Nuclotron and Its Control System

V.Andreev, V.Gorchenko, A.Kirichenko, A.Kovalenko, I.Kulikov, V.Mikhailov, V.Monchinsky,
S.Romanov, B.Sveshnikov, A.Tsarenkov, B.Vasilishin, M.Voevodin, V.Volkov
Laboratory of High Energies, Joint Institute for Nuclear Research, 141980 Dubna, Russia

Abstract

The status of Nuclotron is presented. The main parameters and the progress of the Nuclotron Control System (NCS) are described.

1 Nuclotron status

The first superconducting synchrotron Nuclotron based on miniature iron-shaped field SC-magnets was put into operation in March 1993 at the Laboratory of High Energies of JINR in Dubna. Eleven runs of the new accelerator have been performed by the present time. The investigation of the accelerator systems operation as well as data taking for physics have been performed. General layout of the LHE accelerator facility is presented in Fig.1.

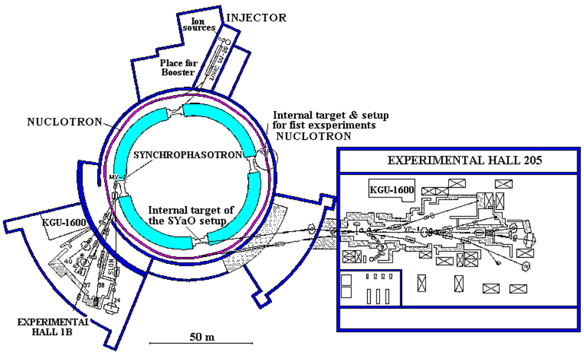

Figure 1: General layout of the accelerator facility.

The Nuclotron [1] is intended to accelerate nuclei and multicharged ions including the heaviest ones (uranium) up to an energy of 6 Gev/u for the charge to mass ratio Z/A = 1/2. There are 96 dipole, 64 quadrupole, 32 correcting multipole SC-magnets in the Nuclotron magnetic ring with a circumference of 251.5 m. The maximum value of the magnetic field is about 2 T.

2 NCS structure

2.1 General

The Nuclotron Control System project, which is in progress, started in 1992 and has provided an efficient support for the machine commissioning through all its phases.

The Nuclotron Control System [2] in its present form, together with the Main Control Room and the local consoles, comprises the following subsystems: cryogenics, thermometry, magnet diagnostics, an injection beam line, beam injection, beam diagnostics on the first turns, magnetic field correction, vacuum, circulating beam diagnostics, radio frequency, main power supplies, and radiation safety. The slow extraction and external beam diagnostics subsystems are still under development.

The basic structure of NCS is shown in Fig.2. The control system architecture is hierarchical in nature and consists of two physical levels, an Operator Control Level and a Front End Level.

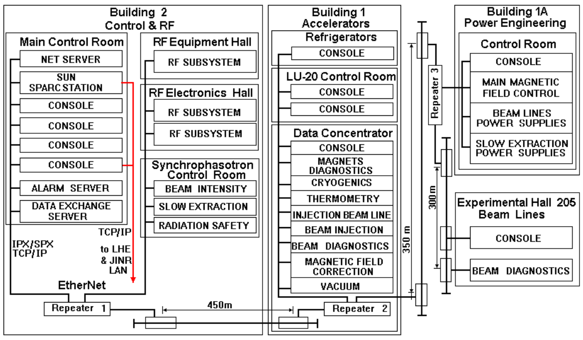

Figure 2: Basic structure of NCS.

2.2 Operator control level

The Operator Control Level supplies all the appropriate man-machine tools for operators to run the accelerator. High performance workstations, together with general-purpose server computers, are used at this top level. The workstations act as operator consoles, while the servers provide the communication process, data storage, printing utilities, a common database, alarm service, a program library, and data exchange between the Nuclotron and the users.

The NCS is a distributed system, its subsytems are geographically separated by as much as 500 m. The common backbone of the system is an Ethernet Local Area Network (LAN). It runs IPX/SPX and TCP/IP communication protocols and connects console computers to the Front End Level and physicists' workstations. As the system has four geographically separated parts, LAN is divided into four independent segments. A SUN Sparc station is used as a LAN bridge to filter communication between the General JINR Ethernet and Nuclotron network.

The system includes both static and dynamic database. The static database contains the information necessary to drive all the devices connected to the control system. The complete information set about the status of the whole machine is available in the dynamic runtime database. It is updated each accelerator cycle. The archive database keeps a long-term history of machine parameters. The status of all the equipment is recorded into log files once every 30 minutes for further analysis. Access to the database information is gained by the consoles independently in order to display relevant parameters about the elements required by the operators. The library of database access routines named the Data Viewer has been developed. These applications allow users to select data sets for visual observation or color graphic printing on remote workstations. Multiple Data Viewers can be activated simultaneously.

