UPGRADE OF THE NUCLOTRON INJECTION CONTROL AND DIAGNOSTICS SYSTEM

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Abstract

The Nuclotron is a 6 GeV/u superconducting synchrotron operating at JINR, Dubna since 1993. It will be the core of the future accelerating complex NICA which is under development now. The report presents details of the Nuclotron injection hardware and software upgrade to operate under future NICA control system based on Tango. The designed system provides control and synchronization of electrostatic and magnetic inflector devices and diagnostics of the ion beam injected from 20MeV linear accelerator to the Nuclotron. The hardware consists of a few controllable power supplies, various National Instruments' acquisition devices and a custom-designed controller module. The software consists of a few C++ Tango device servers and NI LabView client applications.

INTRODUCTION

The project to build a new accelerator complex NICA (Nuclotron-based Ion Collider fAcility) on the basis of the modernized Nuclotron accelerating facility is currently under development at JINR. The main goal of the project is to provide experiments with colliding ion beams to study both hot and dense strongly interacting baryonic matter and spin physics (in collisions of polarized protons and deuterons). Experiments on the Nuclotron extracted beam and internal target will be continued as well.

The project implementation requires the construction of new high intensity ion sources, modernization of the existing linear accelerator LU-20 and construction of a new heavy ion linear accelerator, a superconducting booster synchrotron, two superconducting collider rings and a few necessary beam transfer lines.

The main element of the collider injection chain is the Nuclotron synchrotron. It will provide the acceleration of heavy ions up to the experiment energy in the range of 1÷4.5 GeV/u and protons in the 5÷12.6 GeV energy range [1]. The Nuclotron is currently used for fixed target experiments at extracted beams and experiments with the internal target.

The new accelerator complex distributed control system based on TANGO is being developed within the framework of the NICA project. Particularly, the modernization of the existing Nuclotron synchrotron control system is carried out now. Several Nuclotron subsystems were fully rebuilt during the last year to upgrade their hardware and implement new software compatible with the TANGO based control system. The upgrade of the Nuclotron injection control and diagnostics system is described in the report.

SYSTEM OVERVIEW

The Nuclotron injection system (see Fig. 1) is intended for a one-turn injection of the heavy ion beam with the energy of 5MeV/u from the linear accelerator LU-20 into the Nuclotron ring.

The injection scheme provides beam deflection in the vertical plane. The layout of the one-turn injection consists of two main elements – the superconducting deflecting septum magnet and the electrostatic kicker (inflector plates) [2]:

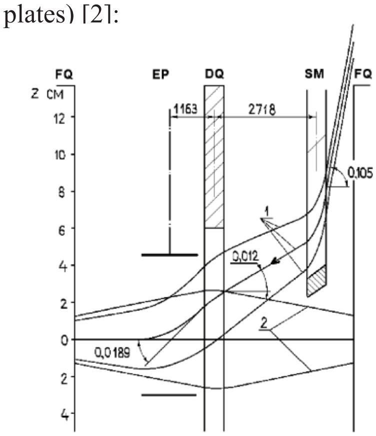

Figure 1: Nuclotron injection layout.

The superconducting septum magnet is supplied with direct current while the voltage between inflector plates is periodically changing. One of the plates is charged to voltage, which is required for the final beam fitting into the Nuclotron orbit, and then discharged by a gas-filled thyratron after the one-turn injection. The residual voltage between the plates must be rather small to prevent disturbance of the circulating beam.

The main characteristics of the electrostatic kicker are shown in the table below:

Table 1: Electrostatic Kicker Parameters

1. Nonlinearity of electric field in the working area	< 1%
2. Voltage on the plates	(40+0.4)kV
3. Discharge time	<100 nsec
4. Rest voltage for 1 msec after discharge	<2%
5. Total capacity of the potential plate relative to ground	280pF
6. Total inductance	0.4 µH
7. Wave impedance	37.8 Ohm

The injection control and diagnostics system upgrade includes design and installation of the new hardware - septum magnet and electrostatic kicker power supplies, a thyratron modulator, custom-designed electronics units, a

