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THE SUBSYSTEM OF THE INTERNAL BEAM INTENSITY DIAGNOSTICS AT THE NUCLOTRON

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The superconducting synchrotron Nuclotron is the base of a new accelerator complex NICA designed at the LHEP, JINR. It is very important to monitor dynamics of its internal beam intensity during an acceleration cycle for proper tuning and functioning of the setup. The new parametric current transformer of Bergoz Instrumentation with frequency response DC to 10 kHz is used for measuring the beam DC intensity in the Nuclotron ring. Data acquisition is performed by multifunctional DAQ device NI6284 (18-bit) of National Instruments. The software complex provides efficient work of the intensity monitoring subsystem. It consists of the subsystem server and several clients specialized for operators, stuff member and experimentalists. The software has been designed in the TANGO Controls concept and fully integrated into the TANGO system of NICA. The structure, principle of functioning, operational experience in the recent Nuclotron runs and further improvement of the software complex are reported.

Keywords: synchrotron, control system, beam diagnostics, TANGO Controls

1. The New Parametric Current Transformer

The 6 GeV/u superconducting synchrotron Nuclotron [1] is the base of a new accelerator complex NICA [2] designed at the LHEP, JINR. It is very important to monitor dynamics of its internal beam intensity during an acceleration cycle for proper tuning and functioning of the setup.

The Parametric Current Transformer is used at the most of accelerators in the world to measure the average beam current and, consequently, the intensity and lifetime of the beam. At the Nuclotron we apply the New Parametric Current Transformer (NPCT) [3] of Bergoz Instrumentation. The toroid sensor head of the NPCT is embedded on the accelerator ring near the internal target station (see Fig.1) while the Transformer chassis with electronics and power supplies is mounted in a rack placed above the accelerator tunnel.

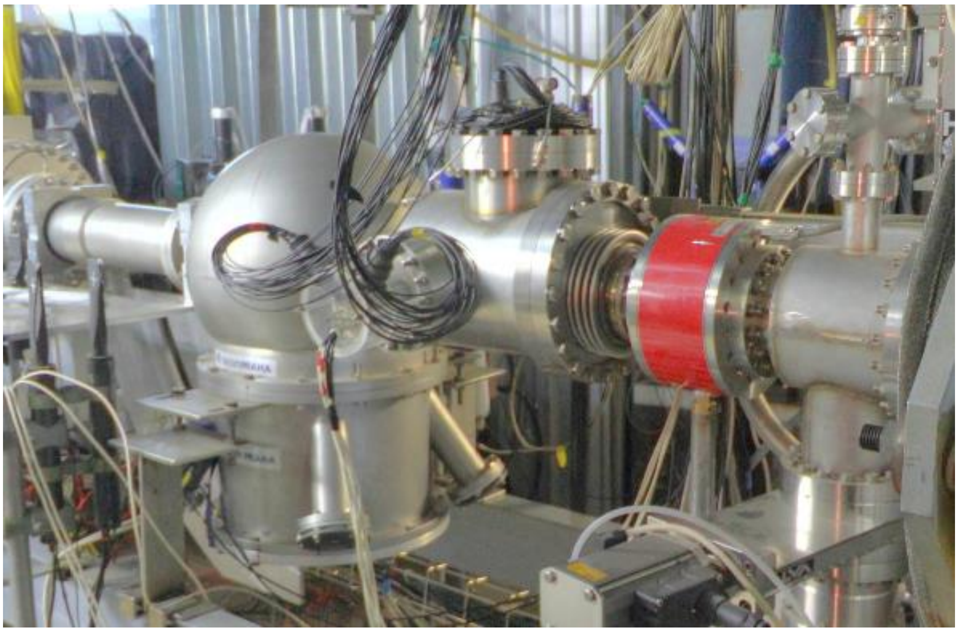

Figure 1. The NPCT sensor embedded on the Nuclotron ring

The transformer produces a voltage signal proportional to the beam current. The frequency response DC of the NPCT is up to 10 kHz.

