

STATUS OF THE NUCLOTRON

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Abstract

Since last RuPAC two runs of the Nuclotron operation were performed: in January – March of 2015 and June 2016. Presently we are providing the run, which has been started at the end of October and will be continued up to the end of December. The facility development is aimed to the performance increase for current physical program realization and preparation to the NICA Booster construction and Baryonic Matter at Nuclotron experiment.

INTRODUCTION

The Nuclotron is the basic facility of the Veksler and Baldin laboratory for high energy physics (VBLHEP). Its scientific program includes experimental studies on relativistic nuclear physics, spin physics and physics of flavours. At the same time, the Nuclotron beams are used for research in radiobiology and applied research.

VBLHEP accelerator complex includes Alvarez-type linac LU-20, superconducting synchrotron Nuclotron equipped with an internal target station and slow extraction system and facilities for fixed target experiments located in experimental building of about 10000 m².

In future the Nuclotron will be main synchrotron of the NICA facility being constructed at JINR [1]. Presently the creation of the NICA general elements is realizing in the frame of three officially approved JINR projects: “Nuclotron-NICA” (accelerator part), MPD (the project oriented to creation of one of the collider detectors) and BM@N (Baryonic Matter at Nuclotron – the fixed target experiment with heavy ions, the detector is under construction).

Last two years general attention was paid to development of the injection complex, preparation for the NICA Booster construction and BM@N experiment. The Nuclotron operational time was optimized in accordance with the JINR topical plans with account the plan of the NICA construction. During this period two Nuclotron runs were performed and the spin physics run has been started 26 of October. In this report we are concentrated on the most important results of the machine development works. Results of the injection complex development are presented in dedicated talks [2, 3].

STATISTICS OF OPERATION

During the run #51, performed in the period from 26 January to 15 March 2015, the following machine development works were provided:

- development of Q-meter hardware and software,
- put into test operation of the system for precise current measurement of the Nuclotron magnetic system,
- the works for the current stabilization in magnets of the extracted beam lines,
- put into operation new thermometry system of the Nuclotron,
- methodical investigations of stochastic cooling and different modes of the beam adiabatic capture.

Total duration of the run was about 1150 hours, about 800 hours of the beam time was spent for experimental researches in accordance with JINR topical plan. For the first time all the subsystems of the BM@N detector were tested with the beam. During the run deuteron and carbon ions were accelerating. Maximum deuteron energy was about 5.3 GeV/u (magnetic field at the extraction plateau is 1.855 T).

General task of the technological run #52 was commissioning of new fore-injector, optimization of the source of polarized ions (SPI) and test of polarimetry. The run at total duration of about 650 hours was performed from 2 to 30 of June 2016. Its main result is successive operation of the new fore-injector and acceleration of deuteron beam from SPI at intensity of 10⁹ at the experiment energy. During the run the polarimeters after linear accelerator LU-20, at Nuclotron internal target station and at extracted beam line have been tested. During the machine development shifts the prototypes of the Booster magnetic system power supplies were tested at superconducting load. During a few shifts the beam injection at the field plateau with adiabatic capture into acceleration were used in routine operation. Experimental fragment of White Rabbit Network was tested at BM@N detector systems.

The run #53 was started 26 October 2016 with the scheduled duration of about 1400 hours. Main task of the run is experimental investigations in spin physics in few body nuclear systems (with polarized deuterons). Development of the diagnostics, investigations of dynamic behaviors of the Booster power supply prototypes with the beam acceleration, test of new current source for optic elements in the extracted beam lines,

investigations of stochastic cooling are the main goals of the machine development.

During all the runs the control system based on TANGO framework was in the active development [4]. To implement the Tango control system the following main tasks there were performed:

- 1) The control equipment database was designed and created.
- 2) The web-tool for using and managing of the control equipment database was developed.
- 3) Servers were purchased and configured.
- 4) The necessary toolbox for development, storing, documenting and using of Tango-based software was set up.

All new equipment is design to be compatible with the TANGO system and all old Nuclotron systems step by step are modernized in accordance with TANGO requirements.

