# ION MONITOR OF TRANSVERSE BEAM PARAMETERS FOR INR PROTON LINAC*

P. Reinhardt-Nickoulin, A. Feschenko, S. Gavrilov
Institute for Nuclear Research of RAS, 7a, 60th Oct. Anniversary pr., Moscow, Russia

*Abstract*

Residual gas ion monitor was developed and installed on INR Proton LINAC output to provide non-intercepting measurements of beam position, transverse section form and beam profiles for wide energy and amplitude range. The ion transverse section monitor details and TV image processing system are described. The available results of beam pulse measurements are presented.

## INTRODUCTION

At measurements of INR linear accelerators beam parameters it is necessary to give particular attention to non-intercepting measurement processes, as in most other high current accelerators (synchrotrons, cyclotrons and storage rings) [1, 2]. That is minimization of accelerated particle beam perturbations in processes of parameters measurements to save beam parameters and remove additional (defined by measurement process) activation of linac transport line due to beam scattering on beam detectors. As is well known the registration of beam profiles by means of electrons or ions generated in interactions of accelerated particles with residual gas molecules in accelerator vacuum chamber is just the same non-intercepting method. It is greatly advisable to use universal beam monitor to measure a few beam parameters, and it should be suitable for all types of ionizing beams in wide range of beam energy and intensity also.

Fig.1. Output beam line ITSM

Ion Transverse Section Monitor (ITSM) is just the device for measurements a few transverse parameters of any ionizing beams or rays [3, 4]. Proton beam ITSMs of INR linac were destined for observation of beams on energy 400 keV at beam transport line from injector to RFQ and 602 MeV beam transport line on linac output (Fig.1). It gives the possibility to observe and correct next beam parameters of linac at procedures of adjustment and exploitation:

- real form, sizes and particle distribution in transverse beam section,
- beam position and its shift from accelerator axes.

Besides that TV registration of beam spot and computer acquisition and processing of spot image give beam profiles. ITSM has high sensitivity and wide dynamic range. These properties permit to measure transverse sections of beams with intensities from a few nA/mm$^2$ to a few hundred mA/cm$^2$. At present time ITSMs were tested and used on beams of RRC “Kurchatov Institute” and INR RAS linac [5, 6]:

- proton or ion beams of 30 MeV cyclotron with average current 50 nA;
- 400 keV pulse proton current of INR linac injector with duration of 200 μs and 115 mA average pulse amplitude;
- pulse proton beam of linac with energy of 209 MeV and average amplitude 5 mA;
- synchrotron radiation rays of electron storage rings with energy 450 MeV and 2,5 GeV.

ITSM can be widely used for observations, diagnosis and corrections 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.

Double dimension distribution of accelerated beam particles in transverse section of a beam is more informative beam characteristic in comparison with profiles of a beam. 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. It is need to have special tomography software and more than 2 profiles for Radon transformation reconstruction of beam spot for these devices [7]. ITSM is simpler of traditional monitors therefore.

## ITSM DESCRIPTION

ITSM consists of residual gas ion detector in vacuum box, high voltage power supply source, TV-chamber on linac, optical cable with interfaces for image data transmission and PC with frame grabber and software for image processing.

The residual gas of linac beam transport line vacuum chamber is used as ITSM detector material providing of

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measurement non-interception. The device sensitivity depends on residual gas pressure and ionization losses of accelerated particles in residual gas first of all.

The 209 MeV pulse proton beam has not fine bunched structure at 602 MeV output of linac in our measurements.

## ION DETECTOR

The method of measurements is based on preliminary acceleration and following energy analysis of vacuum chamber residual gas ions produced by investigated particle beam. The ions detector is equipped by extracting condenser and analysing condenser. The scheme of multi parameter sensor, detailed distortion consideration and calculations for beam spot registration are given in [5]. ITSM works out parameters information in following manner: vertical extracting electric field (typically 1÷2 kV/cm) of two plane electrodes, forming plane extracting condenser, accelerates residual gas ions in direction of lower electrode. Lower condenser electrode has thin slit. This slit is perpendicular to beam movement direction axes. 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 secondary extracted ions in slit plane corresponds to vertical particle distribution of primary beam.

