an abstraction hiding real equipment or program component behind the standard interface. Tango provides high level client application interface which has necessary programming classes to implement client-server communications – synchronously or asynchronously execute commands, read or write attributes, or use events to acquire the data from the Tango devices. Tango incorporates a number of tools to build efficient control system environment including centralized administration and monitoring, access control, logging system, data archiving and code generation for rapid development of the Tango device servers using C++, Java and Python [5].

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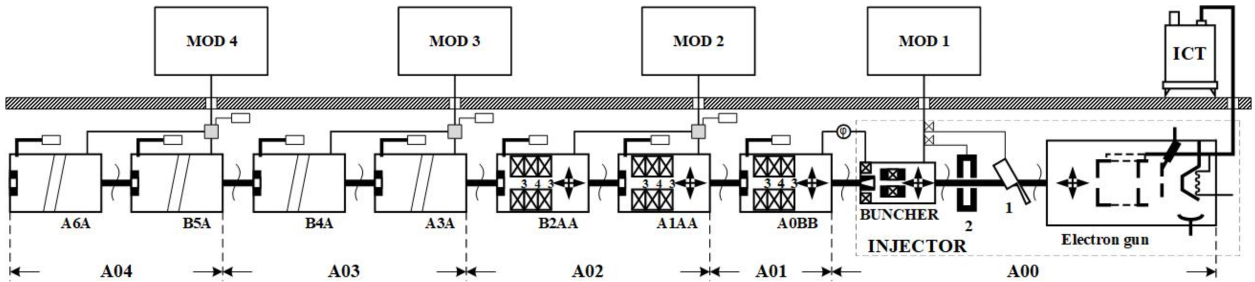

Figure 1: Linac-200 accelerator layout (1 – chopper, 2 – prebuncher).

Control System Structure

Layout of the Linac-200 control system is shown in Fig. 2. The system is implemented as three levels: hardware access level, server level and client level.

At the hardware access level, digital and analog signals are collected and analog signals are converted to digital. This level also includes all equipment that needs to be controlled. The hardware access layer is connected to the server layer through a data transmission channels. Ethernet and RS-485 are used as data transmission interfaces.

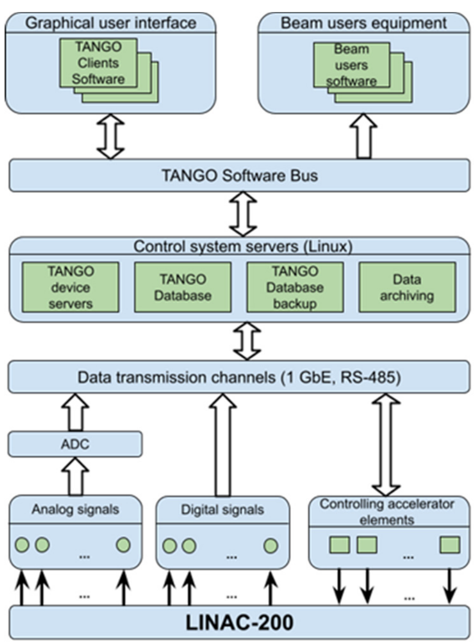

Figure 2: Linac-200 control system layout.

The server level is required for the effective centralized collection, processing and storage of data from the elements of the hardware access level, as well as for the implementation of subsystems control algorithms.

The server level provides a set of software components that are necessary for the effective functioning of the control system. These components include:

- Tango database (for which it is necessary to provide reliable backup methods, the ability to quickly transfer to another server).
- System of differentiation of access rights to the elements of the control system.
- A data archiving system that allows you to store data in a database for short-term or long-term storage.
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Supermicro [6] servers running Linux Debian are used as server computers. C++ and Python languages are used for server software development.

The client layer provides graphical user interface (GUI) for monitoring and controlling various parameters of the accelerator. At the moment, in the Linac-200 control system, client applications are developed in C ++ using Qt5 and QTango [7]. For each subsystem (or, if there is such a need, for individual elements of the subsystem) there is a separate client application. In addition, there is a global client application that provides a graphical interface for launching client applications for individual subsystems (or their elements).

In the future, it is possible to use web clients, which can be implemented using the technology described in [8]. Also, the possibility of using Taurus [9] – a framework for creating both GUI and command-line applications with Python, seems promising.

Network Infrastructure

The Linac-200 global control system is based on the interaction of components included in the Ethernet network, divided into a number of segments serving the main control room, accelerating stations, users control room and accelerator hall. The network infrastructure of the global control system is shown in Fig. 3.

