NUCLOTRON EXTRACTED BEAM DIAGNOSTICS

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Abstract

Twenty-two runs of the superconducting synchrotron Nuclotron have been performed by the present time. The Nuclotron Control System (NCS) provided an efficient support for the machine operation during all runs. The first experiments with the Nuclotron Beam Slow Extraction System (BES)[1] were carried out in December 1999. After the BES commissioning, the study of the system was continued together with experiments on relativistic nuclear physics. At the same time, extracted beam diagnostics was intensively developed.

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. 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 spaced from one another. The Ethernet Local Area Network is the system backbone.

Extracted beam diagnostic 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 from the beginning of the first experiments on beam extraction.

2 BEAM DIAGNOSTICS

Instrumentation must harmonize with the following extracted beam properties:

- kinetic energy - 200 MeV/u…6 GeV/u;
- intensity - 10^2 …10^{11} particles per second (pps);
- spill duration - 200 ms…10 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=12 (magnesium);
- beam extraction periodicity – 5 s…12 s.

To meet these specifications, several types of detectors are used for beam diagnostics: multi-wire proportional chambers (MWPC) in analog and digital modes, plane parallel ionization chambers, scintillation counters, fluorescent screen monitors, and proportional counters as beam loss monitors.

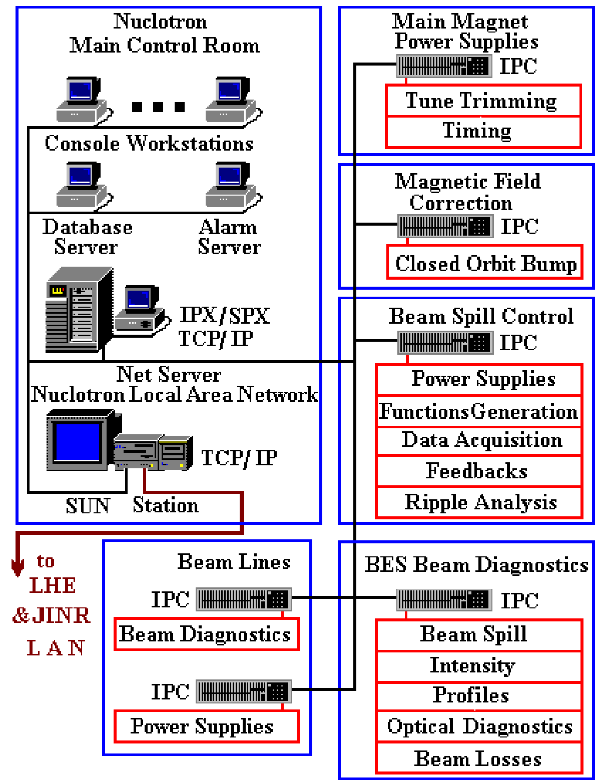

Figure 1: BES control subsystem structure.

2.1 Analog-Mode Proportional Chambers

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 3200 V. The dedicated MWPC apparatus (see Fig.2) permits acquiring and storing several tens of successive beam profiles during one extraction cycle under various timing and gain settings. The charge–to-voltage converters (CV1…CV64) with adjustable sensitivity, sample-and-hold amplifiers (S/H1…S/H64) and a multiplexer (MPX) are placed close by the detector. A timer/synchronizer (T/S) and a 40 kHz buffered ADC of a 10-bit resolution are arranged in the processing center at a distance of 100 m. The external trigger is provided with a machine timing system, and it is the same pulse that drives the extraction elements.

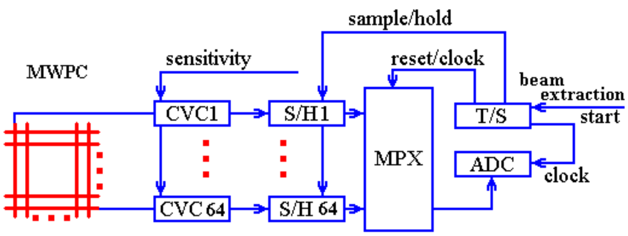

Figure 2: A block-diagram of the analog-mode MWPC read–out electronics.

The data of profile measurements during one extraction period are presented in Fig. 3. The lower traces are integrated profiles and the upper ones show a dynamic behaviour of the profiles during the extraction process.

