BEAM PARAMETERS MEASUREMENTS BY IONIZATION CROSS SECTION MONITOR ON PROTON LINAC OF INR RAS*

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Abstract

The ionization beam cross section monitor (BCSM) is developed and used on proton linac of INR RAS to provide non-intercepting measurements of beam parameters. Operation of the monitor is based on utilization of residual gas ionization. The BCSM configuration design and image processing system are described and estimations of influence of the linac radiation background are discussed. The monitor enables to observe beam cross section and extract from it beam profiles and position as well as their evolution in time within a wide range of beam intensities and energies. The available experimental results of beam spot, profiles and emittances measurements at the linac output are presented.

INTRODUCTION

Starting from 2005, the BCSM [1, 2] operates at 400 keV proton beam [3] of INR linac injector, and from 2007, the monitor operates on 209 MeV output beam of INR linac [4].

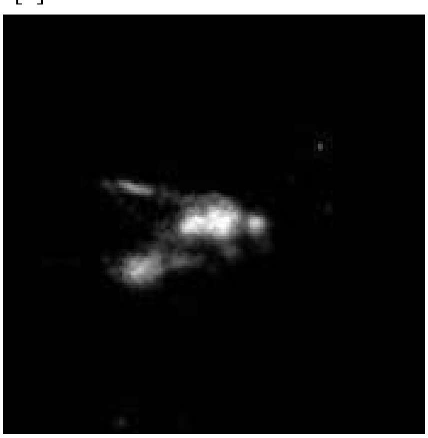

Figure 1: The example of INR linac output beam cross section as the result of collimator inserting at the input of linac at tuning process for medical beam.

The proton beam pulses at the output of INR linac have a continuous structure due to the drift of particles on the length more than 100 meters after the last accelerating cavity: beam bunches expand significantly in longitudinal direction because energy resolution of accelerated particles ΔE/E = 0.25 %. Bunch structure is practically removed in the beam pulse in our case. At the output of INR linear accelerator it is necessary to measure parameters of pulsing beam of protons with energies ranging from 70 to 209 MeV, the amplitude of 0,1 ÷ 15 mA with duration of 0,3 ÷ 200 microseconds and a repetition frequency of 1 to 50 Hz. These beams are used for physics experiments and applied research such as neutron research or proton medicine.

Output beam transport line of linac is equipped by four of 2-wire scanners for measuring of beam profiles and emittances. But these devices can be used at 1 Hz pulse repetition mode of linac only, because the wires are the sources of beam losses and have probability to be destroyed by 50 Hz current. Also 2-wire scanners cannot provide full information about beam cross section shape.

As is well known, observations of complex transverse beam shapes, that are possible during beam tuning process, can be done by beam intercepting monitors such as luminescent phosphor screens or transition radiation screens with mechanical drives. And these devices also insert disturbance and losses and can not be used at 50 Hz.

On opposite a single ionization BCSM, installed in output beam transport line of the linac, offers opportunity to observe the complex beam spot shape (Fig. 1) without beam disturbance and without any mechanics, and receive continuous information about the parameters at the full intensity beam, the same as with fluorescent screens or transition radiation detectors. Besides that BCSM is very compact: it size is 22 cm, the work pressure of residual gas in linac transport line is 10^{-7} Torr.

As in most other accelerators it is necessary to give particular attention on non-destructive beam techniques, in order to eliminate disturbance of the beam in order to preserve its parameters. BCSM is just such device. BCSM gives the possibility to observe the next beam parameters during adjustment and routine operation of the linac: form of beam cross section (BCS), beam position and its displacement concerning linac axes. Besides that BCSM allows to measure beam profiles and emittances due to computer processing of images.

BCSM DESCRIPTION

Detail description of BCSM is done in [1, 2, 3]. Here is given the short summary of information of BCSM functioning. BCS registration is based on preliminary acceleration and following energy analysis of residual gas ions produced by investigated beam (Fig. 2).

Accelerated protons 1 ionize residual gas. Positive ions (q1, q2,) are extracted by a field E_{ex} (typically 1÷2 kV/cm) of flat extracting condenser 2 through a narrow slit in lower electrode of the condenser. The secondary ion beam distribution along of the slit direction corresponds to primary particle horizontal transverse distribution of investigated beam. Energy distribution of extracted ions in slit plane corresponds to vertical particle distribution of primary beam. These ions are captured and

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directed by a field E_a of analyzing condenser 3, which electrodes are placed under 45 degrees to the plane of the extracting electrode. Analyzed ions hit open inputs of chevron micro-channel plate 4 (MCP) of the electro-optical converter 6 with the coordinates depending on coordinates of an ionization point, creating the image of beam cross section on phosphor screen 5.

