NUCLOTRON MAIN MAGNET POWER SUPPLY CONTROL SYSTEM

V. Gorchenko, A. Kirichenko, A. Kovalenko, I. Kulikov, B. Omelchenko, V. Karpinsky,
S. Romanov, B. Sveshnikov, A. Tsarenkov, B. Vasilishin, V. Volkov, JINR, Dubna, Russia

Abstract

The superconducting synchrotron Nuclotron [1] based on miniature iron-shaped field SC-magnets was put into operation in March 1993 at the Laboratory of High Energies, JINR in Dubna. Thirteen runs of the new accelerator have been performed by the present time. The Nuclotron Control System (NCS), which is in progress [2], has provided efficient support for a successful operation of the machine during all runs. The dedicated control subsystem for the main magnet pulsed power supplies (MPSC) is described.

1 INTRODUCTION

The Nuclotron 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 251.1m. The maximum value of the magnetic field is about 2T. The bending (BM), focusing (QF) and defocusing (QD) magnets are powered by three supplies. The BMs are driven by the supply of a 6.3kA nominal current. The QFs and QDs are connected in series and excited by the supply of 6kA. Besides, an additional supply of 200A for the QFs is used to keep the required ratio Iqf/Iqd during an accelerator cycle.

The NCS is hierarchical in nature and consists of two physical levels: an Operator Control Level and a Front End Level. The first one supplies all appropriate man-machine tools for operators to run the accelerator. High performance workstations and server computers are used at this level. The workstations act as operator consoles, while the servers provide a communication process, data storage, printing utilities, a common database, alarm service, a program library, and data exchange between the Nuclotron and the users. The Front End Level deals with real-time control. This level comprises both industrial PCs and intelligent CAMAC crate-controllers with embedded micro-PCs.

The NCS is a distributed system; its subsystems are geographically separated by as much as 500m. The common backbone of the system is an Ethernet Local Area Network. Up to now, 30 computers are installed in the NCS. The power supply control system integrated into the NCS (Fig. 1), has successfully operated since the beginning of the Nuclotron commissioning.

2 MPSC FUNCTIONALITY

2.1 General

The main distinguishing features of the MPSC include:

- Downloading, interpreting and calculation of complex ramp forms, including a parabolic waveform approximation.
- Digital input and output for power supplies status setting and reading, analog input and output for power supplies control and monitoring.
- Trigger lines for synchronization of the accelerator subsystems with a magnetic cycle.
- Presentation of data in graphical and text formats; transmission of the complete information set of the MPSC status to the database and alarm servers.

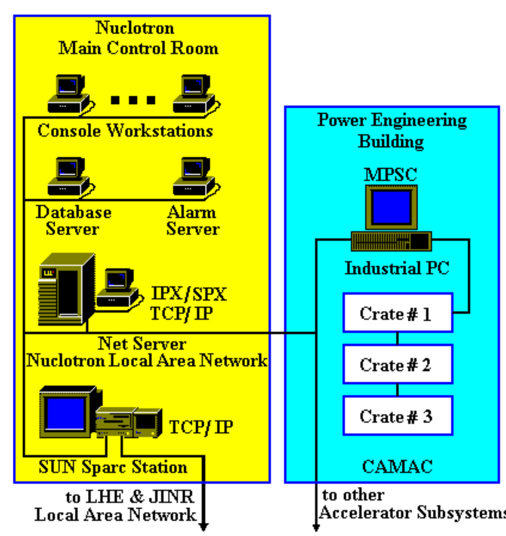

Figure 1: Fragment of the NCS structure.

To provide such functionality, an extensive collection of hardware and software components has been developed for the MPSC.

The magnet cycle is specified at the B(t) level, and the waveforms which drive the power supplies are generated by function generators controlled through console software. The BM magnetic field shape at the initial stage is set by the pulse function generator (PFG) which produces a reference burst (B_o-train) with a 0.1Gs resolution (Fig. 2). This train increments the pattern analog function generator based on a 16 bit DAC. The real B-train off the reference bending magnet and the corresponding analog function are used for the feedback loop. The BM current magnetic field is used as a reference 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. At present, the machine cycle has the following typical parameters: the ramp rate is as a rule 7kGs/s; the cycle repeats at a 0.1…0.2Hz band; the flattop duration ranges in value from hundreds of milliseconds to 10 seconds. Acceptable performance of the machine is substantially dependent on the stability of the magnetic field at the instant of injection. When the field reaches this critical point (294Gs) about 90ms after ramping is started, the transients in the power supplies are completely damped. The parabolic form of some ramp segments (initial parts of the cycle and flattops, etc.) significantly improves a transient response of the power supplies and quench protection electronics.