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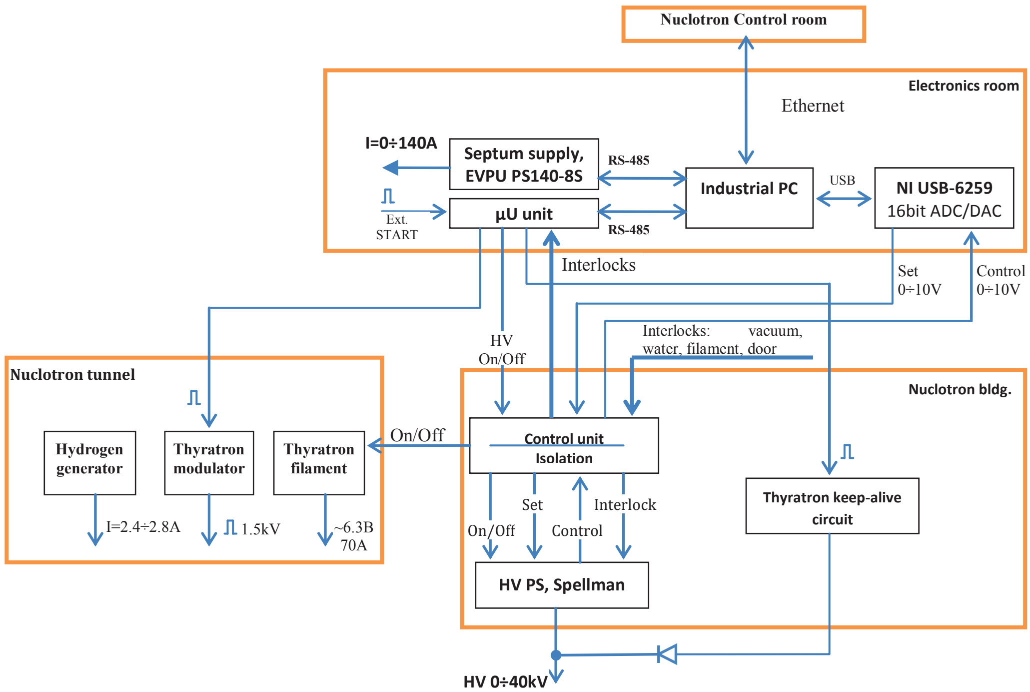

Figure 2: Nuclotron injection control system structure.

few acquisition boards to implement beam diagnostics and development of software to control all the injection system electronics.

The upgraded injection control system structure is shown in Fig. 2.

The injection system control and diagnostics equipment is located in the electronics room of the Nuclotron building. It consists of an industrial PC Advantech, an intelligent controller based on Atmel AVR MEGA128 microcontroller and a complex programmable logic device (CPLD) Altera MaxII, National Instruments' (NI) acquisition boards USB-6259 and a multichannel digitizer NI PCI-5105. Communication between the equipment and the control computer is carried out by means of USB, PCI and RS-485 bus (using Modbus and Profibus fieldbus protocols). The power part of the equipment consists of a high voltage power supply Spellman SL60P300, a septum magnet power supply EVPU PS140-8S, a thyratron modulator and thyratron control units. The power electronics is located in the Nuclotron building hall and the thyratron of TGI1-2500/50 type with its control units is installed in the accelerator ring tunnel. All electric signals are galvanically isolated from control signals.

Several high voltage and thyratron filament interlocks are provided, that protects the equipment from insufficient vacuum pressure, low thyratron cooling water flow and prevents personnel access to the equipment under high voltage.

OPERATIONAL PRINCIPLES

The superconducting septum magnet is supplied by the direct current power supply EVPU PS140-8S and permanently deflects heavy ion beam in the vertical plane. A voltage of 40 kV from the high voltage power supply Spellman SL60P300 is applied between the electrostatic plates before the injection start. After injection, right before the beam completes its first turn (duration is about 8 µs) the power supply is turned off immediately by means of output blocking signal and the thyratron is switched on in the short period of time. The thyratron dumps voltage between the electrostatic plates down to zero during 100 ns. It has been observed that in a certain period of time the voltage between the plates tends to increase, that can lead to the beam deterioration and destruction. In order to avoid spurious voltage, a special electric circuit keeps the thyratron fired during beam acceleration period, that is made by applying a voltage of about 90-100 V to the thyratron anode to keep the thyratron switched on with about 100 mA current flowing. This voltage level doesn't affect the beam quality. When the cycle of acceleration is completed the thyratron is turned off.

Necessary signals to control the high voltage power supply and thyratron are produced by the intelligent controller unit according to the external injection start signal. The control signals timing can be adjusted with 10 ns accuracy by using 32-bit counters clocked with 100 MHz signal. The time intervals up to 1000 seconds can be achieved. Both the high voltage supply and thyratron filament supply are immediately switched off in case of interlock alarms. The time structure of control signals is given in Fig. 3.

