BEAM DIAGNOSTICS AND INSTRUMENTATION FOR PROTON IRRADIATION FACILITY AT INR RAS LINAC

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Abstract

A new proton irradiation facility to study radiation effects in electronics and other materials has been built in INR RAS linac. The range of the specified current from 10^7 to 10^{12} protons per beam pulse is covered with three beam diagnostic instruments: current transformer, phosphor screen and multianode gas counter. Peculiarities of the joint use of the three instruments are described. Experimental results of beam parameters observations and adjustments are presented.

INTRODUCTION

A proton irradiation facility (PIF) at INR RAS linac is intended to research on proton irradiation induced effects in different electronics, devices and materials. PIF is installed at the outlet of the linac, where bending magnet is used to deflect a beam for in air irradiation of targets. Beam energy at the PIF is adjusted in 20÷210 MeV range. Beam flux is defined by a combination of three parameters: pulse duration, pulse repetition rate and pulse current, which can be controlled in the range of 10^7÷10^{12} p/pulse by two collimators at the linac injection channel.

A general PIF layout is shown in Fig. 1. The main parts are: bending magnet with vacuum beam pipe, beam dump, target positioning system with energy degrader and beam diagnostic instrumentation.

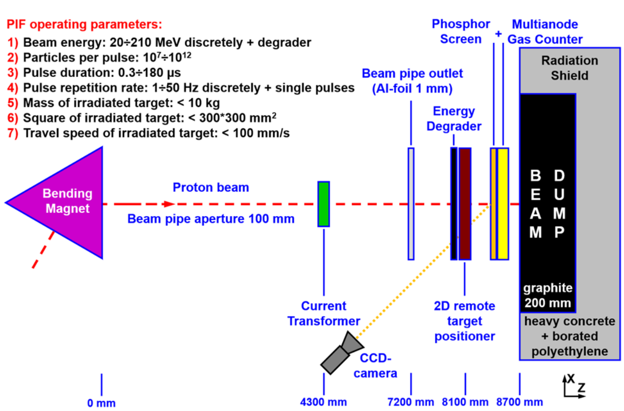

Figure 1: PIF layout.

The beam current transformer (BCT) is installed in the beam pipe about 3 m upstream the outlet window and provides absolute nondestructive measurements of beam pulse current with the amplitude > 25 μA, that corresponds to ~10^{10} p/pulse with typical durations 50÷150 μs (full range is 0.3÷180 μs). For less intensive beams more sensitive diagnostic instruments are foreseen.

MULTIANODE GAS COUNTER

A multianode gas counter (MGC) was proposed initially as the main detector for low intensity diagnostics at the PIF. MGC is a combination of ionization and proportional air chambers, formed by an array of five plates (Fig. 2), which are fabricated as a standard 5 accuracy class printed-circuit boards made of FR4 with 0.5 mm width. Electrodes consist of 18 μm nickel, plated with 0.5 μm immersive gold.

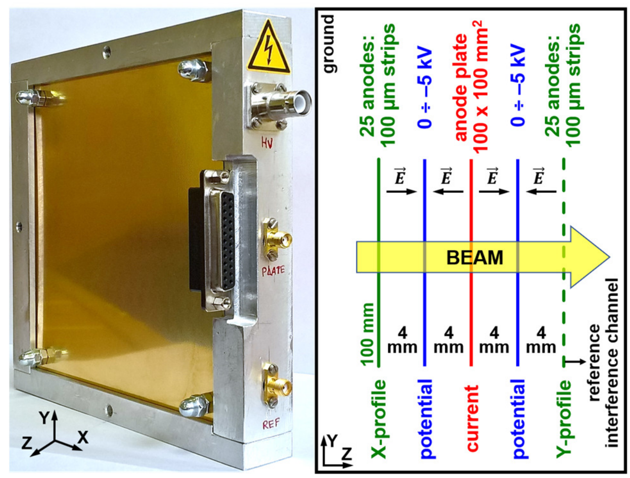

Figure 2: MGC photo and layout.

Central region operates as an ionization chamber to count particles in a beam pulse. A quasi-uniform electrostatic field is formed by two electrodes under negative potential and anode electrode under virtual ground of read-out electronics. All three electrodes have a duplex geometry, straddling the FR4 plate. Ionization electrons move to the current electrode from both sides, forming a relative beam intensity signal.

Lateral regions are proportional chambers for beam position and profile measurements. Each chamber is formed by the potential electrode and a multichannel structure, which consists of 25 anode stripes with 100 μm width, 100 mm length and 4 mm spacing. Strong non-uniform field around stripes (Fig. 3) leads to electron avalanches, increasing the desired signal.