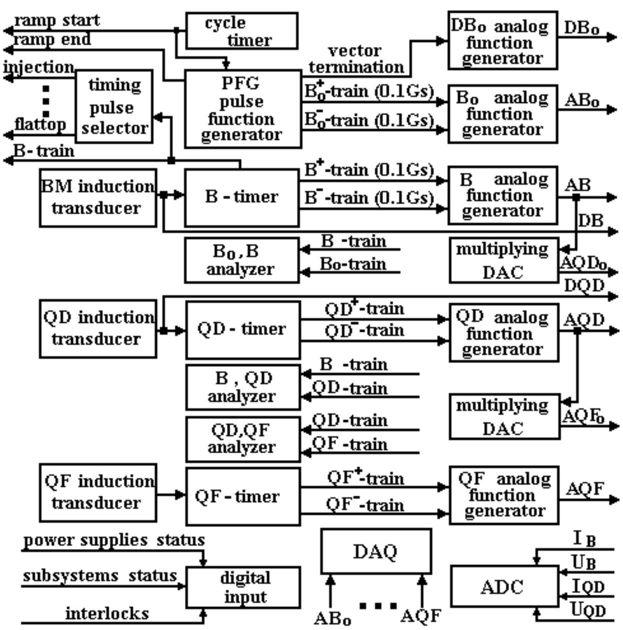

Figure 2: Schematic diagram of the MPSC.

The MPSC is based on the industrial rack-mountable PC from ADVANTECH equipped with I/O and communication boards. To prevent the deterioration of control and measurement signal quality with long cable routs, the system is located in the vicinity of the power supplies. The main part of the hardware interface is in the CAMAC standard. There are three crates to connect the power supplies and external systems to the computer. All modules of the total number up to 50 were developed and manufactured to implement the MPSC at the LHE, JINR. The principal cluster of the modules maintains function generation, digital and analog control and measurement, timing. Auxiliary modules include transmitters and receivers, logic-level converters, signal conditioners. The control system is required to provide a high degree of stability in a harsh power engineering environment. That is why such noise reduction technique as signal isolation and filtering, the elimination of the possibility of ground loops, differential signals, shielded twisted pairs is widely used.

2.2 Function Generators

The base clock of the PFG is a 1MHz signal generated by the master oscillator of the MPSC. This ensures that the B_o-train does not vary by ±0.01Gs and is locked to the master oscillator.

The pulse function is approximated by vectors; up to 4096 vectors per function can be used. Their number is only limited by an internal memory size. Each vector is approximated by a staircase function (train of pulses) with a step size from 1μs up to 2^{24}μs. The number of pulses in one vector can be selected from 1 up to 2^{24}. Thus, each vector is determined by two 24 bit integers: N = number of steps (pulses) and S = step size. S is a multiple of the basis step size, therefore the duration of a vector equals $(N\times S)$μs. The functions are programmed as a sequence of pairs of numbers defining successive vectors to be produced. The external trigger pulse (ramp start) causes the restoration of the initial state of the PFG and starts function generation. To maintain a more stable operation of the power supplies, this trigger pulse is synchronized with the zero-crossing of the U phase of the 50Hz power line. The function proceeds until the last defined vector has been produced. The PFG has separate outputs for rising part of the function (B_o^+) , falling part (B_o^-), and sum burst ($B_o^+ + B_o^-$).

As mentioned above, the B_o-train, as well as the B-train, are then converted into 16 bit analog representations (AB_o, AB) to control the BM power supply. Vector termination pulses are used to drive the 16 bit analog function generator of the magnetic field derivative DB_o. This function, in combination with the real field derivatives DB and DQD, is used to improve the dynamic performance of the power supplies.

The AQD and AQF functions are also generated by the 16 bit precision DACs. The AQDo and AQFo are derived from the B and QD analog function generators and scaled by the multiplying DACs to provide the required transverse tunes during the ramp cycle. The final adjustment of the ramp waveforms is a beam-based procedure.

