BEAM CROSS SECTION MONITOR FOR INR LINAC*

P. Reinhardt-Nickoulin#, S. Gavrilov, A. Feschenko, I. Vasilyev
Institute for Nuclear Research of RAS, Moscow, Russia

Abstract

The monitor to measure a cross section of the accelerated beam has been developed and implemented in INR Linac. Operation of the monitor is based on utilization of residual gas ionization. Secondary ion flux cross section after extraction of the ions from the beam line by electrostatic field and subsequent energy separation in electrostatic analyzer reproduces a cross section of the accelerator beam. A microchannel plate intensifier followed by a phosphor screen is used to observe ion cross section. The image is optically transmitted to a CCD camera installed remotely and shielded for protection. The monitor enables to observe beam cross section, beam profiles and beam position, as well as their evolution in time within a wide range of beam intensities and energies. Monitor operation and parameters are described. Some experimental results are presented.

INTRODUCTION

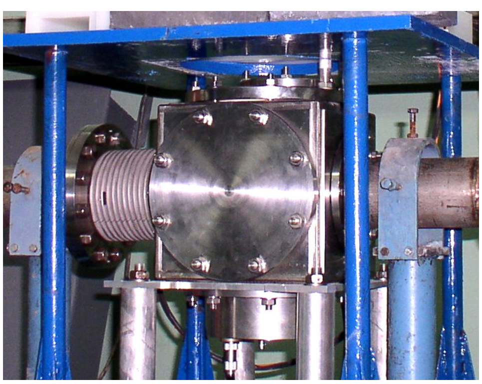

Figure 1: Output beam line BCSM.

During measurements of INR linear accelerator beam parameters it is necessary to give particular attention to non-intercepting and non-destructive beam measurement processes, as in most other high current accelerators, that is minimization of beam perturbations for the purpose of beam parameters saving. For such measurements well known method based on registration of products of ionization of residual gas in the vacuum chamber of the accelerator is often used. Beam cross section monitor (BCSM) of accelerated protons is installed at an output of INR linac about in 4 m behind last accelerating resonator (Fig. 1). It 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 axis. Besides that BCSM allows to observe distribution of density of the accelerated particles in BCS and beam profiles due to computer processing of images.

BCSM has high sensitivity and wide dynamic range. These properties permit to measure INR linac beam cross sections with intensities from a few nA/mm^2 to a hundred μA/cm^2 of average current. BCSM can be widely used for observations and diagnosis of beam and ray parameters both continues and pulse beams of electrons, ions, protons, ultra-violet and gamma-rays at practically any accelerators and sources of a radiation equipped by beam transport channels with vacuum from 10^{-5} to 10^{-8} Torr [1, 2]. Double dimension distribution of accelerated beam particles in beam cross section is more informative beam characteristic in comparison with profiles of a beam as it is possible to observe any profiles under any angles from cross section; but it is not possible to reconstruct two dimensional transverse section picture of a beam by means of two profiles from wire scanner or multi wire grids or standard profile ionization monitors. Therefore BCSM is not only more informative but more compact than traditional ionization monitors [3, 4].

BCSM DESCRIPTION

The method of measurements is based on preliminary acceleration and following energy analysis of vacuum chamber residual gas ions produced by investigated particle beam (Fig. 2).

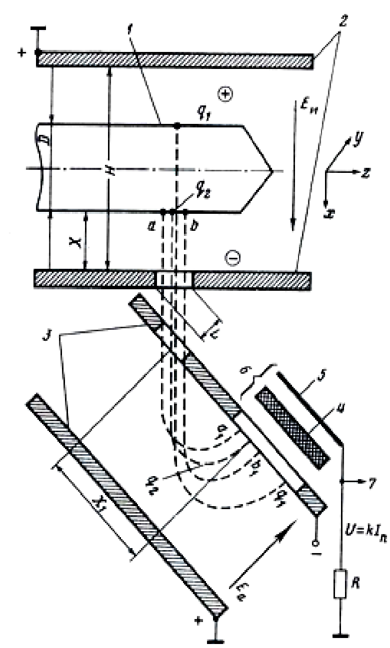

Figure 2: BCSM scheme, 1-Particle beam, 2-Ion extractor with slit, 3-Electrostatic analyzer, 4-MCP image

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#petrrein@inr.ru

intensifier, 5-Luminescent screen, 6-Electro-Optical Converter.