2. The subsystem hardware structure

Data acquisition is performed by means of multifunctional DAQ device NI6284 of National Instruments [4]. NI6284 is used for high-accuracy input of two signals: the beam current from the NPCT and main magnetic field. The acquisition is performed at the sampling rate up to 50 kHz depending on the measurement time. The DAQ device is connected to PCI bus of the industrial computer (IPC) mounted to the same rack with the NPCT chassis.

The subsystem hardware structure is shown in Fig. 2. As one can see, the Field Signal Former device processes B+ and B- pulse series from B-timer of the Main Magnetic Field Subsystem [5] of the Nuclotron and reconstructs the configuration of the magnetic field signal for NI6284. The data acquisition starts by the trigger signal (also from the Main Magnetic Field Subsystem) which is correlated with the beginning of the main field cycle.

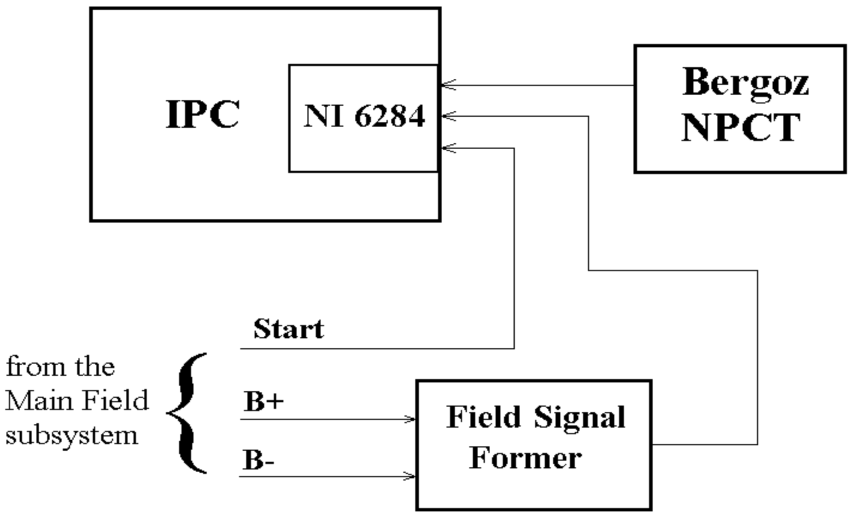

Figure 2. Hardware structure of the subsystem

3. Signal processing

To obtain a value of the beam intensity at the injection level of the magnetic field, it is necessary to multiply the voltage signal U from the NPCT (proportional to the average beam current) by $k=10^{11}$ p/V and divide it by particle charge Z. To get the intensity at another magnetic field I(B), we also need to multiply this value by ratio of particle revolution frequencies at current field F(B) and injection field $F_0 = F(B_{inj})$:

$$I(B) = U * \frac{k}{Z} * \frac{F_0}{F(B)} \qquad (1)$$

To calculate F(B), it is necessary to use the formulae below:

$$W(B) = \sqrt{W_0^2 + \left(300 * \frac{Z}{A} * B * R_0\right)^2} - W_0 \qquad (2)$$

$$F(B) = \sqrt{1 - \left(\frac{W_0}{W_0 + W(B)}\right)^2} * \frac{c}{P} \qquad (3)$$

where W(B) is the particle energy, W_0 - the rest energy, A – the particle mass, P and R_0 – the ring circumference and radius, c – the light velocity.

To reduce the noise component of the NPCT signal, we use such digital filtering techniques as the median filter and central moving average in addition to analog filter in the NPCT input. Also we digitally compensate the NPCT base-line droop and interferences on the Transformer signal.

4. The subsystem software

The subsystem software has been developed in the TANGO Controls [6] standard and fully integrated to the Nuclotron TANGO System [7] which is the base for future NICA Control System.

The Device is the core concept of TANGO. It can represent the equipment (for example, analog I/O board) or a set of instruments, a set of software functions and a group of devices (subsystem). The Device has an interface composed of commands, attributes and properties which provide the service of the instrument. The Device Server provides the process where Device is generated and managed.