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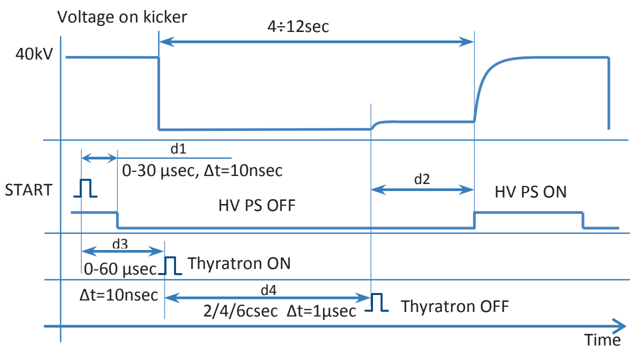

Figure 3: Electrostatic kicker supply time diagram.

The high voltage level between the electrostatic plates is specified by the analog signal of 0÷10V range by means of 16-bit DAC and measured by 16-bit ADC of the NI USB-6259 acquisition board by means of a high voltage divider.

The injected beam diagnostics consists of transversal and longitudinal beam profile measurements in several points of the injection transfer channel and the accelerator ring.

The transversal beam profiles are obtained by four multiwire (32x32) proportional chambers. Signals from all 64 wires are multiplexed into a single analog line. Four ADC channels of the NI USB-6259 are used to digitize the analog signals from each proportional chamber. All ADCs are clocked by an external signal formed by a multiplexer that allows one to derive each wire signals from the single line.

The longitudinal profiles of the injecting bunch are acquired by a 60 MS/s NI PCI-5105 digitizer from three electrostatic pickup electrodes in the transfer channel and in the accelerator ring.

CONTROL SYSTEM INTEGRATION

The injection control and diagnostics system development is a part of the Nuclotron control system upgrading for its operation as a part of the future NICA accelerating complex.

The control system framework choice was determined by the following requirements:

- Simplicity of system maintenance, scalability.
- Minimization of the control system development time expenditures and cost.
- Applications access control.
- Reliable operation during the long runtime of the accelerator complex.

TANGO Controls [3] fully meets the requirements and is accepted as the basis of the future NICA control system. The client applications are developed using the NI LabVIEW Development System [4] which can communicate with TANGO devices by means of LabVIEW Tango bindings.

Therefore the software part of the injection control system consists of the following components:

- The intelligent controller firmware including C program for the Atmel AVR microcontroller and VHDL code for the Altera CPLD – client Modbus protocol implementation, interlocks handling and digital signals generating with 10 ns accuracy.
- Tango device servers implementing fieldbus communication protocols Modbus/RTU and Profibus.
- A Tango device server to control the EVPU PS140-8S power supply (utilizing Profibus Tango device) – setting and controlling the superconducting septum magnet current with slow increase and decrease and error processing.
- A Tango device server to communicate with the intelligent controller (utilizing Modbus Tango device) – obtaining and resetting alarms, adjusting the signals delays according to the accelerating cycle duration.
- Tango device servers to operate NI acquisition devices based on the NI-DAQmx drivers – analog input and output, digital input and output, time measurements and pulse generation using counters.
- Tango device servers to control NI digitizers using the NI-SCOPE drivers – multichannel acquisition with desired sampling frequency and number of samples.
- Tango device servers to control NI digital multimeters using the NI-DMM drivers – static voltage and current measurements with high accuracy.
- High-level Tango device servers implementing injection control algorithm and beam diagnostics. They control low-level tango devices, acquire data from them and convert the data to physical quantities.
- Client applications developed in the NI LabVIEW environment using LabVIEW Tango bindings. The client applications communicate with high-level Tango devices using events and only implement the operator interface and data visualization. The control algorithm is realized in high-level Tango devices.

The Tango device servers are developed in C++ language with paying attention to the cross-platform usage under Linux and Windows. All the injection control and diagnostics device servers are running on the single industrial PC located in the Nuclotron electronics room and are remotely controlled via the Starter Tango service.

The injection control client application is shown in Fig. 4. Operator can control subsystems and interlocks status, set and control current and voltage levels of the power supplies. The necessary signal time structure can be either set automatically based on the accelerator cycle length or manually by individual delays of the high voltage supply and thyratron switching on and off.