MACHINE DEVELOPMENT

New thermometry system was put into operation during the run #51. It consists of 10 measurement loops. 8 of them correspond to structural elements of the Nuclotron octants. One loop required for the standard cell, inflector magnet and electrostatic septum. The last loop – for all inserted elements and nitrogen shield. The system is based on 608 thermo-resistors and 28 precise test resistors and include ten 64- channel switches which output signals are transferred to 24-bits registrators. The system provide additional (non-temperature) information about cryogenic system: pressure at the input and output of both helium tracts, helium level in two liquefiers and nitrogen pressure in the tank. At the Fig. 1 the TANGO web-client window of the thermometry system is presented.

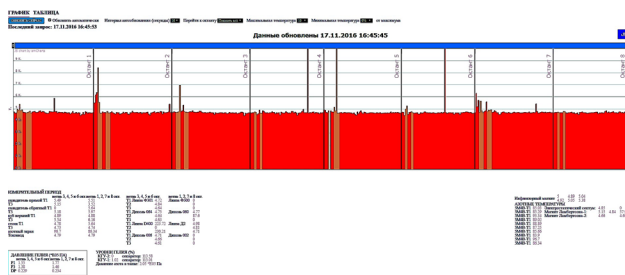


Figure 1: TANGO window of new thermometry system.

During the run #51 the system for precise current measurement in the Nuclotron magnets was put into test operation. The Nuclotron power supply system consists of main source feeding all structural elements connected in series (maximum current is 6 kA), two small units for current variation in focusing and defocusing lenses, three units for slow extraction control. All these sources were equipped with the current transformers ITZ Ultrastab (Fig. 2) with the absolute relative inaccuracy $6.5 \cdot 10^{-5}$. After ADS the signal are used in feed-back system for the current control. The system possibilities can be illustrated by the following example: during slow extraction of the beam for experiment at current at the plateau of 3741.8 A

the ripple amplitude was measured as 0.071 A, that corresponds to the relative instability below $2 \cdot 10^{-5}$.

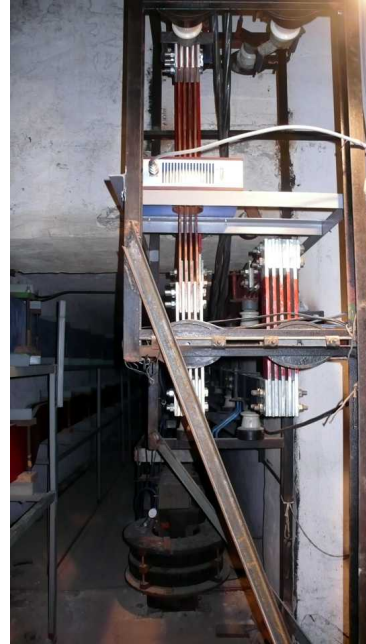


Figure 2: Current transformer ITZ Ultrastab at the current line.

For optimization of longitudinal beam dynamics the equipment for the RF amplitude control (Fig. 3) were developed. To improve the RF system performance a preamplifier based on modern technical solutions was constructed in Budker institute of nuclear physics (BINP, Novosibirsk). During the run #52 it was put into test operation. A few shifts the beam injection at the magnetic field plateau and adiabatic capture into acceleration was used in the routine operation.

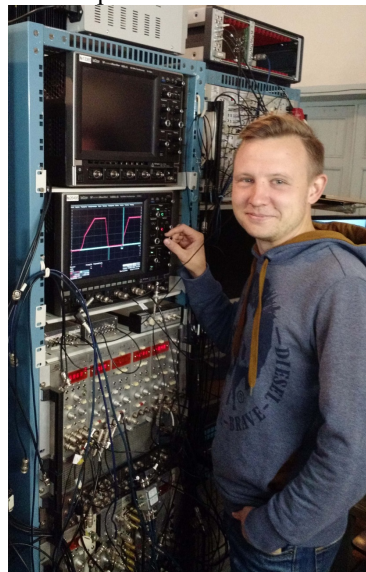


Figure 3: Equipment for the RF amplitude control during adiabatic capture.

