NUCLOTRON BEAM EXTRACTION CONTROL

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Abstract

The superconducting synchrotron Nuclotron was put into operation in March 1993. Seventeen runs of the accelerator have been performed by the present time. The first experiments with the Nuclotron Beam Slow Extraction System (BES) were carried out in December 1999 and in March 2000. The Nuclotron Control System (NCS)[1] provided an efficient support for the machine operation during all runs. Design and pilot configurations of the control subsystem for the BES are described.

1 INTRODUCTION

The NCS consists of two physical levels: an Operator Control Level and a Front End Level. The former 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 comprises both industrial personal computers (IPC) and intelligent CAMAC crate-controllers with embedded micro-PCs. The NCS is a distributed system. Its subsystems are 500 m far from one another. The backbone of the system is the Ethernet Local Area Network.

The Beam Slow Extraction System[2] is intended to eject ion beams over the range of energies from 200 MeV/u up to about 6 GeV/u. The main purposes of the dedicated control system are: a) support of the BES commissioning; b) experimental study of the extraction processes, attainment of the extracted beam design parameters; c) maintenance of the BES operation during physics experiments.

The pilot version of the BES control system integrated into the NCS has been operating successfully since the beginning of the first experiments on beam extraction.

2 BES STRUCTURE AND OPERATION

The extraction process is realized by excitation of the third-order radial betatron oscillation resonance Qx = 20/3. The 20th harmonic of sextupole nonlinearity is excited by two pairs of extraction sextupole lenses (ES1...ES4). Four extraction quadrupole lenses (EQ1...EQ4) perform the coherent tune shift ΔQx within the resonance band. The beam is extracted by means of the electrostatic septum (ESS) and the two-section Lambertson magnet (LM) placed in the long drift spaces of the fifth superperiod. The LM is connected in series with the lattice bending magnets (BM). Besides, an additional power supply for the LM will be used for beam angle correction in the vertical plane. A new extraction beam line which is under construction and adjustment integrates the BES with the LHE experimental halls.

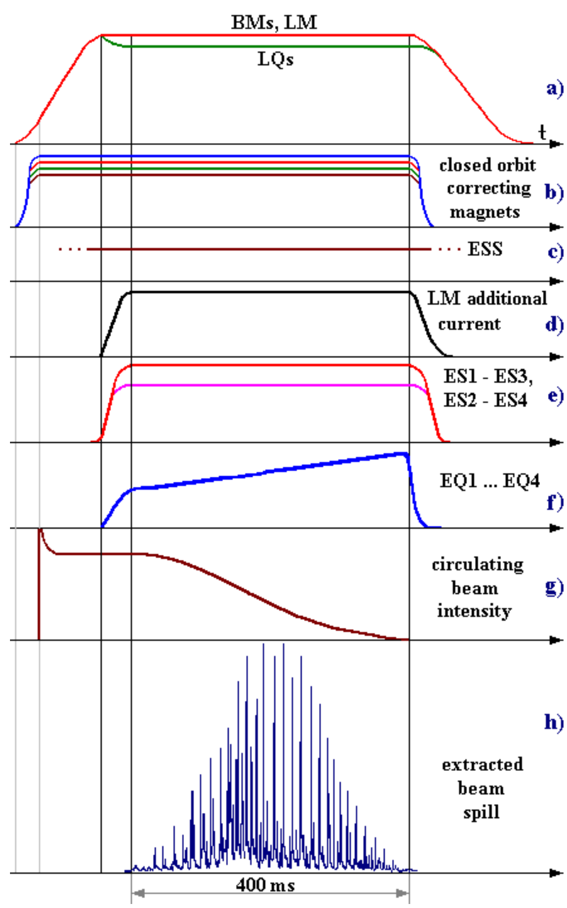

Figure 1: Timing diagram of extraction processes.

