NEW CONTROL SYSTEM FOR NUCLOTRON MAIN POWER SUPPLIES

V. Volkov, V. Andreev, E. Frolov, V. Gorchenko, V. Karpinsky, A. Kirichenko, A. Kovalenko, S. Romanov, A. Tsarenkov, B. Vasilishin, JINR, Dubna, Russia
D. Krusinsky, L. Ondris, IMS SAS, Bratislava, Slovakia

Abstract

The superconducting synchrotron Nuclotron was put into operation in March 1993. The Control System for the Main Magnet Power Supplies (MPSC) [1] has been operating successfully since the beginning of the first Nuclotron runs. The first experiments with the Nuclotron Beam Slow Extraction System (BES) [2] were carried out in 1999. The MPSC was upgraded at the same time for precise tuning the betatron oscillation frequency at the flattop for the slow extraction process. A new control and monitoring system for the Nuclotron main power supplies was designed in 2005 in order to substantially extend functionality of the existing equipment and software.

INTRODUCTION

There are 96 dipole, 64 quadrupole, 32 correcting multipole SC magnets in the Nuclotron ring. The maximum value of the magnetic field is about 2 T. The banding (BM), focusing (QF) and defocusing (QD) magnets are powered by three supplies. The BMs are driven by the supply of nominal current 6.3 kA. The QFs and QDs are connected in series and are excited by the supply of 6 kA. An additional supply of 200 A for the QFs is used to keep the required ratio I_{QF}/I_{QD} during the accelerator cycle. At present the machine cycle has the following typical parameters: the ramp rate is as a rule 7 kGs/s; the cycle repeats within the 0.2...0.05 Hz band; the flattop duration ranges from hundreds of milliseconds to 16 seconds.

The MPSC is part of the Nuclotron Control System. The control Front End industrial PC equipped with analog and digital I/O boards is connected into the Nuclotron Local Area Network.

MPSC FUNCTIONALITY

Operational Features

The main distinctive characteristics of the MPSC (Fig. 1) embrace:

- Downloading, interpretation and calculation of complex ramp profiles in accordance with the parameters specified by the machine operator, including parabolic waveform approximation.
- Highly accurate reproduction of the corresponding prototype digital functions.
- Generation of the precision analog functions for the Nuclotron main power supplies control.
- Employment of correction and calibration methods to reduce residual errors in the analog control electronics. Extensive monitoring of waveforms.
- The digital input and output for the power supplies status setting and reading. Generation of timing pulses for synchronization of the accelerator subsystems with a magnetic cycle.
- Data presentation in the text and graphical formats; transmission of the complete data set on the MPSC status to the database and alarm servers.

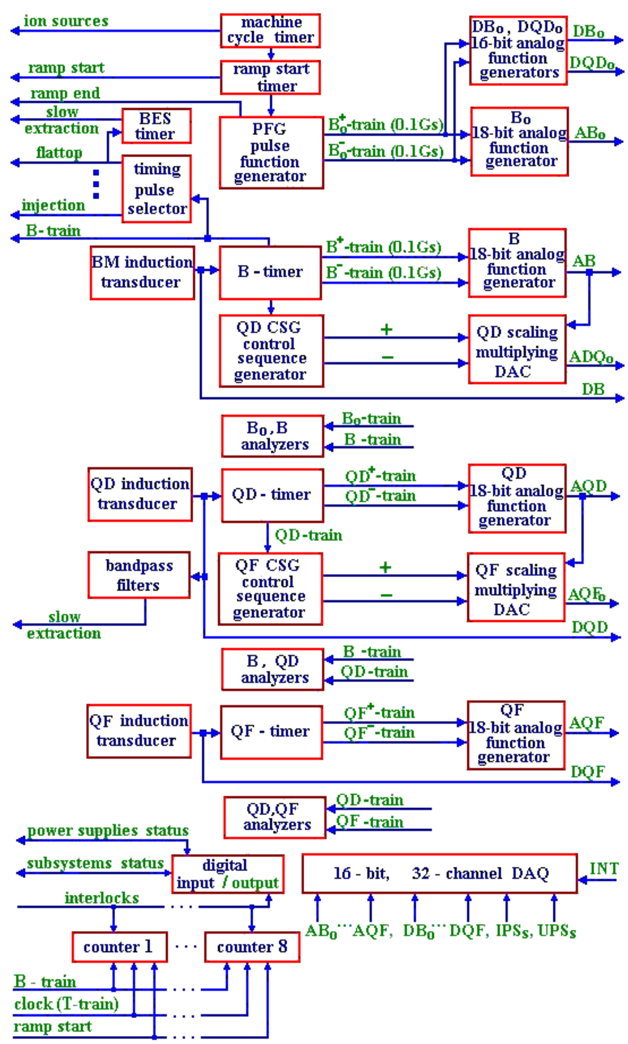

Figure 1: Schematic diagram of the MPSC.