The beam of the accelerated protons 1 moves in the vacuum chamber of the accelerator and ionizes residual gas. Secondary positive ions (q1, q2,) are extracted by a homogeneous field E_{ex} (typically 1÷2 kV/cm) of flat electrostatic extractor 2 (extracting condenser) through a narrow slit in lower electrode of the condenser Accelerated gas ions pass the slit and form the taped beam. 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 directed by a field of electrostatic analyzer 3 (analyzing condenser) which electrodes are placed under 45 degrees to a direction of extraction of ions and to the plane of the extracting electrode. After that analyzed ions hit open inputs of double microchannel plate 4 (MCP) of the electro-optical converter 6 (EOC) with the coordinates depending on coordinates of an ionization point, creating the image of beam cross section on phosphor screen 5 registered by TV-camera.

BCSM sensitivity at invariable vacuum pressure depends on ionization energy losses of accelerated beam particles in residual gas. BCSM sensitivity is made better by well known hardware and software methods: CCD matrix cooling, regulation of MCP voltage, application of phosphor screen with light radiation wave length to correspond CCD highest possible sensitivity, frame background subtraction and summation of frames, median filtering of image

INFLUENCE OF THE LINAC RADIATING BACKGROUND

Operation of sensitive TV-camera with CCD matrix creates radiation damages (hot pixels) during monitor running in conditions of a high radiating background at the linac. Therefore it is necessary to protect TV-electronics without losing sensitivity. Lens-mirror periscope system (PS) was developed and established at the linac for this purpose. PS collects and transmits optical radiation from phosphor screen of BCSM to TV-camera behind 70 cm concrete protection of the linac. Neutron streams were simulated in the hadron transport code SHIELD [5] by Monte-Carlo method for estimations of protection efficiency (Fig. 3). The full stream 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 in a point of TV-camera installation the full stream is equal 67 n/cm^2*s with average energy of neutrons 21 MeV. Also for comparison there are results of modelling with absence of a hole in concrete protection. In this case the full stream would be 61 n/cm^2*s with average energy of neutrons 23 MeV. Thus it is possible to see that existing hole in the protection does not influence practically on results and affects only small strengthening of soft neutron components.

The concrete protection allows minimize damage effects at the CCD matrix from neutrons and γ-quanta, and in addition PS passes optical radiation without essential loss that allows to measure parameters of beams with small intensity.

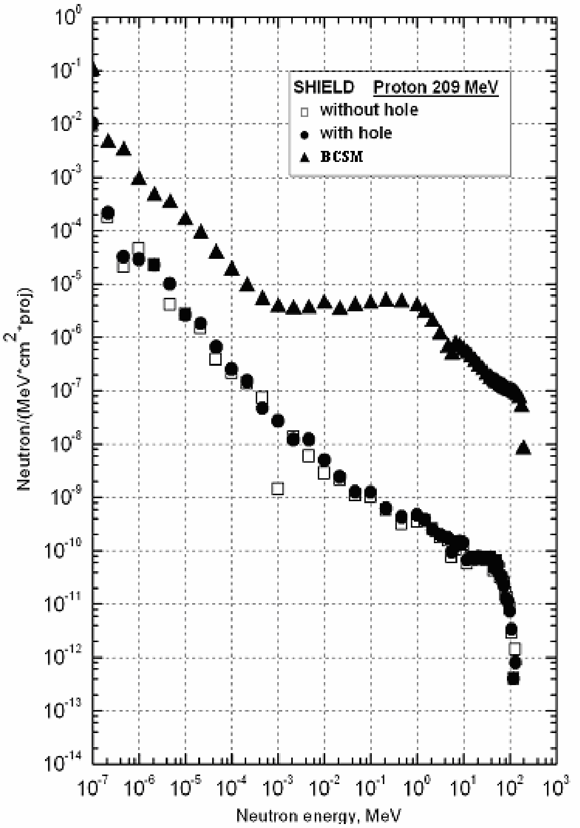


Figure 3: Neutron spectrum simulation around BCSM.

