

BEAM DIAGNOSTICS AND INSTRUMENTATION UPGRADE FOR MULTIPURPOSE RESEARCH COMPLEX OF INR RAS

S. Gavrilov[†], V. Gaydash, V. Gorbunov, Y. Kalinin, Y. Kiselev, P. Reinhardt-Nickoulin, I. Vasilyev
 Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia

Abstract

Accelerated proton beam of INR linac is used for various facilities in multipurpose research complex of INR RAS, including experiments of neutron investigations and medical physics laboratories. In recent years beam instrumentation for transport channels of the complex has been upgraded and supplemented. Electrostatic pick-ups, beam current transformers, ionization chambers, multiwire SEM-grids, as well as its front-end and processing electronics were developed and combined to improve beam diagnostics. Some technical details and available results of beam measurements are presented in the paper.

INTRODUCTION

Multipurpose research complex (MRC) [1] of INR RAS includes four beam outlets (Fig. 1): three neutron facilities of neutron investigations laboratory (time-of-flight RADiation Experiment, pulse neutron source IN-06, lead neutron slowing-down spectrometer LNS-100) and research Complex of Proton Therapy, which is a part of medical physics laboratory.

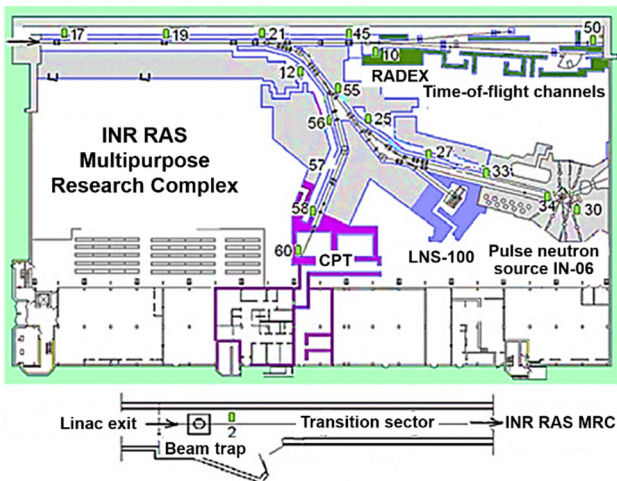


Figure 1: Layout of INR RAS MRC.

Depending on beam user requirements INR RAS linac has to provide beam parameters in a wide range of values: beam energy 100÷209 MeV, pulse current 0.01÷15 mA, pulse repetition rate 1÷50 Hz, pulse duration 0.3÷180 μ s. Moreover, these parameters can be changed several times during a shift for different research groups, that needs not only reliable operation of the linac in different duty cycles, but also a universal beam instrumentation available for routine beam control in the whole range of parameters.

[†] s.gavrilov@gmail.com

DIAGNOSTICS AT THE LINAC EXIT

Beam emittance and position measurements at the linac exit are of importance for proper matching with the linac-MRC transition sector. In-flight beam diagnostics before a beam trap is provided by Beam Cross Section Monitor (BCSM) [2]. The monitor, utilizing a residual gas ionization, enables to observe 2D beam cross section, beam position and profiles, as well as transverse emittance ellipses (Fig. 2), which can be reconstructed [3] from beam profiles data during linear transformations in phase space by variation of fields in upstream quads.