The alarm server monitors continuously any changes of the state of predefined equipments and detects fault conditions; anomalies are displayed on an alarm screen and duplicated by multimedia audio devices for the operator to take an appropriate action. Alarm messages are archived for retrieval and off-line inspection.

An information management subsystem was designed and is now under implementation to interchange information between the NCS and the Nuclotron users (Fig.3).

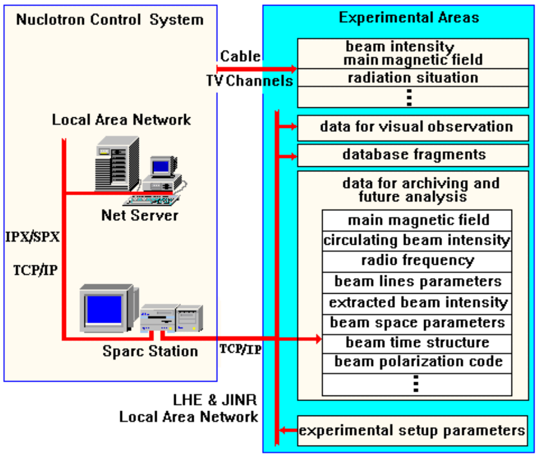

Figure 3: The simplified data exchange diagram.

The element tables in the dynamic database are duplicated at the data exchange server in order to be available to the physicists. This information can be both observed on display screens, and processed and written on disks together with experimental data for future off-line physics analysis. Some data are broadcast via cable TV channels. The same subsystem also sends experimental information, such as background levels and detector counting rates to the NCS. The Nuclotron operators use this information to adjust the machine.

2.3 *Front end level*

The Front End Level deals with real-time controls. At present, the total number of points for measurement and control are about 3000. This number will be increased by about 20% when the beam slow extraction subsystem is completed. The expected average rate of real-time acquisition is 90 kByte/s.

This level comprises both industrial rack-mountable PCs from ADVANTECH, equipped with I/O boards and data acquisition modules, and intelligent CAMAC crate-controllers with embedded micro-PCs. These ones, as a rule, are diskless systems, and they can be installed in harsh environments. The controller developed by our own staff is based on an OCTAGON micro-PC. An onboard Ethernet interface allows software downloading and remote device control. The main part of the existing hardware interface is in the CAMAC standard. All CAMAC modules of the total number up to 600 were developed and manufactured at the LHE, JINR. However, we are planning to implement more extensively acquisi-tion and control boards in the industrial PC standard.

3 Subsystems

3.1 *Cryogenics & thermometry*

The parameters under control are the quality of a two-phase flow (the mass vapour content of helium in the supply headers), the density and flow rate of two-phase cryoproduct flows. The principle of measurement is based on the dependence of the resonance frequency of an oscillating RF-resonator with a high Q-factor on the dielectric permeability of the controlled flow [3]. At the same time, the subsystem provides a helium pressure measurement in direct and back flows, the helium and nitrogen levels and pressure in the separators and storage tanks, as well.

The temperature measurement is one of the central points in the cryogenic subsystem. This makes it possible to monitor and control cool-down and warm-up of the accelerator magnets, to support operational conditions during machine runs, to indicate the deviations of cooling parameters from nominal ones, and to carry out temperature diagnostics of the cryogenic components during accidents (quenches, vacuum breakdowns, etc.). The subsystem provides the temperature measurements of the Nuclotron elements at more than 600 control points. The measurement range is from 4 to 300 K with the resolution of 25 mK at temperatures of ~4 K. Fig.4 illustrates one set of the data presented by the subsystem.

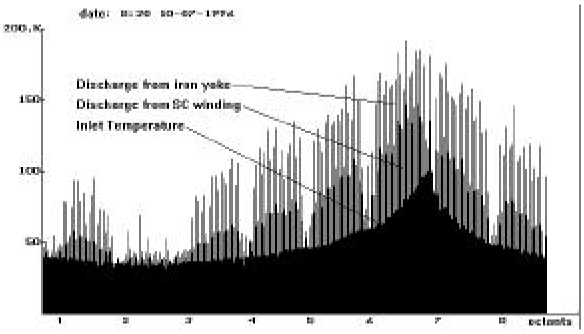

Figure 4: The temperature distribution along the Nuclotron ring in a process of cool-down.

3.2 *Beam injection*

The subsystem has been set up to control and monitor the equipment on a beam transport line, power supplies, a superconducting inflector magnet, inflector plates, beam instrumentation elements in the ring, timing and synchronization.

