NUCLOTRON EXTRACTED BEAM SPILL CONTROL

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Abstract

The first experiments with the Nuclotron Beam Slow Extraction System (BES)[1] were carried out in December 1999. After the BES commissioning, the improvement of the system was continued together with experiments on relativistic nuclear physics. At the same time, extracted beam diagnostics was intensively developed. Substantial progress in quality of the beam spill parameters was achieved.

INTRODUCTION

Extracted beam spill control tools are part of the BES control subsystem (see Fig. 1) which is in its turn integrated into the Nuclotron Control System. The BES control subsystem [2] has been operating successfully since the beginning of the first experiments on beam extraction.

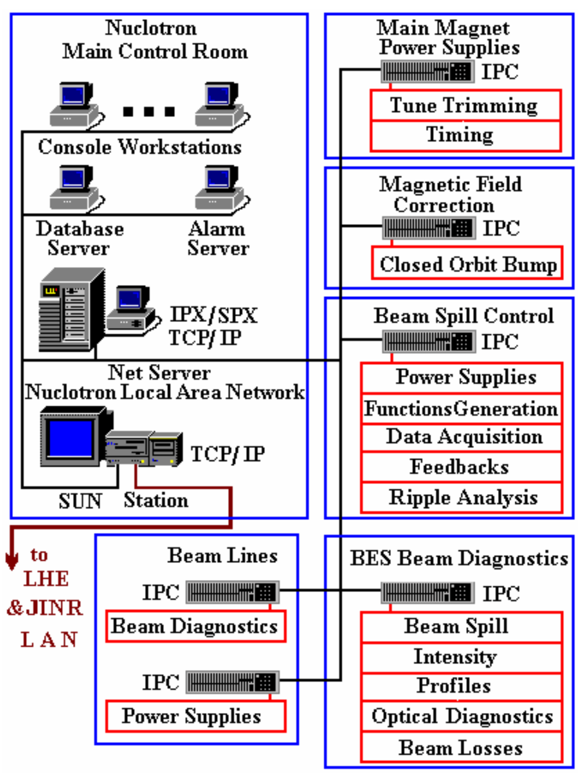

Figure 1: BES control subsystem structure.

BEAM SPILL CONTROL

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 fast 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 is used for beam angle correction in the vertical plane.

Slow extraction is carried out according to the timing chart shown in Fig. 2. The machine cycle (Fig. 2a) 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 16 seconds [3].

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 EQs are excited according to the function generator and feedback signals.

Beam Spill Monitoring

Instrumentation must harmonize with the following extracted beam properties:

- kinetic energy - 200 MeV/u…6 GeV/u;
- intensity - 10^3 …10^{11} particles per second (pps);
- spill duration - 400 ms…16 s;
- spill time structure frequency band - 10 Hz…5 kHz;
- transverse beam sizes - 5 mm…100 mm;
- particle charges (at the present time) – Z = 1 (protons, deuterons)…Z = 26 (iron);
- beam extraction periodicity - 5 s…18 s.

To meet these specifications, multi-wire proportional chambers (MWPC) in the analog and digital modes and scintillation detectors are used for the beam spill monitoring.

The analog-mode proportional chambers are used as profile monitors over an intensity range 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. The space between signal wires is 1, 2 or 4 mm depending on the beam size. 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 operation voltage ranges from 100 V to 3500 V. The MWPC with 64 signal wires connected in parallel is used to monitor the extracted beam spill over a frequency band from DC to 5 kHz. The detector covers an intensity range from 10^5 to 10^{11} singly charged particles per second. The high-frequency structure of the spill is measured with scintillometers.

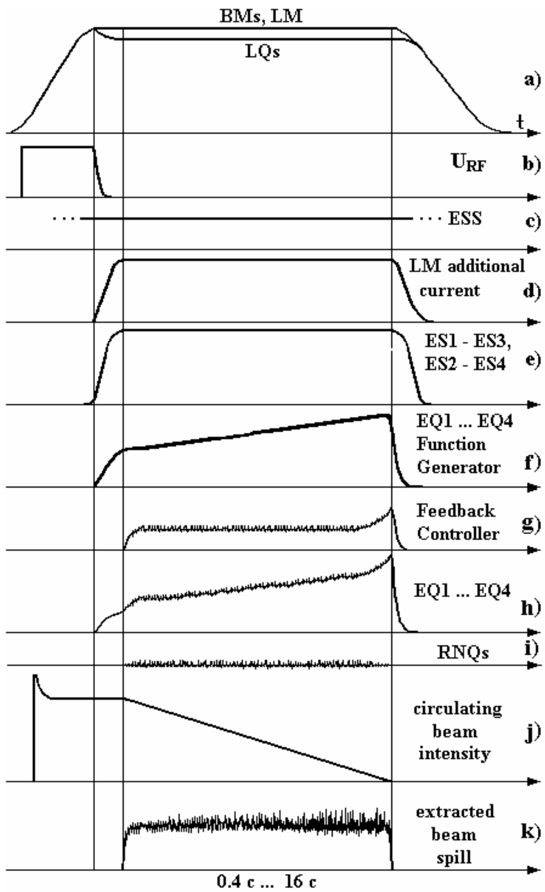

Figure 2: Timing chart of extraction processes.