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. Originally, the BM ramp profile is set in the form of a digital image with the pulse function generator (PFG).

The PFG produces reference bursts (B_o–train) with a 0.1 Gs resolution. This train increments and decrements the pattern analog function generator based on the 18–bit DAC. The BM induction transducer produces an analog signal proportional to the derivative (DB) of the real magnetic field. This signal enters a B–timer which generates a B–train with a 0.1 Gs resolution. The B–train from the reference bending magnet (digital function) and the corresponding analog function are used for the feedback loop. The scaled value of the BM current magnetic field is used as a reference for the defocusing magnets. The QD current field is used as a reference for the focusing magnets in exactly the same way. The parabolic form of some ramp segments (initial parts of the cycle and flattops, etc.) essentially improves the transient response of the power supplies and the quench protection electronics.

To prevent deterioration of control and measurement signal quality with long cable routes, the system is located in the vicinity of the power supplies. Noise reduction technique such as signal isolation and filtering, elimination of the possibility of ground loops, differential signals, shielded twisted pairs are widely used.

Control Hardware Components

The base clock frequency of the PFG (Fig. 1) is 2.5 MHz. It generates 3 reference bursts: a B^{+}_{o}–train for rising parts of the magnetic field, a B^{-}_{o}–train for falling parts of the magnetic field, and a B_o–train ($B^{+}_{o} + B^{-}_{o}$).

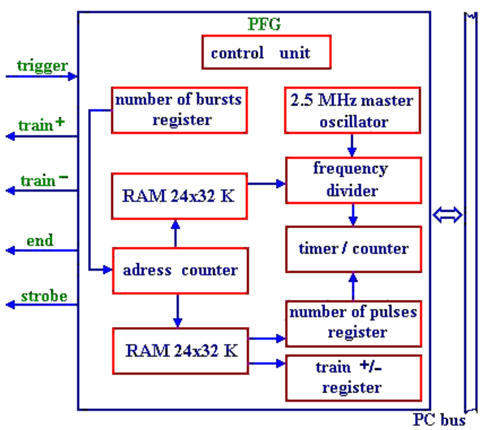

Figure 2: Block diagram of the PFG.

Each train consists of pulse sequences (vectors); up to 32K vectors can be used per digital function. The vector is approximated by a linear staircase function with a step size from 0.4 µs to $0.4{\times}2^{24}$ µs, the number of steps can be selected from 1 to 2^{23}. Thus the sequence is specified by two integers: step size and a number of steps (with the identifier of $train^{+}$ or $train^{-}$). The functions are programmed as a sequence of pairs of numbers defining the successive vectors to be produced. One vector defines part of the magnetic cycle with the constant time derivative. The parabolic form of some ramp segments is approximated by a set of linear parts. The ramp start trigger pulse causes restoration of the initial state of the PFG and starts function generation. The function proceeds until the last defined vector is produced.

As mentioned above, the B_o–train as well as the B–train is converted into the 18–bit analog representation (AB_o, AB) to control the BM power supply. The B_o–train is used to drive the 16–bit analog function generators of the magnetic field time derivatives DB_o, and DQD_o too. These functions in combination with the real field time derivatives DB and DQD are used to improve the dynamic performance of the power supplies.

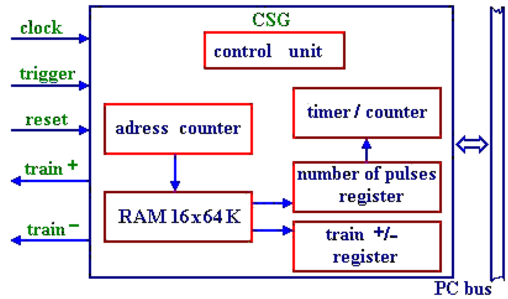

Figure 3: Block diagram of the CSG.

The AQD and AQF functions are also generated by the 18–bit precision DACs. The AQD_o and AQF_o are derived from the B and QD analog function generators respectively and are scaled by the multiplying DACs to provide the required transverse tunes during the ramp cycle. The multiplying DACs are driven by control sequence generators (CSG, Fig. 3). The CSG generates control pulse sequences that increase (+) or decrease (-) the scale factor of the DAC. The maximal number of sequences is 64K. The trigger pulses locked to the current magnetic field define the periodicity of the control sequences. The minimal sampling interval is 0.5 Gs.