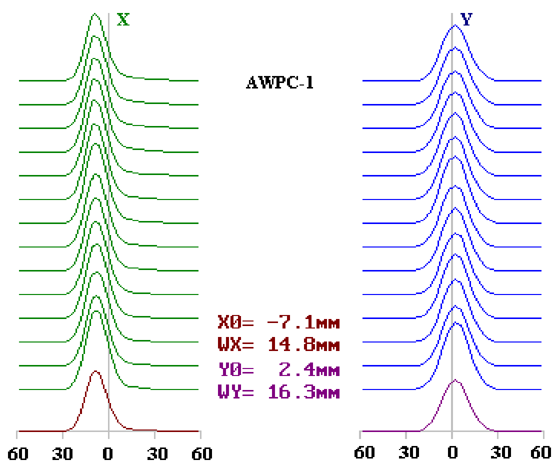

Figure 3: Extracted beam profiles.

The profile monitors based on analog-mode MWPCs are now installed at more than 10 different locations of the beam transfer lines. Three profilometers located at an initial part of the transfer line (Fig. 4) enable one to measure the beam emittance and to match the extracted beam to the transfer line more exactly.

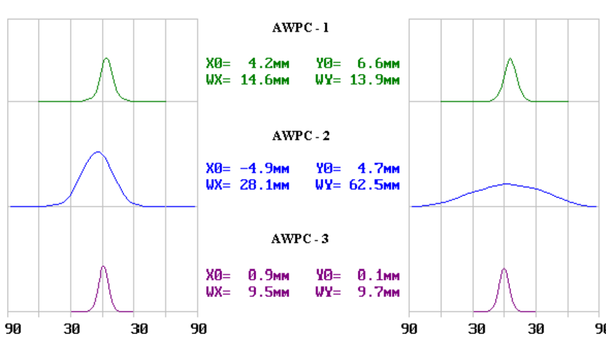

Figure 4: Integrated profiles at three points of the beam line.

2.2 Digital-Mode Proportional Chambers

The profilometers based on digital-mode MWPCs, which are under operation tests [3], will be used over a range of up to 10^7 pps. A structural scheme of the corresponding diagnostic apparatus is shown in Fig. 5.

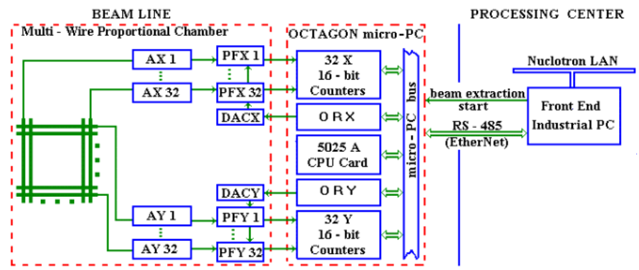

Figure 5: A block-diagram of the digital-mode MWPC electronics.

Amplifiers (AX,AY), pulse formers (PFX, PFY) and digital-to-analog converters (DACX, DACY) controlled by parallel output registers (ORX, ORY) for the threshold of shapers determination are located in the chamber box. Two modules of 16-bit binary pulse counters are made in the OCTAGON micro-PC standard on the basis of programmable logic devices. The microcomputer as well as the counter modules and output registers are mounted in a separate crate located at a distance of about 2 meters from the chamber box.

There are two modes of extracted beam profile monitoring:

- Data acquisition of beam parameters for the whole extraction time and one-shot information reading (integrated beam profile acquisition, see Fig. 6). In this mode, counting starts after a synchronization pulse “extraction start” and stops after the extraction end.
- Multiple data reading and counters resetting within the extraction time – obtaining information about beam space parameters evolution during the extraction process. This mode allows one to avoid an overflow of the counters for an arbitrary extraction time. The operator sets an initial delay, a period and the number of data readings.