The profilometers based on digital-mode MWPCs [4], are used over a range of up to 10^7 pps. A modified version of the apparatus will also be applied to the beam spill monitoring (Fig. 3).

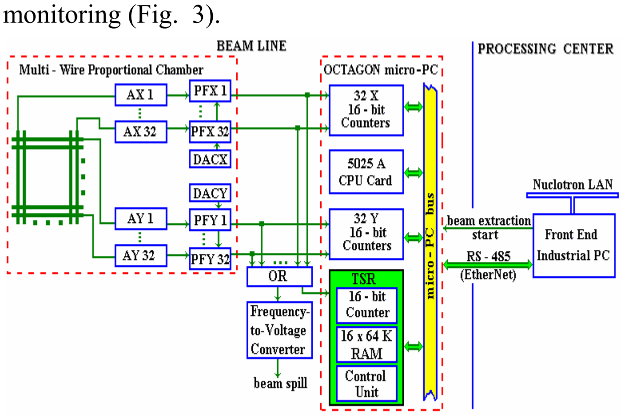

Figure 3: Block-diagram of the digital-mode MWPC electronics.

Amplifiers (AX,AY), pulse formers (PFX, PFY) and digital-to-analog converters (DACX, DACY) for the threshold adjustment are located in the chamber box. Two modules of 16-bit binary pulse counters accumulate information on beam profiles. The frequency-to-voltage converter (FVC) delivers the analog signal corresponding to the extracted beam current. The dedicated time structure recorder (TSR) registers the beam spill shape. In the last module the MWPC count measured by a 16-bit counter is accumulated in 64K RAM in fixed time intervals. The interval length is an integer multiple of 8 µs. The microcomputer as well as the above-listed modules are mounted in a separate crate located at a distance of about 2 m from the chamber box. The same beam spill monitoring technique is extended to the scintillation detectors.

Spill Control

The spill has modulation components in the 50...600 Hz subharmonic ripple range mainly due to the LQ power supply and 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. To achieve a stable extracted beam current, special control components are needed in combination with low-ripple power supplies for the main magnets and the extraction magnets. All power supply outputs are filtered. Furthermore, an active filter for the LQ power supply was developed to reduce fluctuation components. However there are residual frequency components in the 50...600 Hz subharmonic ripple range, modulating the spill structure. An example of the beam spill features without an active filter of LQ and without feedback is given in Fig 4 (Fig. 4a - beam spill, Fig. 4b - beam spill spectrum).

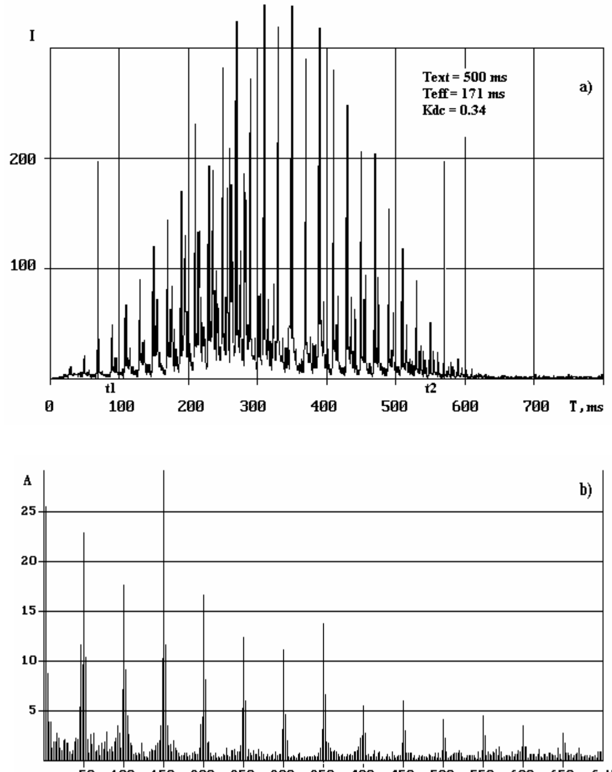

Figure 4: Beam spill characteristics without an active filter of LQ and without feedback.