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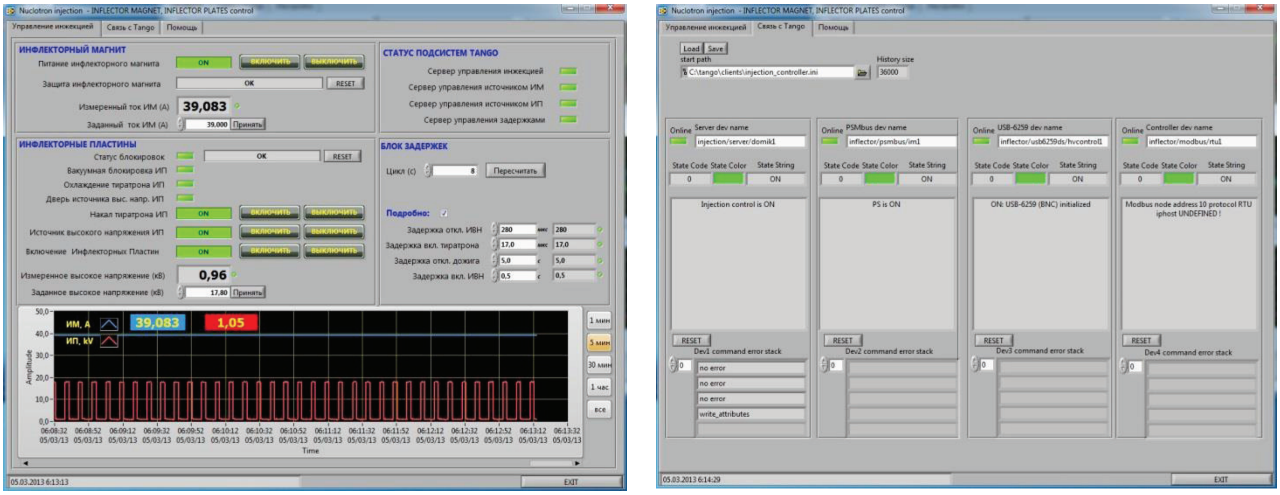

Figure 4: Injection control client application.

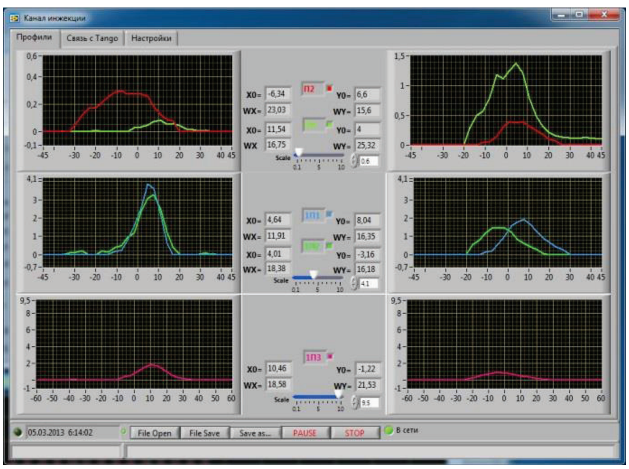

Figure 5: Transversal beam profiles in the transfer line.

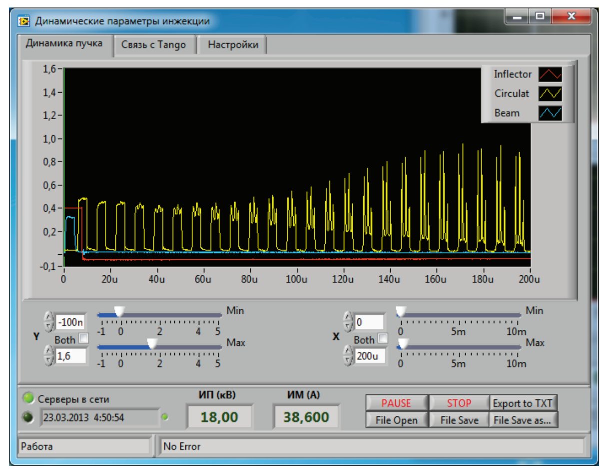

Figure 6: Injected beam circulation.

Recovery from error conditions (interlocks or power supplies protections) is initiated by the operator after error conditions clearance and carried out automatically.

Current and voltage settings are periodically saved to the archive database using the standalone Tango Archiving Service.

The injecting beam diagnostics application window is shown in Figure 5. It represents transversal beam profiles in four points of the transfer channel as well as spatial statistical parameters such as the beam position and dispersion taking into account the chosen distance between the wires in each profile-meter.

Figure 6 demonstrates the longitudinal profile of the bunch from the linear accelerator, time position of the voltage pulse between the inflector plates and longitudinal profile of the injected beam during a several turns in the Nuclotron ring.

CONCLUSIONS

The upgraded Nuclotron injection control and diagnostics system was put into operation during the 47 run of Nuclotron in March 2013. It has demonstrated high reliability, operation convenience and fulfilled the injected beam quality requirements. Both hardware and software parts of the system were fully redeveloped. The software implementation using TANGO framework allowed to reduce the development time significantly and confirmed the usage of TANGO concept as a basis for the future NICA control system.

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