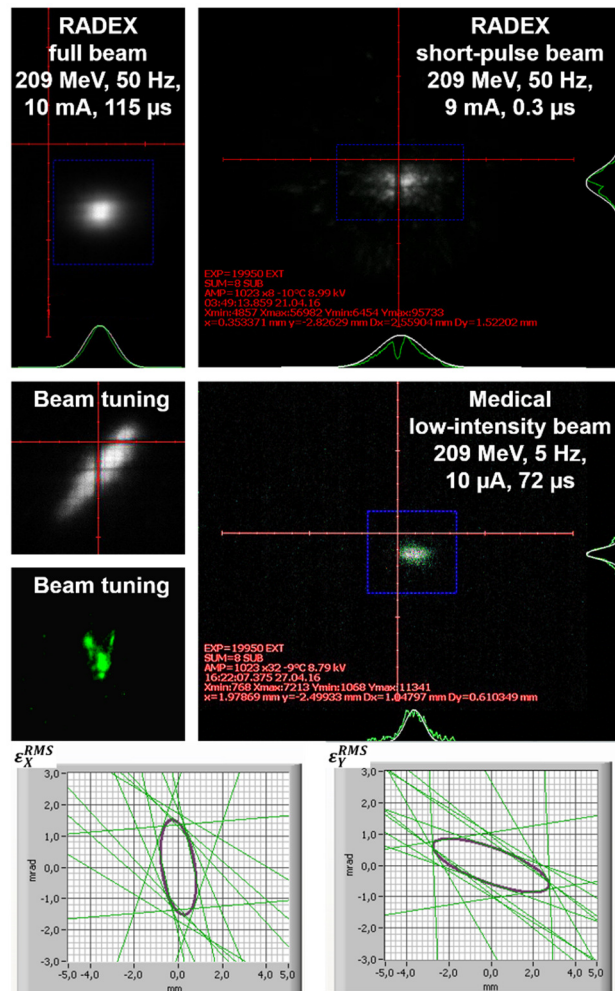


Figure 2: BCSM results for different beam parameters.

Now BCSM is a reliable tool for efficient beam tuning and an accurate non-destructive diagnostics at the linac exit in the whole required range of beam parameters.

ELECTROSTATIC PICK-UPS

Beams with given energies are transported about 400÷500 m to the research facilities without acceleration. Due to the momentum spread ($\Delta p/p \approx \pm 3.5 \cdot 10^{-3}$ at the base) a beam bunch structure ($T_{Bunch} \approx 200$ ps, $f_{RF} = 198.2$ MHz) is lost and the measurements are done for debunched coasting beams. For a bunched beam a measurement is performed by radio frequency methods, but in case of a debunched beam it is transformed into measurement of quasi-steady-state charge during the whole macropulse.

Ten linear-cut electrostatic pick-ups (Fig. 3) upstream and downstream of elements with reduced aperture are installed for non-destructive measurements of beam position and tilt in a wide range of beam intensity.

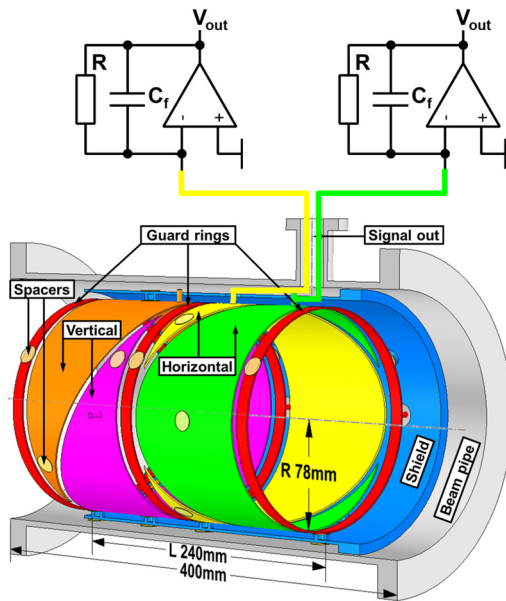


Figure 3: Pick-up scheme with charge amplifiers.

The design and operation principles of used pick-ups are discussed completely in [4]. Signal-to-noise ratio is limited by a total capacitance C_t which is the sum of plate-to-ground $C_{pg} = 110$ pF, plate-to-plate $C_{pp} \approx 2\div 3$ pF and capacitance C_c of an interconnecting cable. The main implemented feature is a charge amplifier based on operational amplifier with JFET inputs and $C_f = 10$ pF, $R = 100$ M Ω . In this case an output signal is practically independent of a total detector capacitance, so pick-up calibration can be performed with arbitrary cable length. With second stage gain of 10 and input referred noise of 16 nV/ $\sqrt{\text{Hz}}$, the output noise is 15 mV peak-to-peak.

High value resistor R defines DC gain and provides a path for the bias current to flow. In parallel with C_f it forms a high pass filter that causes pulse droop. Small droop can be assumed as linear for compensation by simple baseline restoration algorithm after digitization.

Signals from pick-up plates during a beam pulse as well as beam position calculated from a difference-over-sum measurement are shown in Fig. 4. Unfortunately, a bandwidth of used processing electronics, based on National Instruments modules, is insufficient for diagnostics of pulse durations less than about 10 μs .