The main module of the intensity diagnostics software is the logical device server BERGOZ DS (see Fig. 3) which represents the intensity diagnostics subsystem as a whole. It controls the operation of the low level device server of the NI6284 - DAQmxAI DS. The subsystem device server organizes the working cycle of the subsystem, performs data processing, allows the operator to change its settings and provides access to the data acquired for clients via TANGO interface.

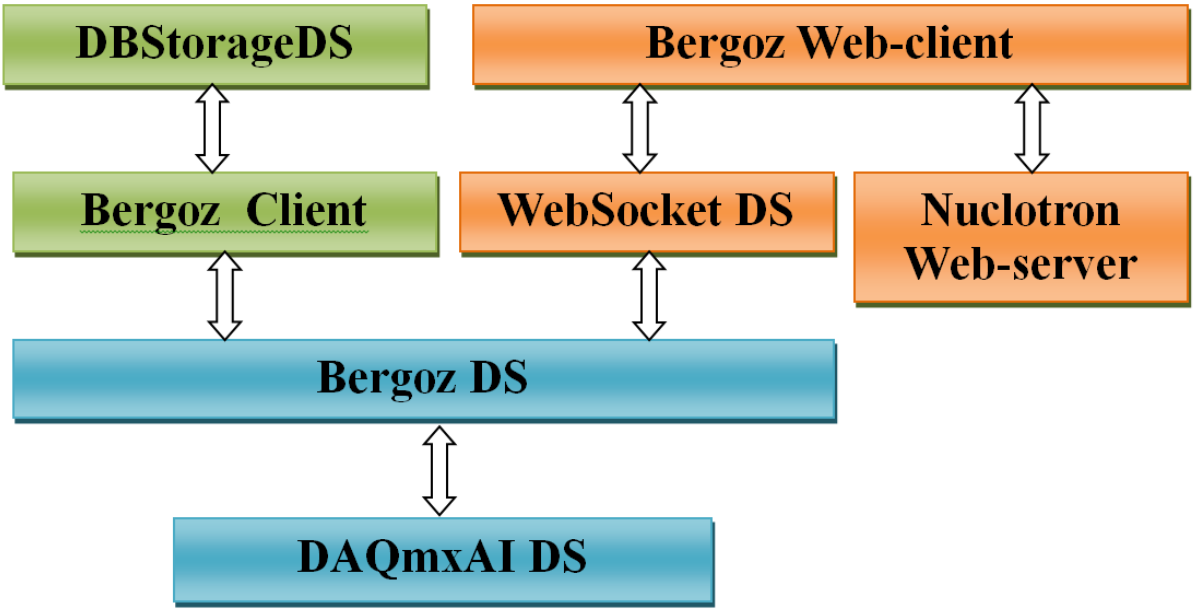

Figure 3. TANGO structure of the Subsystem software

The set of client applications was developed for several groups of the subsystem users:

- accelerator operators and experts;
- other accelerator stuff;
- experimentalists;
- web-users.

The operator client gets and displays three signals from the subsystem device server: voltage from the NPCT (blue), beam intensity (orange) and the main magnetic field (green) (see Fig. 4) at a full sampling resolution (total 200k samples for every signal). It allows the operator to change the subsystem setting such as measurement cycle durations, the type of accelerated particles and the value of the injection field. The client is also enabled to read/write data arrays of these signals and acceleration parameters from/to the subsystem MySQL TANGO database via DBStorageDS device server. The data column format in the base is MEDIUMBLOB because of a large amount of data.

The stuff client gets only two signals: intensity and field in the reduced sampling resolution. It is also granted to work with the subsystem database.

The experimentalist client was designed to support experiments on the Nuclotron internal target. It is an enhanced version of the staff client and allows researchers to determine the number of particles which hit the internal target during one acceleration cycle or a number of cycles. It also performs the text-format cycle-by-cycle logging of the accelerated beam intensity and the amount of particles trapped by the target.