In order to observe the beam behavior during injection and at the initial stage of beam circulation, various monitoring devices were made for the subsystem. The diagnostics of the beam injection transport line include 2 wire collector profilometers, 1 wire collector beam current monitor, 2 destructive screen monitors, and 2 Faraday cups. The beam profile monitor consists of X- and Y-wire planes. Each plane has 32 golden tungsten wires 0.1 mm in diameter separated by 2 mm. The beam current monitor has one plane with wires connected in parallel. Image processing technique based on fluorescent screens, CCD cameras, and frame-grabbers ensures the following possibilities: fluorescent screen selection and setting inside the beam, video tuning, background subtraction, pseudo-color for displays, the ability to save and restore specific images, snapshot and live mode selection.

The accelerator ring diagnostics are composed of 5 wire collector profilometers, 21 electrostatic beam position monitors (BPMs), 1 electrostatic intensity pick-up, 1 magnetic pick-up, 4 destructive screen monitors, 4 Faraday cups. Two of five profilometers are placed at the entrance and the exit of the inflector magnet. We are planning to measure emittance using the profilometers at the end of the transport line, at the inflector magnet entrance, and in the first straight section of the ring. It will allow us to adjust more exactly injected beam matching to the ring lattice. Using the position and intensity pick-ups with fast (10-50 MHz) buffered ADCs of 8-bit resolutions, beam information for each revolution can be acquired. It is possible to obtain transverse and longitudinal information for 800 first turns in parallel with orbit acquisition. Fig.5 shows incorrected closed R- and Z- orbits measured at the field of injection.

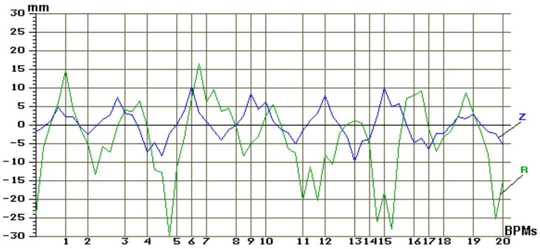

Figure 5: Closed R-and Z- orbits.

3.3 *Main magnetic field control*

The dedicated control subsystem for pulsed power supplies of the magnets was designed, allowing the reproduction of the desired B and Q fields to better than $5 \cdot 10^{-4}$ at injection.

The bending (BM), focusing (QF) and defocusing (QD) magnets are powered by three supplies. The BMs are driven by supply of a 6.3 kA nominal current. The QFs and QDs are connected in series and powered by supply of 6 kA. Besides, an additional supply of 200 A for the QFs is used to keep the required ratio I_{QD}/I_{QF} during the accelerator cycle.

The BM magnetic field shape is set by a pulse function generator which produces a reference burst (Bo-train) with a 0.1 Gs resolution. This train increments a pattern analog function generator based on a 16-bit DAC. A real B-train off the reference bending magnet and the corresponding analog function are used for feedback loop. The current magnetic field of the BMs is used as reference function for the focusing and defocusing magnets, i.e. the BM power supply is a master and the QF and QD supplies are slave ones. The QF and QD trains are utilized for control as described above. Fig.6 shows the magnetic field cycle parameters.

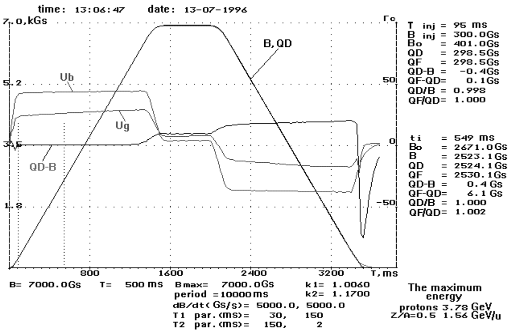

Figure 6: Example of magnetic field cycle parameters.

4 Conclusion

At present, though not at its final dimension, the control system is fully operational and has the proposed functionality. An essential step to provide the accelerator with a high performance and flexible computer control environment has been accomplished. Up to now, 28 computers and 35 CAMAC chassis are installed in the control system.

Acknowledgments

We would like to thank our colleagues who have contributed to the NCS project. The authors are grateful to L.Sveshnikova for her help in preparing this paper.

References

[1] A.D.Kovalenko, "Status of the Nuclotron", Proc. of the Fourth European Particle Accelerator Conference (EPAC 94).

[2] V.Andreev et al. "Nuclotron Control System", Proc. of the 1997 Particle Accelerator Conference (PAC 97)

[3] A.I.Alexeev et al, "Application of Radio Frequency Method to Measurements in Cryogenics", Cryogenics, 1991, Vol.31, pp.1020-1029.