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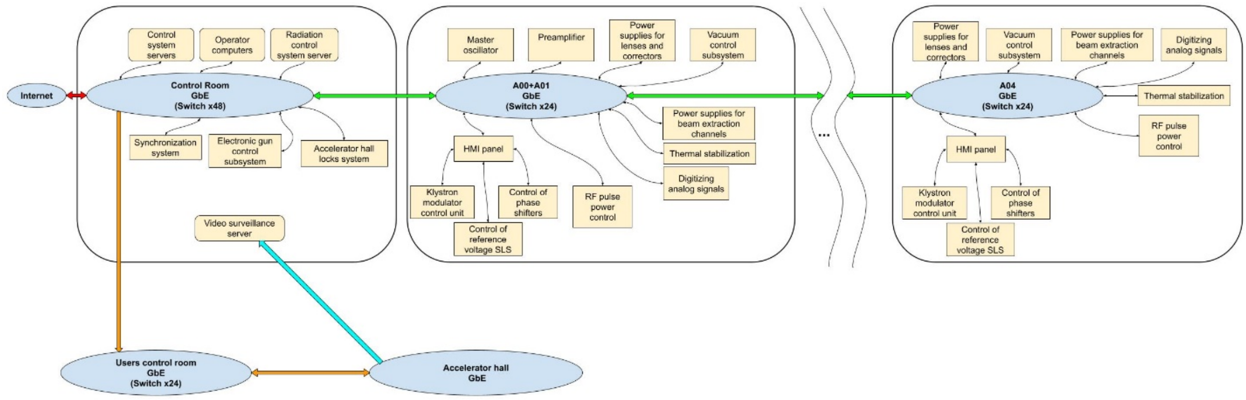

Figure 3: The network infrastructure of the Linac-200 global control system.

Local Control

Local control is available for a number of subsystems and is done with the Weintek MT8071iP [10] operator panel.

In addition to displaying the local control graphical interface, the Weintek MT8071iP panel acts as a Modbus server. Slave devices are connected to the panel by means of RS-485 interface according to Modbus RTU protocol. Data is transmitted to the Tango-based global control system via Ethernet using Modbus TCP and Modbus RTU over TCP protocols.

LINAC-200 CONTROL SYSTEM SUBSYSTEMS

Electron Gun Control System

The beam is generated by the 400-kV DC triode-type electron gun with a thermionic cathode. As part of the development of a global Tango-based control system, new software for the electron gun control was developed.

More information about electron gun control system can be found in [11].

Synchronization System Control

The new synchronization system is a multichannel generator that generates sync pulses to control the accelerating system and synchronize the accelerator subsystems. It consists of a master oscillator and a multichannel delayed pulse generator.

At the moment, a separate software running on a Windows computer is used to control the synchronization system. In the future, it is planned to integrate the synchronization system software into the global Tango-based control system. For this purpose, a corresponding Tango class will be implemented, as well as a client application with a graphical interface.

Control of RF system elements

At the moment the following RF system elements are controlled:

- Master oscillator.
- Preamplifier.
- Klystrons modulator control units.
- Phase shifters.

Master oscillator. A high-frequency signal generator AKIP-7SG384 is used as a master oscillator. The interface for interaction with the control system is Ethernet. Data exchange via Ethernet is carried out using the Tango Socket device [12]. The control of the frequency and amplitude of the output signal is realized.

Preamplifier. A specially designed power amplifier DIALTEK UMP245-300 is used as a preamplifier of the RF system. The control of the output power and RF pulse width is realized. Data exchange between preamplifier and the control system is implemented using Modbus RTU over TCP protocol.

RTU over TCP provides a method to transmit RTU messages with a TCP/IP wrapper through a gateway onto Ethernet without changing any of the bytes in the message. Standard Modbus RTU is meant for transmission over serial lines. The message starts with a one byte Slave ID and ends with a two byte CRC (Cyclical Redundancy Checking). In RTU over TCP, the server does not have a slave ID and uses an IP address instead.

Since the existing Tango class [13] does not support this protocol, a new TangoPyModbus class to handle the Modbus protocol was implemented base on the PyModbus library [14].

Klystrons modulator control units. The solid state modulator consists of the special multicore pulse adding transformer and 40 PFN (Pulse Forming Network) units. Each of these units is a printed circuit board with a 2 kV line-type (50 μs) modulator. Two units feed a primary of the pulse adding transformer [15]. Such a layout allows generation of pulses which amplitude can be changed by changing the number of active PFN units. This number is controlled by the special Weltek controllers. These controllers also provide information on the modulator status to the control system [16]. Interaction with global control system, as well as the local control is realized by means of Weintek MT8071iP operator panel.

Phase shifters. A specially designed mechanical phase shifter (Fig. 4) is used to control the phase shift of the klystron actuating signal of the Linac-200 accelerator station. It has a high resolution positioning of the sliding coaxial line along the length, due to the use of a stepper motor and high manufacturing precision of the ballscrew.

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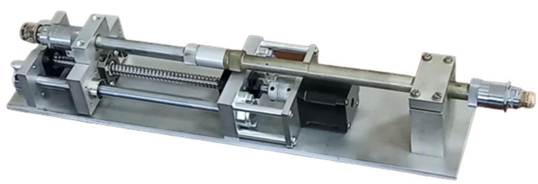

Figure 4: Mechanical phase shifter.