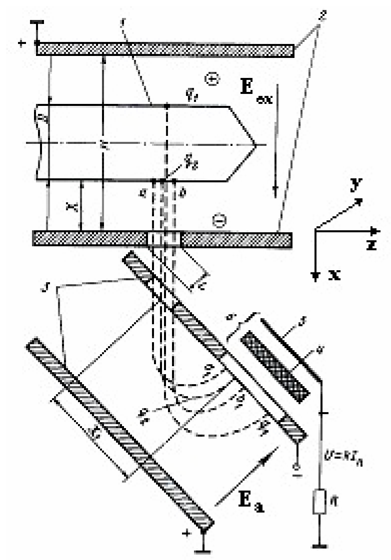

Figure 2: BCSM scheme: 1-Particle beam, 2-Ion extractor with slit, 3-Electrostatic analyzer, 4-MCP image intensifier, 5-Luminescent screen, 6-Electro-Optical Converter.

BCSM sensitivity at invariable vacuum pressure depends on ionization energy losses of accelerated beam particles in residual gas.

The distance ***X1*** from the entrance slit of analyzing condensor to the point of impact on MCP input is described by the equation: $X1=2(E_{ex}/E_a)X$ and does not depends on the mass and ion charge.

TV-camera with CCD matrix records luminescent screen image and transmits it over 150 meters to the computer.

NEUTRON AND GAMMA RADIATION BACKGROUND INFLUENCE

Neutron and γ radiation background in the linac tunnel creates radiation damages (hot pixels) of TV-camera CCD matrix and electronics. Periscope system (PS) was developed and installed at the linac for electronics protection. PS collects and transmits optical radiation from phosphor screen to TV-camera behind 70 cm concrete wall of the linac. Neutron flux was simulated in the hadron transport code SHIELD [5] to estimate the protection efficiency (Fig. 3). The flux near accelerator beam pipe is equal $2{,}8 \cdot 10^5$ n/cm^2*s with average energy of neutrons 47 MeV. Behind concrete protection at the TV-camera installation point the flux is equal to 67 n/cm^2*s with average energy of neutrons 21 MeV. Also for comparison there are results of modelling with no hole in concrete protection.

The concrete protection decreases damage effects to the CCD matrix from neutrons and γ-quanta over than 10^3 times.

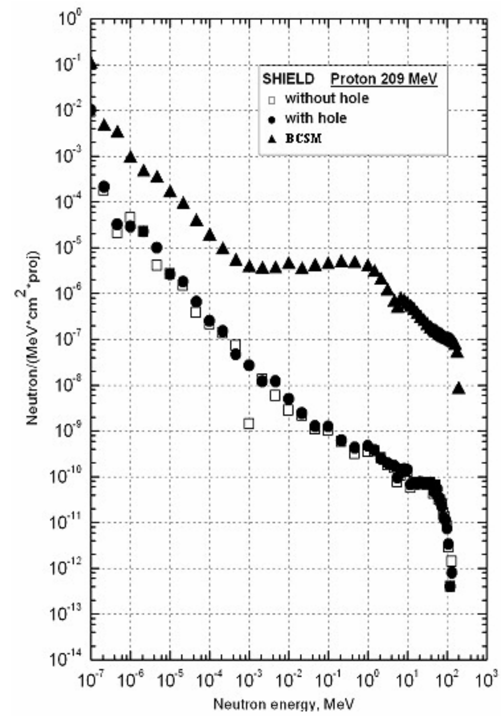

Figure: 3: Neutron spectrum simulation around BCSM.

BCSM IMAGES AND PROFILES DISTORTIONS AND RESOLUTION

Extracting condenser slit width, beam losses, hot pixels, γ-radiation, stochastic nature of MCP currents and luminescent radiation produce distortions and the noises, that influences on BCSM image and its profiles resolution.