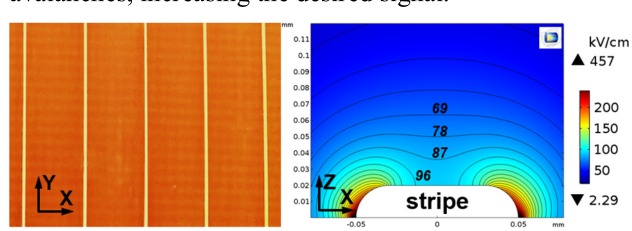

Figure 3: Photo of 100 μm stripes at the FR4 plate and distribution of electric field near a stripe at -4 kV potential.

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ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-MOPA07

LUMINESCENT DIAGNOSTICS

A system of luminescent diagnostics was foreseen as alternative instrumentation to control beam position and profiles. It consists of a phosphor screen (PS) with 100 x 100 mm^2 operating area, fixed at the entrance plate of MGC (Fig. 4), and CCD-camera.

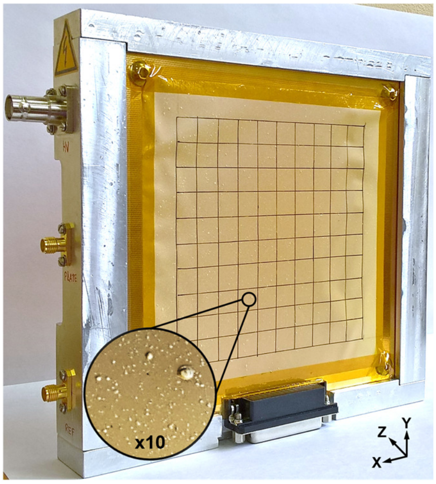

Figure 4: Phosphor screen fixed at MGC.

PS is made of P43 powder melted with polyimide – such process provides easy-to-use, but non-uniform luminescent film. However these nonuniformities of the powder are tens times smaller, than foreseen beam size.

The light emitted by PS is registered by monochrome CCD-camera Basler acA780-75gm in 12-bit mode. The lens (Azure 7524MM) and the CCD sensor (Sony ICX415) are sensitive to PS emission spectrum. The camera can be triggered by external sync pulse with beam pulse repetition rate as well as by an internal trigger with frequency up to 75 Hz. Data are transmitted to the control room in GigE standard by 130 m 6e-SFTP cable.

Besides measurements of spatial transverse parameters PS can be used as a pulse particle counter due to a high linearity of P43 light yield as a function of incident particles number [1]. Certainly, this type of intensity measurements, as well as MGC, demands a calibration by some absolute measurer, in our case – BCT.

The camera is located at a distance about 4 m and under an angle about 70° relative to PS plane, so registered image needs to be corrected (Fig. 5) and scaled. This procedure is realized with NI LabVIEW (IMAQ Vision module), which is used both for image capture and real-time postprocessing. In the actual PIF layout the reproduction PS scale is 2.2 pixel/mm.

Also, such software functions as background frame subtraction, frame summation and control of the camera parameters are implemented.

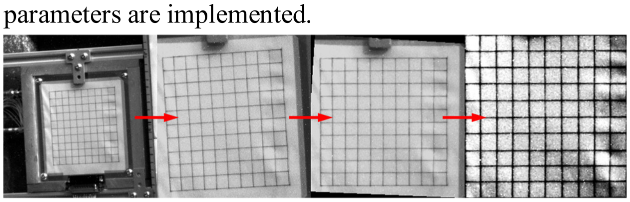

Figure 5: Image correction procedure in NI Vision.

BEAM TEST RESULTS

Beam tests were done in the full range of PIF parameters. The current range $10^{11}\div10^{12}$ p/pulse is totally covered by BCT for current measurements and partially covered by PS for position, but not for profile and current measurements. It was shown, that the beam density ~10^{10} p/cm^2 leads to PS light yield saturation (Fig. 6). Besides, at peak beam currents about 10^{12} p/pulse and beam energies > 45 MeV, link through GigE interface was lost several times after 50÷100 pulses with 1÷10 Hz repetition rate. Also, after two week-long PIF runs a dark noise of the CCD-sensor increased three times. This small, but accumulative effect, induced by fluxes of γ-rays and neutrons from the irradiated target and the beam dump, deteriorates the sensitivity of the camera.

