NUCLOTRON BEAM DIAGNOSTICS

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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 of JINR in Dubna. The beam diagnostics subsystem of the Nuclotron Control System (NCS) [2] is described.

1 INTRODUCTION

The Nuclotron is intended to accelerate nuclei and multicharged ions up to an energy of 6 GeV/u for the charge-to-mass ratio q/A=0.5. The accelerator magnetic ring with circumference of 251.1 m includes 96 dipole, 64 quadrupole, 32 correcting multipole SC-magnets. The maximum value of the magnetic field is about 2T.

The beam diagnostics subsystem integrated into the NCS is based on the industrial rack-mountable PCs from ADVANTECH and CAMAC electronics.

2 INJECTED BEAM TRANSFER LINE

The injector (Alvaretz type linac) accelerates ions with a charge-to-mass ratio of 0.28<q/A<0.5 up to 5 MeV/u and protons up to 20 MeV/u. The injected beam transfer line is 30 m long and includes 2 bending magnets, 12 quadrupole lenses, and 12 correctors. The equipment of the single-turn injection comprises a superconducting septum magnet and kick electric plates.

Several types of detectors are used for beam diagnostics: 2 Faraday cups, 1 multi-wire beam current monitor, 2 multi-wire profilometers, 2 destructive fluorescent screen monitors, and 1 screen monitor of 95% transparency. These instruments make beam parameter measurements available over a wide range of intensities.

The Faraday cups a sensitivity of 10^6 charge/pulse are used for beam intensity measurement.

The beam profile monitor consists of X- and Y-wire planes. Each plane which is assembled on a movable frame has 32 golden tungsten wires 0.1 mm in diameter separated by 2 mm. The charge-to-voltage converters (CV1...CV32, see Fig. 1) with adjustable sensitivity, sample-and-hold amplifiers (S/H1...S/H32) and a multiplexer (MPX) have placed close by the detector. A timer/synchronizer (T/S), a 40 kHz buffered ADC of a 10-bit resolution and a multiplying scaling DAC (MDAC) are arranged in the processing center at a distance of 50 m. The external trigger is provided with the machine timing system, and it is the same pulse which is driving the injection elements. The sensitivity of the profilometer is ~ 10^8 charges/pulse.

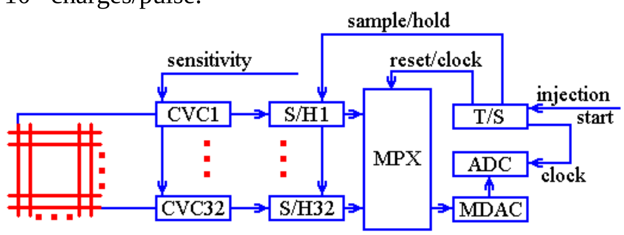

Figure 1: Profilometer block diagram.

The screen monitor of 95% transparency (wire greed assembly) is made of horizontal and vertical tungsten wires 0.1 mm in diameter separated by 5 mm with luminophor beads in the grid junctions. The observation station is equipped with an image amplifier and a photomultiplier to register a low intensity beam current, the profile and shape of the beam pulse.

The image processing technique based on fluorescent screens, CCD cameras, and frame-grabbers ensures the following possibilities: screen selection, video tuning, background subtraction, pseudo-colour for displays, the ability to save and restore specific images, snapshot and live mode selection (Fig. 2).

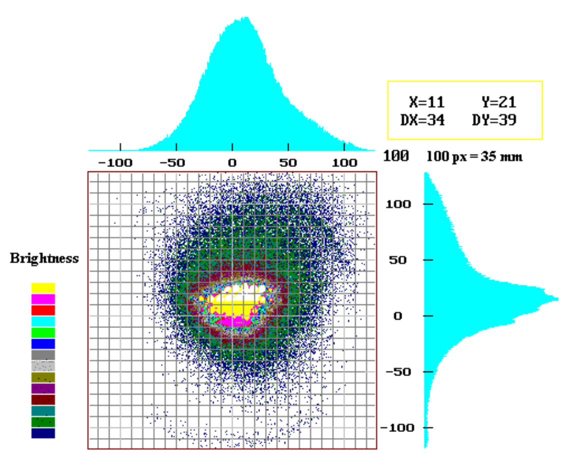

Figure 2: Beam image with X- and Y- profiles.

The monitor for injected beam pulse shape and duration measurement has one plane with 32 golden tungsten wires 0.05 mm in diameter separated by 2 mm and connected in parallel. A fast 50 MHz buffered ADC of a 8-bit resolution is used for beam pulse signal digitizing. The measured data together with the parameters of the septum magnet and kick electric plates (Fig. 3) are presented to the operator to tune the injection.