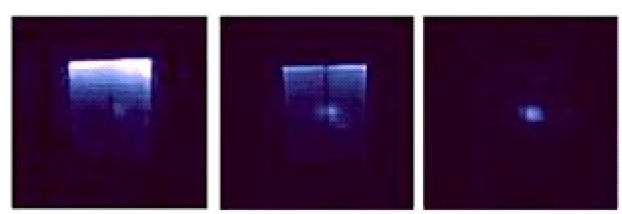

Figure 4: Beam adjustment from heavy losses to small.

Hot pixels were produced at CCD matrix operation near beam pipe at first experience in 2007. These distortions were removed by concrete shielding and cooling of CCD matrix by Peltier cell. Beam losses noise is canceled at process of beam adjustment (Fig. 4). Thus BCSM resolution is defined by extractor slit width L=1 mm, initial ion energy, MCP resolution and for INR output linac beam is $\sigma^2_{measured}=\sigma^2_{beam}+L^2/12+\sigma^2_{mcp}$ approximately [6, 7].

Relocation of the TV-camera behind the concrete shielding increased reliability and lifetime of detector.

BEAM IMAGES, PROFILES AND EMITTANCES MEASUREMENTS

Currently, BCSM is not only used to monitor beam losses and the position of the center of gravity of the beam, but also for the measurement of profiles and emittances. Profiles are calculated from the captured images (Fig. 5) and processed with existing transverse beam matching and correction software [8].

a) b)

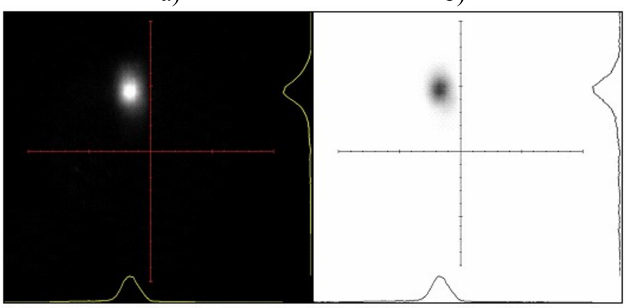

Figure 5: On-line images of INR proton beam cross section: a) 1 Hz, 200 μs, 14 mA pulse current, b) 1 Hz, 3 μs, 10 mA pulse current.

BCSM sensitivity can be increased by means of software options: summation of images, background image subtraction, median filtering of images. New software allows to measure (Fig. 5b) small currents [9] of medical beams (~10 nA of average current).

Beam emittance ellipses (Fig. 6) were measured both with BCSM and wire scanners. As single BCSM is installed only at output beam of the linac, emittance ellipses can be measured by method of quadrupoles lenses forces varying relatively optimal current of lenses. As alternative, method of few wire scanners was applied with the quadrupoles forces varying. Emittance picture on Fig. 6 shows these overlapping (X, X') ellipses.

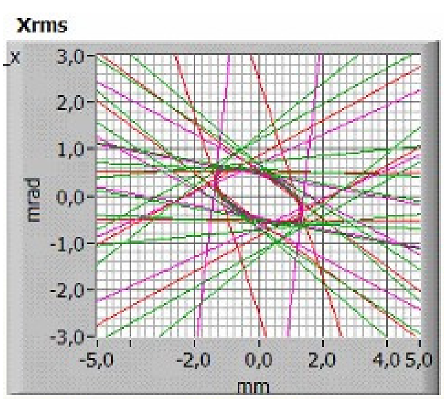

Figure 6: Emittances picture from BCSM (green lines) and wire scanners (red lines).

CONCLUSIONS

Thus BCSM is now the single INR linac monitor for observation and measurement of parameters both high and low intensity beam for both nuclear experiments and medical laboratory needs. BCSM produces both simple and complex cross section images and profiles with inaccuracy of around 5 % for σ_{beam}=2 mm that is quite admissible result for solving the problem of the operative visual control, diagnostics and correction of various parameters of a beam.

BCSM is very compact in comparison with standard Ionization Profile Monitor.

Taking into account that the profile measurements with wire scanners take 180 seconds with increased beam losses versus 140 ms for BCSM without additional losses, the advantage of BCSM is significant during the procedure of beam adjustment.

The speed of image data processing is defined by our TV-camera frame rate and can be increased with other camera type.

Using of previously developed software for BCSM profile data processing allows faster beam profiles and emittances information output.

The received results confirm considerable opportunities for BCSM operation practically at any accelerators, equipped by beam transport lines, over a wide range of beam currents and energies, with various types of accelerated particles and ionizing radiation beams.

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