The beam uniformity for the presented illustration

$$Kdc = \left(\int_{t1}^{t2} \frac{dN}{dt} dt \right)^2 \Bigg/ \left((t2 - t1) \int_{t1}^{t2} \left(\frac{dN}{dt} \right)^2 dt \right)$$

is Kdc = 0.34 (N is the number of particles, t2 - t1 = 500 ms is the nominal duration of a spill).

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 Hz, a spill control subsystem (SCS) was put into operation. It consists of a feedback loop in parallel with a feedforward control (Fig. 5).

In the feedback loop, the extracted particle flux measured with the MWPC 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 gain can be adjusted separately. The output control signal is added to the EQ power supply pattern generated by the corresponding function generator. A closed-loop servo is gated on at the beginning of the flattop. The feedback reference signal is a trapezoid with a variable flattop and a constant rise and fall time of 10 ms. The parabolic form of the initial part of the flattop improves the transient response of the power supplies and allows an overshoot of the spill to be avoided. The height of the trapezoid sets the extracted beam flux and the spill duration. The circulating beam intensity signal measured and stored just before extraction is used as a reference for obtaining the constant-time-length spill.

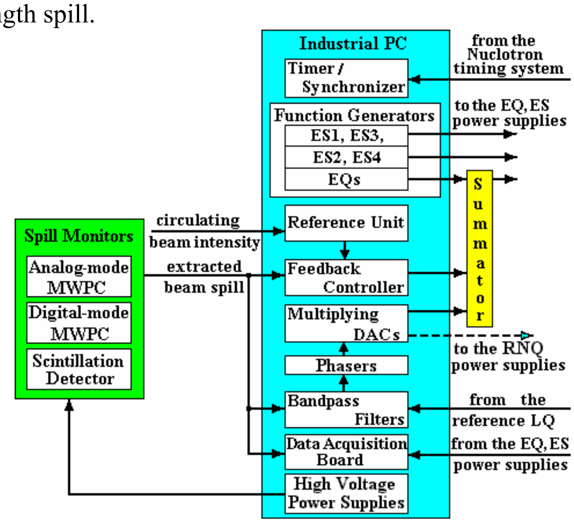

Figure 5: Schematic diagram of the spill control subsystem.

A feedforward loop was added to the SCS for the purpose of suppressing any ripple effects more effectively. To verify the principle of such a control mechanism, first experiments were carried out during the latest runs. The main origin of spill fluctuation, as mentioned above, is variation of the horizontal tune due to the LQ ripple current. Feeding the signal of the LQ ripple to the EQ in addition to the feedback signal decreases the tune variation. The ripple signal from the reference LQ is inverted, passed through bandpass filters, phasers, scalers (multiplying digital-to-analog converters), and then fed to the EQ power supply. The phase and the amplitude are independently adjusted by observing the spill time structure. The optimum scale factor is somewhat different for each frequency component. The reduction factor of about 5 was observed for 50…150 Hz components. The beam spill uniformity of about 0.9 is achieved at the extraction length from 0.4 s to 5 s (Fig. 6a). For a more extended time of extraction this value is in the vicinity of 0.8 (Fig. 6b).

We plan integration of the specialized ripple-neutralizing quadrupoles (RNQ, Fig. 2, 5) with the fast power supply into SCS for further improvement of the spill time structure.

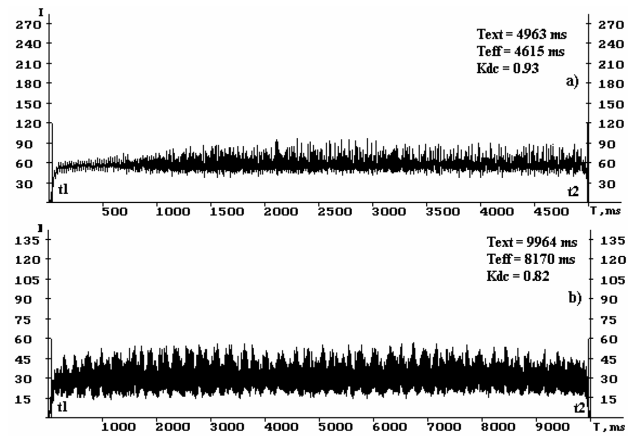

Figure 6: Beam spills with a closed feedback loop.

CONCLUSION

The spill control subsystem now in use makes it possible to obtain the beam spill duration over the range up to 16 s. It has proven to be reliable and has substantially extended the BES functionality. The SCS operational conveniences allow an operator to rapidly respond to the experimentalist's requirements for beam intensity and spill duration. Now the SCS characteristics are being extensively investigated and upgraded in order to attain a closer approximation to the uniform beam spill.

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

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