ISBN 978-3-95450-181-6

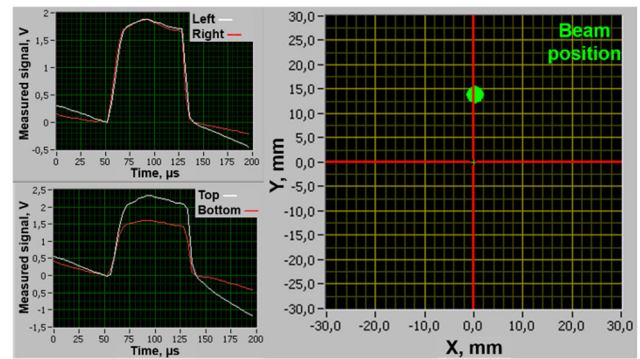


Figure 4: Pick-up signals and calculated beam position.

BEAM CURRENT TRANSFORMERS

Operation with high-intensity beams for RADEX and IN-06 requires protection systems, based on beam losses control. One of them, so-called Δ BCT, is based on beam current transformers (BCT) and registers an absolute value of beam losses by a beam current difference between the linac exit and entrances to the research facilities.

BCT signals from every beam macropulse are read-out and compared by special electronics, which turns off a beam directly in case of specified difference threshold ($1\div 5\%$ typically) is exceeded in three successive pulses. In addition, this system holds on 1 Hz tuning mode as long as the difference remains.

There are nine BCTs, based on ferrite rings installed in vacuum, with different design and electronics. Two standard BCTs with preamplifiers, based on AD810 op-amps, are used for routine range of beam parameters. Three sensitive BCTs with OPA827 and ADA4627 – for medical beams with pulse currents down to 10 μA . Four fast BCTs measure short-pulse beams (Fig. 5) for RADEX and LNS-100. Fast BCTs have 10÷15 turns in signal windings and low input impedance preamplifiers, based on AD844.

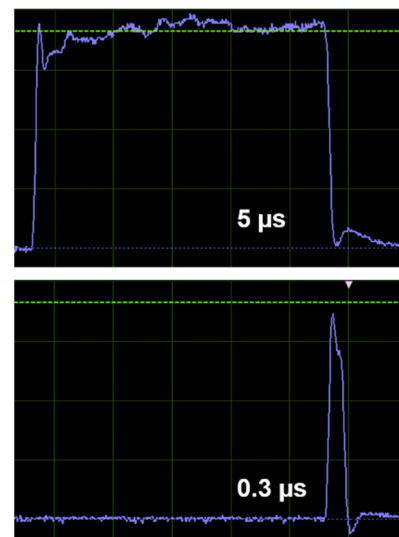


Figure 5: BCT signals from short-pulse beams.

Current signals and calibration signals of all BCTs are transmitted in differential mode by twisted-pair cables, so interferences are minimized, and preamplifiers can be distant for hundreds meters from a control room.

IONIZATION CHAMBERS

Ionization chambers (IC) [5] form another system for beam losses control. There are 32 double IC fixed on the outside of beam pipes from the beam trap to the research facilities: inside quadrupole doublets and near steering magnets generally. Protons and neutrons from beam losses ionize air in a volume, enclosed by comb electrodes with 600 V potential difference, that produces a current between the electrodes proportional to the dose rate.

A new electronics allows to control beam losses in every macropulse, but only in a relative manner, because of the absence of any proper calibration mechanism. One another drawback is a small value of signal currents for beam losses during routine linac operation. The comb electrodes form a condenser, which is a high responsive to an external electrical noise, so signal-to-noise ratio decreases crucially at acceptable beam losses.

Nevertheless, IC system plays a significant role during a beam tuning process, indicating critical points, like in Fig. 6, where chambers # 2, 8, 9 show heightened levels of beam losses due to not so good correction of a beam position after the beam trap and near two lifting magnets at the beginning of the transition sector correspondingly. Also ICs can be used as a fast emergency protection system, like Δ BCT, but pointwise distributed across the whole MRC.