3 NUCLOTRON RING

3.1 General

The Nuclotron ring diagnostics equipment is composed of 5 multi-wire profilometers, 20 electrostatic position pick-ups, one electrostatic intensity pick-up, 2 beam current transformers, 4 screen monitors, and 4 Faraday cups.

The ring profilometers have the same construction and parameters as described above. Two of the five profilometers are placed entrance and exit of the inflector magnet respectively. The profilometers which are located at the end of the transfer line, at the inflector magnet entrance, and in the accelerator ring straight section permit to measure the injected beam emittance and to adjust more exactly the injected beam matching to the ring lattice.

The localization of beam losses around the accelerator ring facilitates machine tuning. Therefore, it is planned to mount beam loss monitors and to develop data acquisition electronics.

3.2 Intensity Monitors

The intensity and shape of the bunches (Fig. 3) are measured with a special-purpose electrostatic pick-up.

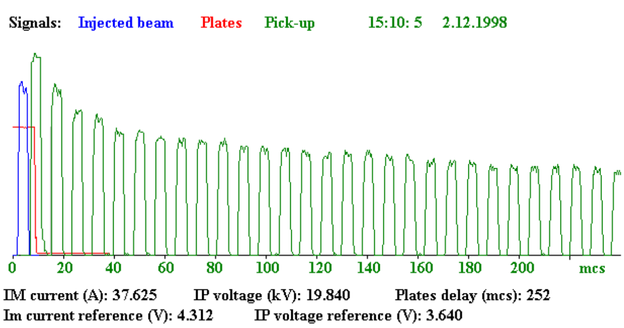

Figure 3: Example of the bunch intensity and shape measurement during first turns (RF off).

The corresponding amplifier has a bandwidth of 30 MHz and a controllable gain within a range of 60 dB. The base line restorer insures the specified output level between bunch signals. This device covers a beam intensity from 10^9 to 10^{12} charges per pulse. The average beam intensity signal is digitized with a 12-bit ADC after analog processing.

Additional opportunities for beam diagnostics are maintained by beam current transformers. To observe the longitudinal profile of the bunched beam, a fast current transformer with a frequency band of 50 kHz...10 MHz is used. The transformer toroid core is made of thin (0.02 mm) high permeability alloy tape with an amorphous structure. There are coil with 30-turn winding connected to the amplifier and a test coil with a one-turn winding allows a calibration signal to be fed in. The measured beam current ranges from 0.1 to 10 mA.

The DC current transformer is employed for average current measurements of the circulating beam. It consists of 2 cores with 2 exciting , 1 measuring, and 1 calibration windings. The exciting frequency of the modulator is 25 kHz. A filter together with a demodulator and an integrator is used for selection the second harmonic and its conversion into a DC voltage. The sensitivity of the device is 200 V/A, and the frequency band is 0...60 kHz.

3.3 Beam Position Monitors

20 BPM electrostatic pick-ups in the form of diagonally cut 66(H)×132(W)×110(L) mm boxes are arranged in the Nuclotron ring for non-destructive measurements of the beam position along the machine. The BPM front end amplifiers are placed close to the pick-ups but outside of the vacuum chamber and are at room temperature. The processing electronics are located in the centre of the ring so that the longest cable segment is smaller than 50 m. This allows us to have a precise signal matching and negligible attenuation with a relatively inexpensive cable. The main purpose of the BPM hardware and software is to provide accurate information for the correction of orbit errors. Some results obtained with the BPM system are presented in Fig. 4. The dashed line is the original closed horizontal orbit without correction at the field of injection. The solid line is drawn after correction.

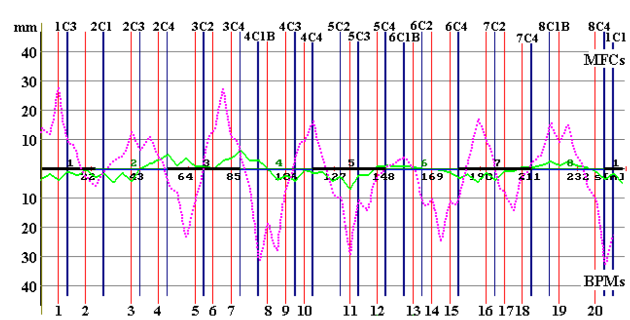

Figure 4: X-closed orbit before and after correction.