NEAREST PLANS

Two Nuclotron runs are scheduled for 2017 before shut down for the Booster assembly and commissioning. First of them in February - March will be performed with laser ion source. It will be dedicated to experiments with light ions (d, Li, C) in accordance with the JINR topical plans. The run at the end of 2017 is aimed to test BM@N detector with heavy ions (Ar, Kr) providing by electron string ion source. The systems of the Nuclotron Booster are under construction in cooperation with BINP and scientific centers from member states of JINR. Serial production of the Booster magnets has been started in 2015. Preparations for the Booster construction and BM@N experiment were actively provided during the Nuclotron runs.

PREPARATIONS FOR THE BOOSTER ASSEMBLY AND BM@N EXPERIMENT

The BM@N detector is located inside the existing experimental building at a distance of 160 m from the exit of slow extraction. The beam line includes 8 dipole and 18 quadrupole magnets. Reconstruction of the line vacuum system is provided to diminish a material budget along the beam transfer line. For stabilisation of the current in the magnet coils new current control units were developed. One of them was tested during the run #51 and permitted to obtain relative instability during long-term operation below 10^{-3} . First prototype of the modern current source produced by LM Invertor company (Moscow) was successfully tested during the run #53.

The NICA synchronization system decided to be based on White Rabbit technology because it is developed by wide international collaboration including CERN and FAIR, based on existing standard, namely Ethernet, Synchronous Ethernet and PTP, open hardware and software and provide sub-nanosecond accuracy. Experimental segment of the White Rabbit network of about 3 km of the length was created at the Nuclotron complex and tested for BM@N sub detector operation during the run #52.

The Booster magnet power supply system will consist of three main units: for all structural elements connected in series (maximum current is 11 kA) and two small units for current variation in focusing and defocusing lenses. Three companies are participating in the tender for the power supply construction: LM Invertor, EVPUas (Slovak Republic) and Frako-Term (Poland). Prototypes of the source were installed at JINR and during the run #52 they were tested at superconducting load. Test of their dynamic properties with the beam acceleration is started in the run #53.

New helium liquefier OG1000 at capacity of 1100 ± 100 l/h constructed especially for the NICA project was commissioned in June 2016 two days before the run #52.

Serial production of the Booster magnet was started in 2015 and now the cryogenic tests and cold magnetic measurements of the dipole magnets are in the active

phase [5]. Example of TANGO based software developed for these works is presented in the Fig. 4.

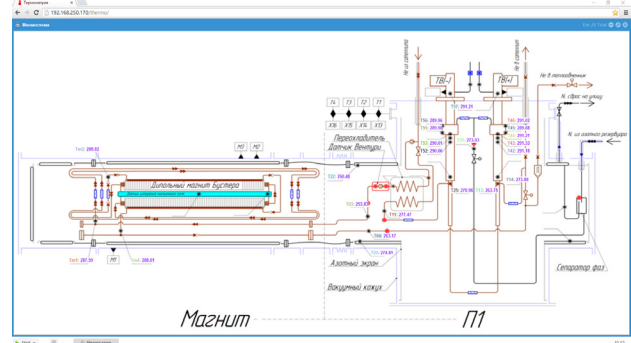


Figure 4: TANGO software for thermometry at the magnet test facility.

The Booster electron cooling system was constructed and successfully tested at BINP in May 2016 [6]. Construction of all other Booster systems is in progress.

CONCLUSION

Main result of the VBLHEP accelerator complex development during last years is commissioning of two new linear accelerators: RFQ fore-injector for LU-20 and HILac. The Nuclotron operational time is optimized in accordance with the JINR topical plans with account the plan of the NICA construction. Main attention during 2016 was paid for spin physics in few body nuclear systems (with polarized deuterons).

The beam time dedicated to the machine development is used for enhancement of the Nuclotron performance for current physics program realization and for tests of the equipment, diagnostics and operational regimes of the new NICA accelerators. Construction of the Booster elements and BM@N detector is in active phase. The Booster assembly is scheduled for 2018.

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