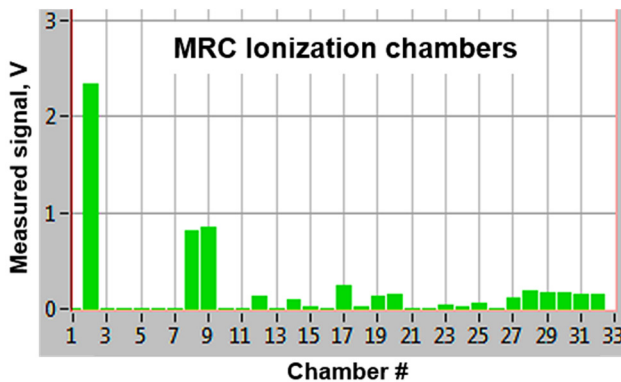


Figure 6: IC signals along MRC channels.

MULTIWIRE SEM-GRIDS

Multiwire SEM-grids are used to control beam profiles and position at inlets of the research facilities. There are 16 gilded tungsten wires 100 μ m diameter with 4 mm spacing in each horizontal X- and vertical Y-plane of the grid. Polarization grids are not used.

A plate with a grid can be moved in/out a beam by a DC-actuator, but such grid is practically transparent for operational beam energies, besides the total designed aperture lets through beams with the sizes up to 120 mm at the base. Thus it can be used for continuous in-flight control during the whole accelerator run without an appreciable influence on a beam. Dosimetric measurements after several runs confirm this assumption.

A beam current signal from every wire is integrated in a separate channel during each beam macropulse, then the signal readout is done by time multiplexing with channel switching time equal to 10 μ s.

Such coarse grids are proved to be sufficient, because it needs to retain beam transverse sizes as big as possible with RMS value about 10 mm (Fig. 7) for a thermal load reduction of the neutron production targets. For IN-06 beam sizes should be made asymmetric due to X-stretched rectangle inlet window.

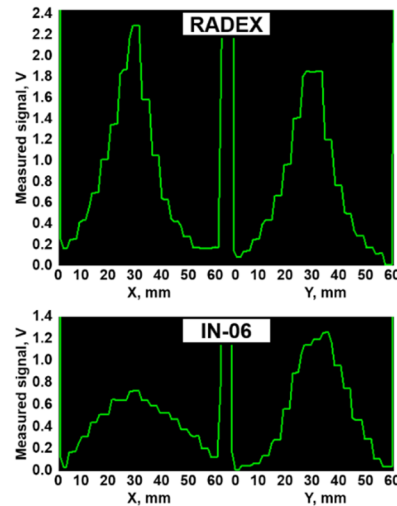


Figure 7: Beam profiles at RADEX and IN-06 inlets.

CONCLUSION

All beam instrumentation systems at MRC transporting channels were recalibrated and upgraded by extra new units and/or electronics. Data from electrostatic pick-ups, beam current transformers, ionization chambers, multiwire SEM-grids is gathered now in the central control room for in-flight diagnostics in a wide range of beam parameters. Also a protection system Δ BCT of beam losses control by beam currents difference is implemented.

Operation in different extreme modes with high and low beam intensities as well as long and short pulse durations reveals some drawbacks, such as: a lack of the electronics bandwidth, excessive susceptibility to an external noise or wires overheating in the SEM-grids in case of high-intensity beams, that leads to profile distortions.

Beam diagnostics and instrumentation development will be continued during the next maintenance periods with the view of enhancement of MRC INR RAS resources.

REFERENCES

- [1] A. Feschenko et al., "Multipurpose research complex based on INR high intensity proton linac", in *Proc. RUPAC2012*, Saint-Petersburg, Russia, pp. 90-94.
- [2] S. Gavrilov et al., "Two-dimensional non-destructive diagnostics for accelerators by Beam Cross Section Monitor", 2014 *JINST* 9 P01011.
- [3] P. Reinhardt-Nickoulin et al., "Emittance measurements at the exit of INR linac", in *Proc. RUPAC2012*, Saint-Petersburg, Russia, pp. 668-670.
- [4] S. Gavrilov et al., "Electrostatic pick-ups for debunched beams", 2014 *JINST* 9 T10007.
- [5] Y. Davydenko et al., "Registration of losses of protons with energy 200-600 MeV", in *Proc. XVII Conf. on Charged Particle Accelerators*, Protvino, Russia, pp. 220-224.