The phase shifter is controlled by means of a specially designed electronic board, the main elements of which are a microcontroller and a stepper motor drive.

Interaction with global control system, as well as the local control is realized by means of Weintek MT8071iP operator panel.

Focusing and Steering Magnets Control

Magnetic elements are used to focus and steer the position of the beam, which are mainly required to reduce the loss of particles during acceleration. Focusing is carried out using solenoidal and quadrupole lenses. Steering magnets are used to adjust the position of the beam relative to the accelerator axis.

The magnetic elements are powered by the KORAD KA3005P and KA6003P power supplies. Modifications (KA3005P / 6003P) differ in the range of currents and voltages (0–30 V, 0–5 A and 0–60 V, 0–3 A, respectively) and are selected based on the power consumed by a particular element of the accelerator magnetic system. Remote control interfaces include USB and RS-232.

The integration of these power supplies into the global Tango-based control system is hampered by the fact that the USB and RS-232 interfaces are unsuitable for transmitting data to the control room of the accelerator (a distance of about fifty meters), and the built-in software of the power supplies does not allow each unit to be assigned a unique address for its unambiguous identification.

To solve this problem, intelligent interface modules KPI-11 were developed. Based on these modules, a control system for magnetic elements was developed (the diagram is shown in Fig. 5). This system allows to remotely and independently control the network of power supplies KORAD KA3005P / 6003P [17].

Vacuum Control System

The diagram of the vacuum control system is shown in Fig. 6.

The vacuum system is controlled by the B&R Industrial Automation PLC model X20CP3584 [18]. The PLC software was developed in C in the B&R Automation Studio 4.5 integrated development environment. Interaction with the global control system is carried out through the Modbus TCP protocol.

Precise Temperature Regulation System

Its planned to use the Unichiller 100-H circulators from Huber [19] for precise temperature regulation. A special Pilot ONE unit would be used to control the circulators. This unit is equipped with a touch screen for local control and also supports remote control via Ethernet, which in turn makes it possible to integrate it into a global control system.

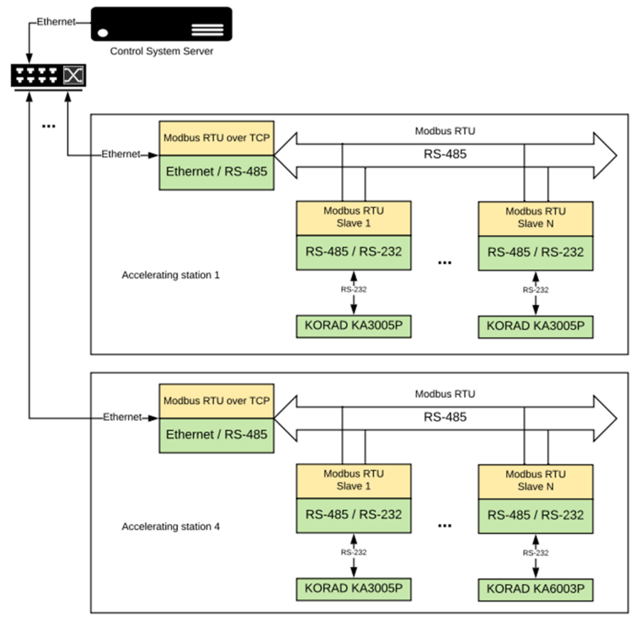

Figure 5: Magnetic element control system layout.

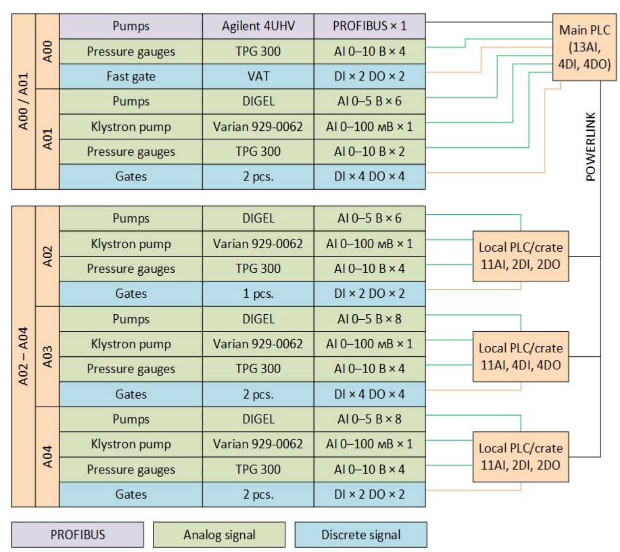

Figure 6: Vacuum control system layout.

CONCLUSION

The general concept of the global control system which capable of providing launch and control of the main accelerator subsystems has been designed. Tango-based software for individual subsystems of the Linac-200 has been developed.

The accelerator building is undergoing major repairs. After the completion of the first phase of the repair, it is planned to launch the accelerator with a new control system.

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