During the last two runs slow extraction was carried out according to the timing chart shown in Fig. 1. The machine cycle (Fig. 1a) has the following typical parameters: the ramp rate is as a rule 7 kGs/s; the cycle repeats within the 0.1...0.2 Hz band; the flattop duration ranges from hundreds of milliseconds to 10 seconds[3]. Just after the beginning of the magnetic field cycle the horizontal closed orbit bump is created in the 5th straight section to shift the circulating beam to the inner wall of the vacuum chamber. This allows one to avoid beam losses on the septa of the ESS and LM during the injection and the first turns. After the flattop energy is reached, the radio frequency is switched off and the horizontal beam tune is shifted from the operating value Qx = 6.73 to the resonance band edge by decreasing the field gradient of the lattice quadrupole magnets (LQ) within 100 ms. The magnetic fields of the ESs and EQs are increased to the set values at this time. During extraction the EQ current is linearly varied with a rise time of 400 ms. The beam spill duration has approximately the same value. In further machine runs EQs will be excited according to the feedback signal. The spill (Fig. 1h) has modulation components in the 50...600 Hz subharmonic ripple range mainly due to the LQ power supply and to the EQ and ES supplies that are utilized during the extraction process. The stability requirement at the flattop for the power supplies is very stringent. The spill control loop will not be able to correct critically fluctuation effects. Efforts will be made to reduce ripples by improving individual power supplies.

3 CONTROL SYSTEM FUNCTIONALITY

The planned structural model of the system is outlined in Fig. 2. Some of the BES control and measurement tasks are performed with the aid of computers shared by other subsystems. This concerns beam diagnostics, the main magnet power supply control system, and the magnetic field correction system.

3.1 Power Supplies

The main power supply control subsystem was upgraded in 1999 for precise tuning the betatron oscillation frequency at the flattop for the slow extraction process. Two separated rectifiers of nominal current 6 kA are used for the BMs and LQs. An additional supply of 200 A for the focusing LQs is used to keep the set tunes during an accelerator cycle. The magnet cycle is specified at the B(t) level, and the waveforms which drive the main power supplies are generated by the function generators with a resolution of 0.2 Gs controlled through the console software. The time-varying magnetic field of the BM is used as a reference for the LQs, i.e. the BM power supply is a master and the LQ supply is a slave. The LQ reference signal is scaled by the multiplying DAC to provide the required transverse tunes.

The EQ and ES power supplies are controlled by the beam spill control section of the BES.

Four correcting dipole magnets are used to create the closed orbit bump during the injection period. The corresponding power supplies of nominal current 10 A are independently controlled by the Nuclotron magnetic field correction subsystem computer.

Extensive measurement of all current waveforms is performed. The data acquisition cards with a resolution of 16 bit make it possible to measure analog functions every millisecond. Each newly acquired function is compared with the corresponding reference at a predetermined number of points. The difference between the signals is calculated and presented to the operators for analysis. Digital input-output boards are used to read and set the status of the power supplies. The software enables the machine operators to adjust all necessary parameters of the power supplies within a few cycles.

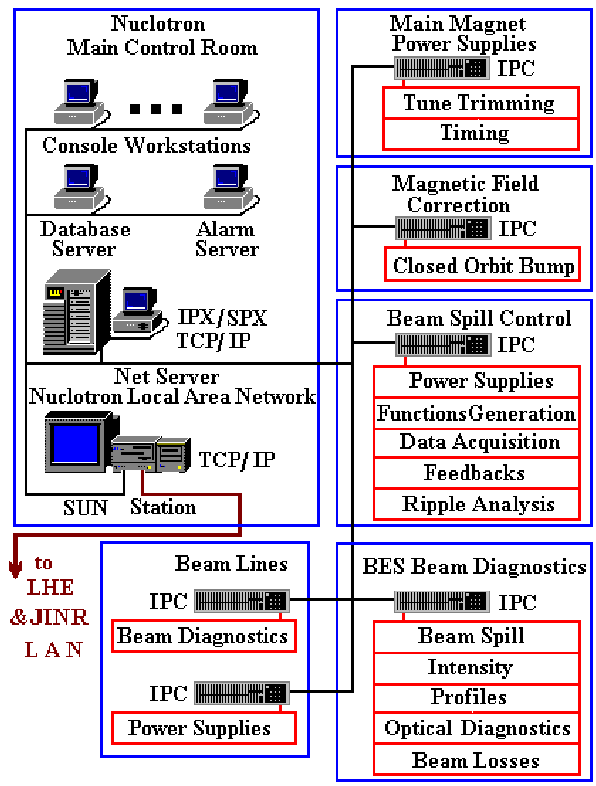

Figure 2: BES Control System structure.

3.2 Beam Diagnostics

Most of the experiments are supposed to use the slow extraction mode with a spill length between 0.4s and 10s. The heavy ion beams which can be accelerated in the Nuclotron have relatively low intensity in comparison with the proton and deuteron beams. The beam monitors are required to cover an intensity range from 10^3 pps (particles per second) to 10^{11} pps. To meet this requirement, several types of detectors are used for beam diagnostics: multi-wire proportional chambers (MWPC), plane parallel ionization chambers, scintillation counters, fluorescent screen monitors.