The web-client is convenient for a brief view of the current acceleration cycle via Internet. It displays signals of the intensity and the magnetic field in dependence on time. For this purpose we use WebSocketDS device server. It obtains the necessary data from the subsystem device server, packs them into the JSON object [8] and sends them to all the browsers connected to it via WebSocket protocol [9]. No access to the data base is provided here.

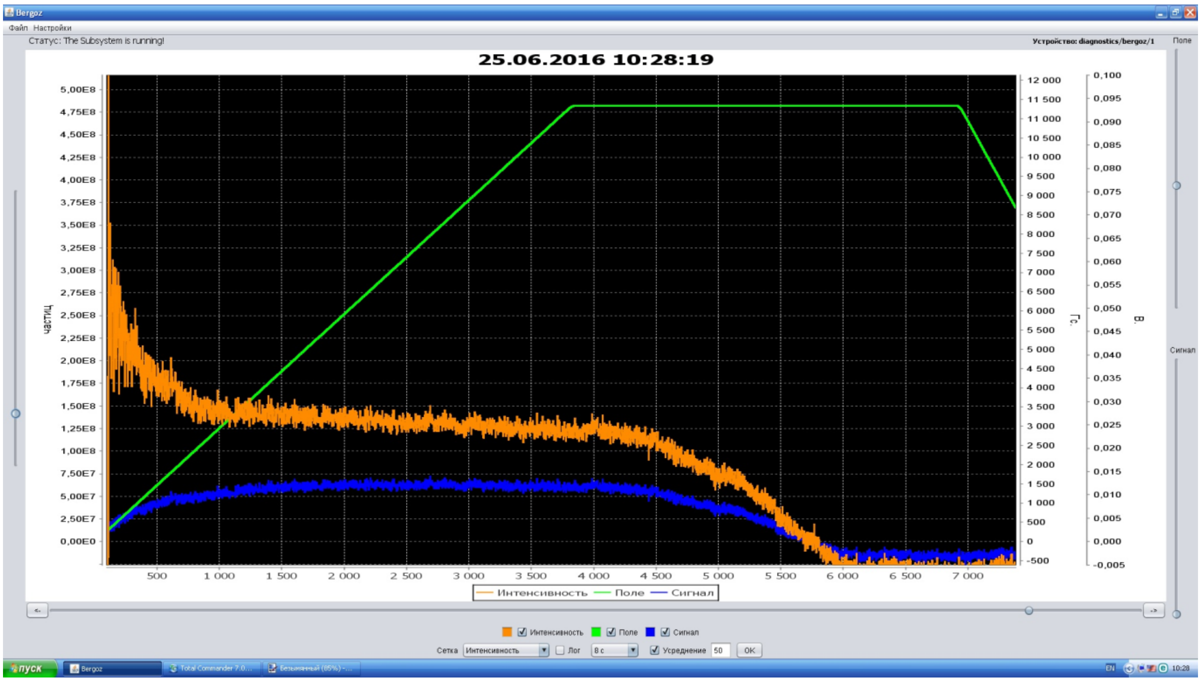

Figure 4. The GUI for the accelerator operators and experts

6. The "oscilloscope" operation mode

When an investigation of a long accelerator cycle (several minutes) is performed, the subsystem works in a specialized, so called "oscilloscope" mode. In this mode the signals are processed and displayed in a series of relatively short (several seconds) chunks throughout the full measurement cycle. In this case we use the DAQmxAISoftRetrig device server specially designed to control DAQ device NI6284. The sampling frequency is 50 Hz in this mode. The measurement duration is up to 1000 s and it can be set by the accelerator operator.

7. Conclusion

The subsystem of the internal beam intensity diagnostics in its current hardware and software configuration has been successfully applied during the latest 3 runs of the Nuclotron. It successfully supported the accelerator operation both with high and low (10^8 particles and less) beam intensity. The high level of the automatization and lots of services make the subsystem a very efficient and convenient instrument for accelerator operators, experimentalists and other users. This subsystem has been fully integrated into the TANGO Controls System of the Nuclotron and can be applied for the future control system of the NICA complex.

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