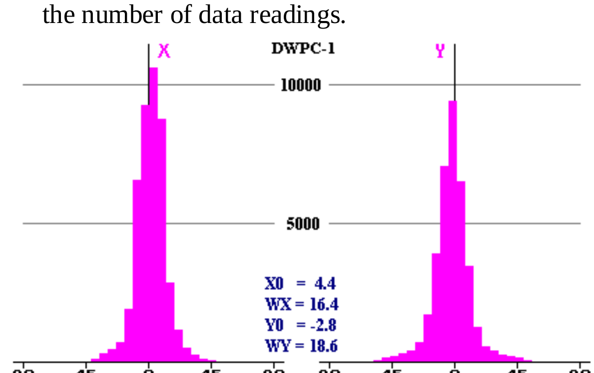

Figure 6: Integrated profiles obtained with the digital-mode MWPC at a beam intensity of 10^5 pps.

2.3 Beam Intensity Monitors

The plane parallel ionization chambers filled with argon at a pressure of 110 kPa are used as detectors to measure the absolute beam intensity. They consist of 8 (or 4) signal electrodes and 9 (or 5) high voltage copper electrodes 10 µm thick and 180 mm in diameter, separated by 10 mm. An applied voltage of 1500 V is sufficient to collect almost all electrons produced by an extracted beam of 10^{11} singly charged particles in the chamber effective volume. Design characteristics of the ionization chamber exclude the ingress of a leakage current into the measuring circuits. The ionization current integrator with 3 ranges of current-to-voltage conversion is a main module of the intensity measurement apparatus. The measurement error for the 8-gap ionization chamber is about 5% in a range of 10^5...10^{11} singly charged particles per spill. The detectors were calibrated by a scintillometer. Scintillation counters are used to measure intensity over a range of up to 10^5 pps.

2.4 Screen Monitors

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 subtractions, pseudo-colour for displays, saving and restoring of specific images, snapshot and live mode selection.

2.5 Beam Loss Monitors

The extraction efficiency is one of the main parameters under investigation during machine runs. At present, an efficiency of roughly 90% is realized. The beam loss monitors used to measure this parameter accurately are being developed. They will also provide quantitative loss data for extraction tuning and BES equipment alignment, in particular of an electrostatic septum. The helium-3 neutron counters installed at three points in proximity to the electrostatic septum and Lambertson magnets are being tested now.

2.6 Spill Control

The MWPC with 32 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.

During the Nuclotron runs, slow extraction was carried out according to the following timing diagram. After the flattop energy is reached, the radio frequency is switched off and the horizontal beam tune is shifted from the operating value to the resonance band edge by decreasing the field gradient of the lattice quadrupole magnets (LQ). Then, extraction quadrupole lenses (EQ) are excited and a current varies linearly with a rise time of 400 ms. The beam spill duration has approximately the same value (Fig. 7). The spill has modulation components in a 50…600 Hz subharmonic ripple range mainly due to LQ power supply and EQ supply that is utilized during the extraction process.

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 design.

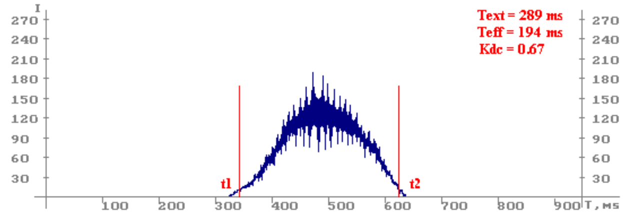

Figure 7: Beam spill without feedback.

The pilot version of SCS feedback loop was realized and tested during the last Nuclotron run in March 2002. In the feedback loop, the extracted particle flux measured with 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 preliminary result of the spill control is shown in Fig. 8. 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=0.98 (N is the number of particles, t2-t1=845ms is the nominal duration of a spill).

The circulating beam intensity signal measured and stored just before extraction will be used as a reference for obtaining the constant-time-length spill.

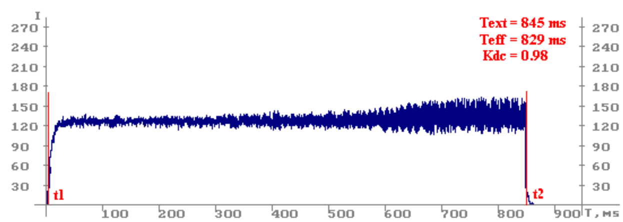

Figure 8: Beam spill with a closed feedback loop.

3 CONCLUSION

The extracted beam diagnostic system has been successfully tested in the Nuclotron runs. Substantial modifications and commissioning of the new equipment are under way in order to extend system functionality.

The authors would like to thank their colleagues for participation in the beam diagnostic system development.

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