The analog-mode proportional chambers are used as profile monitors in the range of intensity from 10^6 to 10^{11} pps. The MWPC consists of two orthogonal signal wire planes. Each plane has 32 gold-plated tungsten wires 25 µm in diameter separated by 2 mm. High-voltage cathode planes are fabricated of Be-Cu wires 100 µm in diameter. The anode-cathode gap is 6 mm. The chamber is filled with a gas mixture of Ar (80%) and CO_2 (20%). The dedicated MWPC apparatus permits acquiring and storing several tens of successive beam profiles during one extraction cycle under various timing and gain settings. The external trigger is provided with the machine timing system, and it is the same pulse that drives the extraction elements. The data of the profile measurement during one extraction period are presented in Fig. 3. The lower traces are the integrated profiles and the upper ones show the dynamic behaviour of the profiles during the extraction process. The digital-mode MWPCs, which are under redesigning, will be used in the range up to 10^6 pps. Three profilometers located in the initial part of the transfer line enable one to measure the beam emittance and to match the extracted beam to the transfer line more exactly.

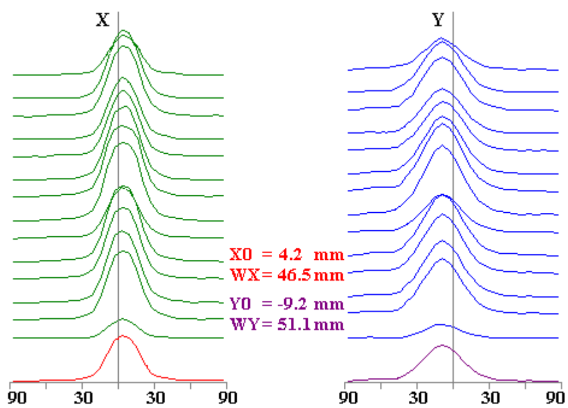

Figure 3: Extracted beam profiles.

There is one plane with 32 signal wires connected in parallel in the MWPC used to measure the shape and duration of the extracted beam spill. The high-frequency structure of the spill is measured with scintillators.

The plane parallel ionization chamber filled with argon at a pressure of 110 kPa is used as a detector to measure the absolute beam intensity. It consists of 4 signal electrodes and 5 high voltage copper electrodes 10 µm thick and 180 mm in diameter, separated by 10 mm. The main module of the intensity measurement apparatus is an ionization current integrator with 3 ranges of current-to-voltage conversion. The measurement error is about 5% in the range of $10^5 ... 10^{12}$ pps. The detector was calibrated by a scintillometer. Scintillation counters are used to measure intensity in the range up to 10^5 pps.

The screen monitors are installed at the entrance of the Lambertson magnets and at the exit of the accelerator. The image processing technique based on CCD cameras and frame-grabbers ensures screen selection and setting inside the beam, video tuning, background subtraction, pseudo-colour for displays, saving and restoring of specific images, snapshot and live mode selection.

The extraction efficiency is one of the major topics to be investigated in future machine runs. At present, the efficiency of roughly 70% is realized. Diagnostic tools, such as beam loss monitors to measure this parameter accurately and to increase it up to the design value of 95%, are now under development.

3.3 Spill Control

To realize the constant-current-beam or the constant-time-length spill and to suppress the low frequency spill structure in the range up to several hundred hertz a spill control subsystem (SCS) is under designing. It consists of a feedback loop in parallel with a feedforward control.

In the feedback loop the extracted particle flux is measured with MWPC and is compared with the request flux. The resulting error signal is fed into a feedback controller. The controller is an analog unit in which integration, differentiation and the gain can be adjusted separately. The output control signal is added to the EQ power supply pattern generated by the corresponding function generator. The feedback reference signal is a trapezoid with a variable flattop (beam spill duration) and constant rise and fall time of 10 ms. The parabolic form of the initial part of the flattop will improve the transient response of the power supplies and will allow an overshoot of the spill to be avoided. The circulating beam intensity signal (Fig. 1g) measured and stored just before extraction is used as a reference for obtaining the constant-time-length spill.

As was mentioned above, the spill intensity fluctuation is mainly due to the LQ ripple current. In the feedforward section of the SCS the ripple signal picked up from the reference lattice quadrupole magnet is passed through the filters, amplified and fed to EQs.

4 CONCLUSION

The pilot configuration of the control system has been successfully tested in the Nuclotron runs. Substantial modifications are under way in order to achieve system design functionality.

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