The accelerated taped beam ions are analyzed on energy by electric field of second analyzing condenser. Analyzing condenser is turned on 45 degrees relatively to direction of accelerated particles movements. Secondary ions move toward double micro channel plate (MCP) in analyzing condenser. The double dimension optical image of investigated beam transverse section is formed on phosphor screen. Phosphor screen is installed the other side of MCP. MCP electron charge accelerates in the space between MCP and phosphor screen and gives light flash of screen. 45 degrees condenser provides linear relation between image sizes and transverse sizes of investigated beam. Calculation of secondary ion trajectory in constant electric fields of condensers shows there is no dependence of ion coordinates on MCP input from ion charge and mass.

As easy to see spatial resolution of ITSM is defined by slit width of extraction condenser.

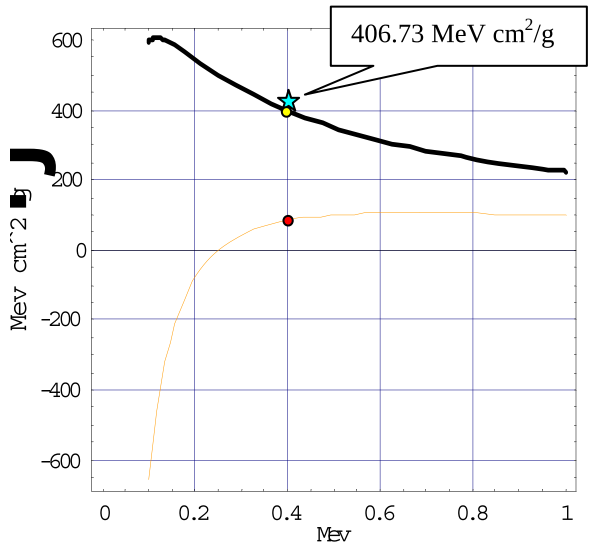
## ITSM SENSITIVITY AND RESOLUTION

ITSM sensitivity at invariable vacuum pressure depends on ionization energy losses dW/dz MeV cm$^2$/g of accelerated beam particles in residual gas. dW/dz proton dependence can be calculated with Bethe-Bloch formula for energy upper 200 MeV. For energy lower 100 MeV energy loss can be taken from reference book [8] (blue stars on Fig. 2 a, b) or by means of formula [9] (black line on Fig. 2a, dark blue on Fig. 2b).

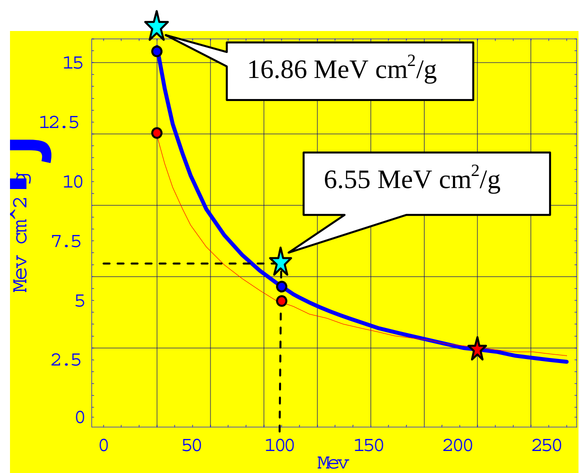
$$-dW/dz = (72q^2*(A/W))\ln(160W/(AZ)),$$

where $q$ – accelerated particle charge, $W$ – particle energy, $A$ – particle mass number, $Z$ – atom number of gas medium (≈7 for air). Orange and red lines are Bethe-Bloch lines.

From energy loss comparison at 400 keV and 209 MeV follows the relation of ions numbers, produced at these energies, is ≈ 140 ($dW_{400\ keV}/dW_{209\ MeV}$ ≈ 140).




a)




b)

Fig. 2

The experience of ITSM application on Kurchatov Institute cyclotron demonstrates relation of Signal to Noise more 3 is provided at average density of residual gas ions $10^{-16}$ A/mm$^2$ or 600÷700 particle/(mm$^2$s).