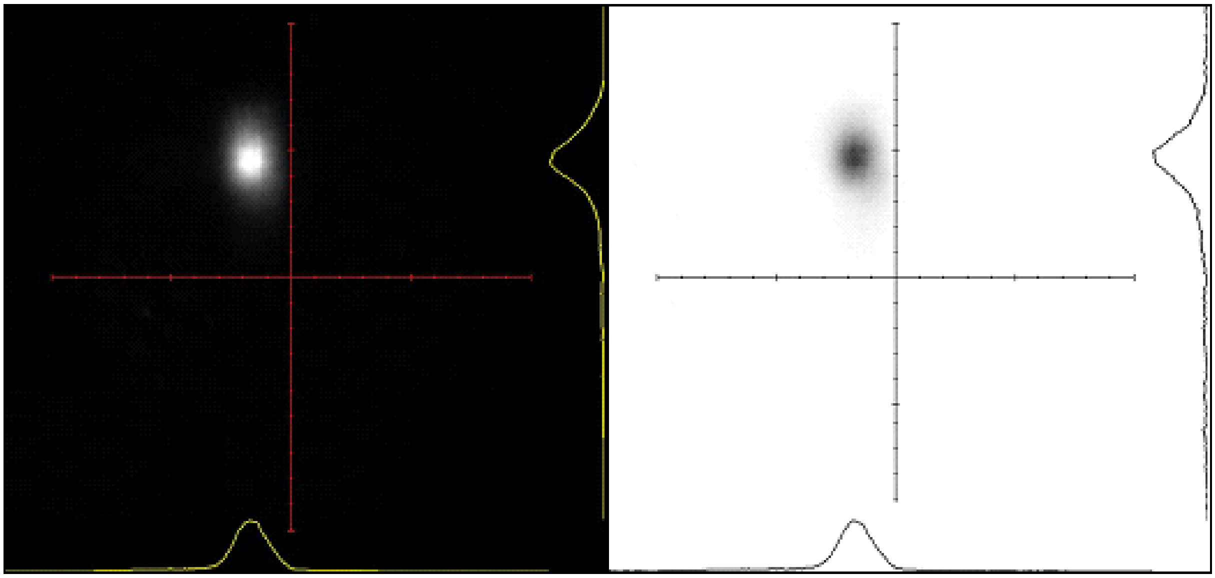
DISTORTIONS OF PROTON BEAM 2-D IMAGES AND PROFILES

One of the most critical image distortion is result of a beam space charge influence on dynamics of ions motion in BCSM vacuum chamber. Also nonzero initial velocities of secondary ions should be taken into consideration.

As shown in fig. 2 for ions «a» and «b», the final 1 mm width of the slit results in image widening if we take into account two thin parallel layers of extracted ions appropriated for «a» and «b». Thus we receive superposition of several BCS. Nevertheless as shown in [6] from the point of view of statistics, it gives error $\sigma^2_{measured} = \sigma^2_{beam} + L^2/12$, where L – width of the slit.

The resolution is also defined by resolution of a chevron MCP assembly which is equal to around 50 micron [7].

Considering the results of these distortions simulated it is possible to tell with confidence, that the upper total error of BCS image received on phosphor screen does not exceed 200 microns.



a) 1 Hz, 200 μs, 14 mA pulse current b) 1 Hz, 3 μs, 10 mA pulse current

Figure 4: On-line images of INR proton beam cross section

EXPERIMENTAL RESULTS AND CONCLUSION

For the first time in operation of BCSM it was possible receive the cross section image of 209 MeV proton beam from single isolated proton beam pulses on INR linac (Fig. 4a). BCSM just also creates a possibility for measurement of beam parameters of INR linac injector with 400 keV energy [4, 8].

Development of the new software and carrying of the TV-camera over concrete protection have given an increase of the detector long time reliability and safety. The sensitivity was also increased due to summation of images, background image subtraction, median filtering of images, and have allowed to measure (Fig. 4b) small currents of medical beams (~10 nA of average current). Thus BCSM is the only INR linac detector to measure both high and low intensities of INR linac for needs both nuclear experiments and medical laboratory at 10^{-7} Torr vacuum pressure.

Beam cross section monitor allows of cross section images registration with inaccuracy around of 1% for σ_{beam}=2 mm that is quite admissible result for the decision of problems of the operative visual control, diagnostics and correction of various parameters of a beam.

Possible reduction of the 1 mm slit size down to 0,1 mm will allow to receive BCS images similar to ideal: at a level of errors less than 1% and final image resolution of 100 microns.

The received results confirm considerable opportunities of using such BCSM practically at any accelerators, over a wide range of beam currents and energies, with various types of particles.

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