2.3 Monitoring

An extensive measurement of all waveforms is performed. The digital functions (B_o, B, QF, QD) are monitored using pulse train analyzers which sample the functions at 256 points during an active part of every machine cycle. The analyzer comprises a 16 bit counter, digital processing circuits and an onboard memory for data storage. A 16 bit data acquisition card (DAQ) makes possible measuring the analog functions (ABo…AQF) every millisecond. Each newly acquired function is automatically compared with the corresponding reference at a predetermined number of points. The difference between the signals for the corresponding points is calculated and presented to the operator for analysis. Complementary diagnostic means are achieved by a direct measurement of power supply output currents and voltages. These signals are digitized by a high performance multichannel ADC with an onboard memory.

Digital input boards are applied to read the status of the power supplies, accompanying subsystems, and interlocks. The operation of the interlock devices is completely independent of the control system to ensure automatic machine equipment protection in emergency situations.

2.4 Timing

Timing modules provide trigger pulses both for MPSC internal needs and for synchronizing the accelerator subsystems and experimental setups with particular machine events such as the beginning of a magnetic cycle, the instant of injection, flattop start and so on. The trigger pulses are derived from three types of modules: cycle timer, B-timer, and trigger pulse selector.

The 2-channel cycle timer is locked to the MPSC master oscillator. It provides magnetic cycle zero time references and bursts to drive the measurement devices. The clock period can vary over a wide range from 1μs to hundreds of seconds.

The multichannel trigger pulse selector based on a 18 bit counter uses the B-train as its internal clock. Each channel is processed by digital circuits to generate the timing references corresponding to preloaded values of B.

2.5 Software

The high level control algorithm enables the machine operators to adjust all necessary parameters of the magnetic field within a few cycles. The complete set of functions and parameters is specified through the console menu which defines the path from the initial to the final state along which ramping will be performed. This set includes, for instance, parameters of parabolic segments and linear fractions at various parts of the magnetic cycle, a maximum value of the field, the number of flattops and their duration, flattop locations with the reference to the magnetic field values, accelerator cycle duration, description of the trigger pulses. Software provides a reliable way of storing and retrieving settings, recording with a time-stamp all adjustments made, as well as providing a means of stepping back through these changes. The status of the MPSC is available in the dynamic runtime database. It is updated each accelerator cycle. The archive database keeps a long - term history of the system. The database access routines named the Data Viewer allow the users to select data sets for visual observation or printing on the remote workstations (Fig. 3). The alarm server monitors continuously any changes of the MPSC state and detects fault conditions.

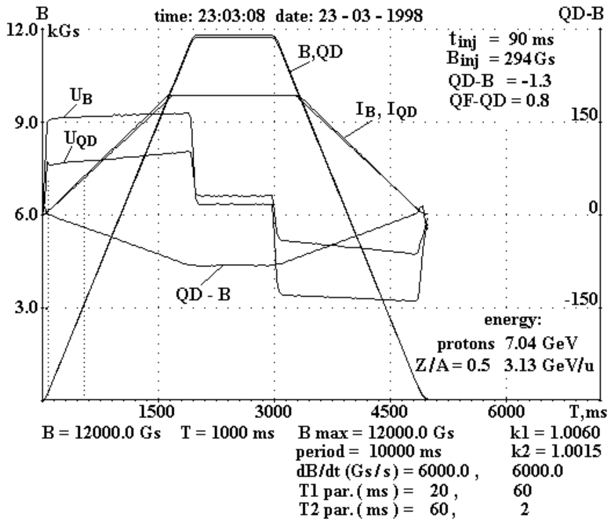

Figure 3: Example of magnetic field cycle parameters.

3 CONCLUSION

The achieved power supplies and control system performance ensures the reproduction of the desired B and Q fields to better than $5 \cdot 10^{-4}$ at the injection point. Long - term stability has been tested intensively. The system operation shows that this characteristic is good within the specification.

Some modifications will be undertaken to improve and to extend the MPSC functionality for slow extraction system operation maintenance. One of them is to replace the 16 bit DACs with the 18 bit devices.

The MPSC has been successfully used in all Nuclotron runs being fully capable of generating precision ramps ranging from a fraction of kGs/s up to 10kGs/s. At present, thanks to the system potentialities, energy ramping has become a routine procedure.

4 ACKNOWLEDGEMENTS

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[1] A. D. Kovalenko, “Status of the Nuclotron”, EPAC’94, London, June 1994.

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