Furthermore ITSM sensitivity can be made better by well known methods:

- Application of monochrome CCD TV camera with binning (signal adding of matrix pixel group).
- 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 adding of frames.

X-ray, γ photons or neutrons are image background sources due to hitting of MCP or CCD camera. Besides that CCD camera electronics deteriorates by neutrons and γ radiation. For electronics saving TV camera should be protected from these radiation sources by means of distance and hardware.

## IMAGE DATA REGISTRATION, ACQUISITION AND PROCESSING

209 MeV proton beam transverse section images were registered by "Videoscan-285" system [10]. It consists from CCD camera with electronic shutter, optical cable with interfaces and the framegrabber.

Data automatic processing is executed by special software supplied with TV-system. The software becomes possible to vary next parameters of TV-system:

- the sensitivity of camera (binning),
- the duration of exposition time from 39 µs to 132 s,
- CCD matrix signals amplification for brightness regulation of image.

Besides that it is possible to start of electron shutter by external pulse. This option solves a investigation of transverse sections and profiles along proton current pulse at short exposition times to observe transverse beam parameters variation.

Also it is possible to process of images for beam profiles.

TV-camera with monochrome CCD matrix was used for highest possible sensitivity providing. This matrix has maximum of sensitivity at green light. Our screen phosphor radiation has just green color.

CCD matrix cooling becomes by Peltier TEC cell. CCD cooling decreases leakage currents of CCD. Leakage currents deteriorate measurements especially at long time exposition because matrix cells can be filled up of thermal electrons. Background signals are created by these electrons.

The use of optical cable permits long distance image signals communication (up to 15 km) without additional signal distortions and interference. That is electromagnetic interference can be as a rule on RF connecting cables of linac but these interference are damped on optical connecting lines.

## RESULTS OF MEASUREMENTS

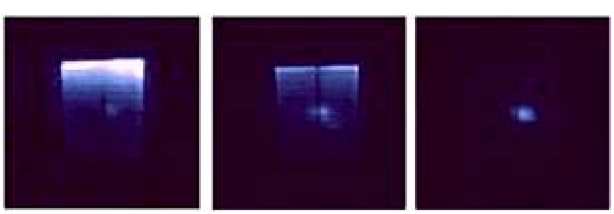


Fig. 3. Beam conditioning process.

Working pressure is not worse $10^{-6}$ Torr in beam transport line of INR linac commonly. It is enough for normal functioning of the detector and MCP. On Fig. 3 209 MeV proton beam transverse section variations are shown at process of beam transverse adjustment. This sequence of frames permits to observe linac conditioning from big losses to small losses. There were registered full frames at 7.7 Hz without binning. One can see black axes are silhouetted on screen surface and thin line white 1 mm grid also. These images were registered at 4.8÷5 mA proton pulse current, 70 µs pulse duration, 7 kV ITSM detector potential difference. The width of extracting condenser slit is 1 mm. The least width of the tested slit was 0.1 mm. That is spatial resolution of ITSM was ±0.5 mm. The binning TV camera application permits increase frames frequency up to 25 Hz.

## CONCLUSION

At present time ITSM are successfully tested both high (209 MeV) and low (400 keV) energy of INR linac proton beam.

ITSM has high sensitivity, high signal dynamic range and lesser processing time. The transverse section images of 209 MeV single isolated proton beam pulses were obtained for the first time. Taking into account that the data from linac wire scanners is received during 180 s with increasing of beam losses flow versus 140 ms from ITSM without additional losses the advantage of ITSM can scarcely be exaggerated at beam conditioning procedure.

It is necessary to accentuate that registration single proton beam pulses have been executed without binning option and adding of frames. It is mean ITSM has not use these possibilities for sensitivity improvement. These results and potentialities inherent in system give some hopes for the use of ITSM for registration transverse parameters of proton beam both greater energy and lesser intensity.

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