All DAC units of the analog function generators and of the scaling modules are optically isolated from the ground and digital circuits. In addition, the DACs have the property of self–calibration. These factors in combination with the effective algorithms of B(QD, QF)–timer drift correction make it possible to generate machine cycles with high stability and reproducibility of the magnetic field and to increase the flattop duration for the beam extraction process up to several minutes.

Monitoring

Extensive measurement of all waveforms is performed. Digital functions (B_o, B, QF, QD) are monitored by using pulse train analyzers which sample the functions every millisecond during the active part of the machine cycle (maximal number of samples is 64K). The analyzer comprises a 16–bit counter, digital processing circuits and an onboard memory for data storage. Each newly acquired function is automatically compared with the corresponding reference. The difference between the signals is calculated and presented to the operator for analysis. A 16–bit, 32–channel data acquisition module (DAQ) provides measurement of the analog functions (AB_o…AQF, DB_o… DQF) at the sampling rate of 1 kHz. The enumerated data presented together with the superimposed circulating beam intensity signal (INT) are expected to be a useful source of information for operators to tune machine parameters. A complementary diagnostics means is direct measurement of power supply output currents (IPSs) and voltages (UPSs).

The DAQ module can be switched into the burst mode to record ripple and other higher–frequency components at a rate up to 10 kHz. This gives a good time resolution to study the ripple at the 600 Hz fundamental frequency of the 12–phase power supplies. The main origin of extracted beam spill fluctuation is variation of the horizontal tune due to the ripple current of the lattice quadrupole magnets. Feeding the ripple signal to the extraction quadrupole lenses in addition to the feedback signal decreases the tune variation [3]. The ripple signal from the reference quadrupole magnet is passed through bandpass filters, phasers, scalers and then fed to the spill control subsystem.

Digital input/output boards are applied to read/control status of the power supplies, accompanying subsystems and interlocks. The interlock operation time points locked to the current magnetic field and to the MPSC master oscillator are recorded with the pulse counters.

Timing

Timing modules provide the trigger pulses both for the internal needs of the MPSC and for synchronization of the accelerator subsystems and experimental setups with the particular machine events such as the beginning of the magnetic cycle, the instant of injection, the flattop start, etc. The trigger pulses are derived from three types of modules: timers locked to the MPSC master oscillator, a B–timer, a trigger pulse selector.

The machine cycle timer provides the advance start pulse for ion sources and at the same time this pulse triggers the ramp start timer. In addition, it generates bursts to drive control and measurement devices. The clock period can vary over a wide range from 1μs to hundreds of seconds. To maintain more stable operation of the power supplies, the cycle timer is synchronized with the zero–crossing of the U phase of the 50 Hz power line. The BES timer makes it possible to combine slow extraction with operation of the internal target at one flattop.

The multichannel trigger pulse selector based on the 18–bit counter uses the B–train as its internal clock. Each channel generates a timing reference corresponding to the defined value of the current magnetic field.

Software

The 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. This set includes for instance parameters of parabolic segments and linear fractions at various parts of the magnetic cycle, the maximum value of the field, the number of flattops and their duration, the accelerator cycle duration and so on. Software provides the storing and retrieving settings, automatic recording with a time stamp all adjustments made, as well as means of stepping back through these changes. Only one machine operator is granted control capabilities at any given time, other users may work in the monitoring mode. 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 alarm server monitors continuously any changes of the MPSC state and detects fault conditions.

CONCLUSION

Now the MPSC is under adjustment and testing. Investigation of the system shows that its performance is well within the specification. Operational conveniences of the MPSC allow an operator to rapidly respond to the experimentalist's requirements for the Nuclotron cycle. Some comparison data of the present and new control systems are presented in Table 1.

Table 1: MPSCs Comparison List

Performance	**Present**	**New**
Pulse function generator:		
– master oscillator frequency	1 MHz	2.5 MHz
– number of vectors	4K	32K
Control sequence generator:		
– minimal sampling step	10 Gs	0.5 Gs
Analog function generator:		
– resolution	16 bit	18 bit
– optical isolation	No	Yes
– self–calibration	No	Yes
B (QD, QF)–timer:		
– drift correction	No	Yes
Pulse train analyzer:		
– number of sampling points	0.4K	64K

The authors would like to thank their colleagues for participation in the MPSC development. The authors are grateful to L. Sveshnikova for her help in preparing this paper.

REFERENCES

[1] V. Gorchenko et al, "Nuclotron Main Magnet Power Supply Control System", EPAC'98, Stockholm, June 1998.

[2] N. Agapov et al, "Slow Beam Extraction from the Nuclotron", PAC'2001, Chicago, June 2001.

[3] V. Volkov et al, "Nuclotron Extracted Beam Spill Control", EPAC'04, Lucerne, July 2004.