At present, we are redesigning the BPM electronics and post-processing software to extend functionality and to improve processing speed, dynamic range, and resolution. In accordance with specification, the BPM system has to function in a first turn mode and in a closed orbit mode. A substantial hardware upgrade enables to acquire beam signals with turn-by-turn and bunch-by-bunch capabilities.

The distinguishing features of the new BPM system are outlined in Fig. 5. Each position monitor electrode has a 30 MHz amplifier with an adjustable gain of 46 dB for use with high and low intensity beams. A gain control loop keeps a maximum signal level to improve the signal-to-noise ratio. For cost reasons, the amplifier has one pair (X or Z) of remotely selected output signals.

The beam revolution frequency (f_{rev}) ranges from 125 kHz to 1.2 MHz. The accelerating frequency harmonic number is 5. The timer/synchronizer uses a B-train with a 0.1 Gs resolution and $f_{RF}=5f_{rev}$ as an external clock to synchronize with the main magnetic field and bunch signal. An ADC1...ADC40 sample rate of 50 MS/s ensures the required signal resolution over the band up to 500 kHz. A simultaneous sampling of all the BPM-stations with a 64 KB record length permits acquiring several hundred successive closed orbits. Waveform digitizers (DSO-2125 from CyberResearch) with a 256 KB onboard memory and a time-bin duration of 4 ns allow more than 1000 turns to be acquired under combined parallel/sequential sampling.

The analysis of the acquired data is a very powerful tool to provide a reliable measurement of the tunes and lattice parameters of the real machine, such as beta values, or a phase advance between BPMs.

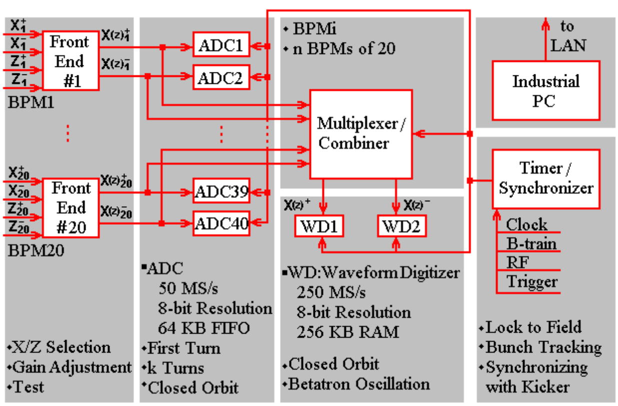

Figure 5: Structural model of BPM hardware.

4 EXTRACTED BEAM TRANSPORT LINE

The horizontal third integer resonance at the tune of Q=20/3 is used in the Nuclotron beam slow extraction system (SES). The SES equipment includes 4 sextupoles, 4 quadrupoles, 2 Lambertson SC-magnets and electrostatic septum. The external beam transfer line of about 100 m length is equipped with dipole and quadrupole magnets at room temperature. The first experiment with slow extraction system is planned for October 1999.

At present, the SES diagnostic equipment includes 2 screen monitors, 3 two co-ordinate multi-wire proportional chambers for profile measurement, one ionization chamber for extracted beam intensity measurement and one proportional chamber for beam current registration. In future we plan to install some more profilometers for slow extracted beam parameters measurement (emittance, envelopes, X,Y-positions and so on).

The screen monitors are installed at the entrance and exit of the Lambertson magnets and have the construction as described above.

The analog mode proportional chambers for profile measurement are located at the external beam line. Each profilometer consists of 3 high voltage and X,Y golden tungsten wire assemblies of 0.1 mm and 0.02 mm in diameter correspondingly placed in a box filled with argon. We use the same profilometer electronics as described above.

For extracted beam current measurement we use one plane proportional chamber with 32 gold-tungsten wires of 0.02 mm in diameter separated by 2 mm and connected in parallel.

The cylindrical ionization chamber filled with argon of a pressure of 110 kPa is used as a detector for absolute extracted beam intensity measurement. It consists of 4 signal and 5 high voltage copper electrodes of 0.01 mm thickness 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 intensity measurement error is about 3 % in a range of 10^5 ... 10^{12} charges/pulse. The calibration of the detector was carried out by a scintillometer.

5 CONCLUSION

The beam diagnostics subsystem has been successfully used in all Nuclotron runs. It ensures reliable operating conditions for different operating modes of the accelerator. Several modifications are still under way in order to improve the beam diagnostics functionality.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] A. D. Kovalenko, "Status of the Nuclotron", EPAC'94, London, (1994)

[2] V. Andreev et al, "Nuclotron Control System", PAC'97 Vancouver, (1997)