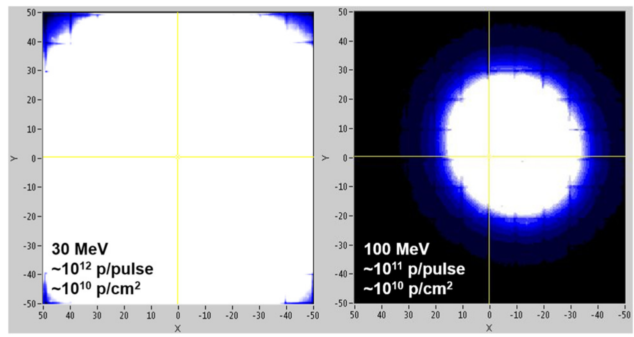

Figure 6: PS light yield saturation at different beam energies and currents, but with the same beam density.

MGC is also saturated in this current range and aging effects appear. The most important one is an irreversible decreasing of the signals from MGC stripes, which starts at beam density >10^{10} p/cm^2. At this density during beam tests the signals from the stripes started to decrease and disappeared totally at about 10^{11} p/cm^2. The main hypothesis about this effect is a sputtering of the gold from the nickel and following burning of the stripe in the avalanche due to O_2 molecular ions, that leads to a total stripe destruction and/or formation of dielectric oxide film on the stripe surface (Fig. 7), which blocks low energy ionization electrons. An obvious decision to resolve this problem is to use the air MGC with less intensive beams or to implement a gas-filled O_2-free design of the counter for the full range of measurements.

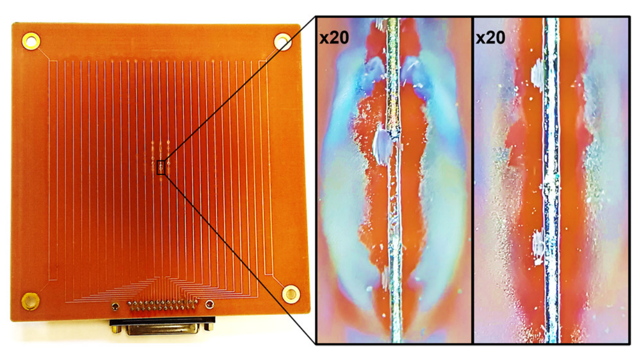

Figure 7: Aging effects at strips of proportional chamber: total stripe destruction and stripe oxidation – temper colors at the stripe nickel surface can be observed at the photos.

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-MOPA07

An initial procedure of calibration is started at about 100÷150 μA pulse current (~10^{11} p/pulse), when BCT signal-to-noise ratio is still good enough, and MGC with PS operate already without saturation.

The front-end multichannel electronics of MGC operates with a maximum gain for each channel 45 mV/pC. The currents of secondary electrons are integrated over a pulse at each channel simultaneously and then signals are transmitted by a multiplexer with the processing time 24 μs per channel. The back-end electronics is NI USB-6003 DAQ module (ADC: 16-bit, 100 kS/s). The software is based on LabVIEW and provides MGC data acquisition, control of high-voltage supply and gain factor (1/10/100/1000) as well as a manual procedure of the calibration by BCT.

The experimental operational range of MGC is 10^7÷10^{11} p/pulse. An example of the experimental gain of MGC ionization and proportional chambers vs. applied potential for 94 MeV beam energy is shown in Fig. 8.

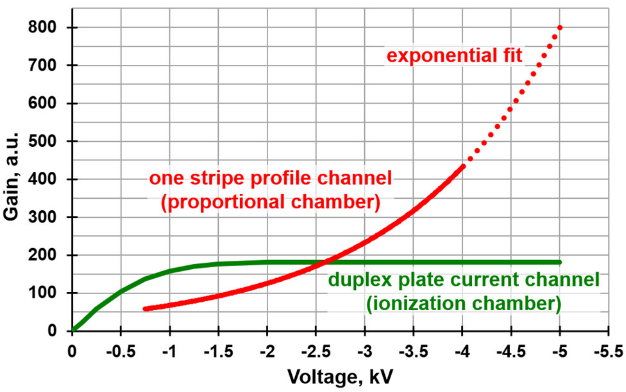

Figure 8: Experimental gain for the duplex plate current channel (green) and one stripe profile channel (red) at 94 MeV beam energy.

The finite thickness of MGC limits an energy of the incident beam to ~21 MeV. At less energies the beam is stopped before the second profile plane due to ionization losses in MGC volume.

Beam profiles measurements with PS are routine. In this case, it is more precise instrument obviously, as provides ~1 mm resolution vs. 4 mm in MGC (Fig. 9).

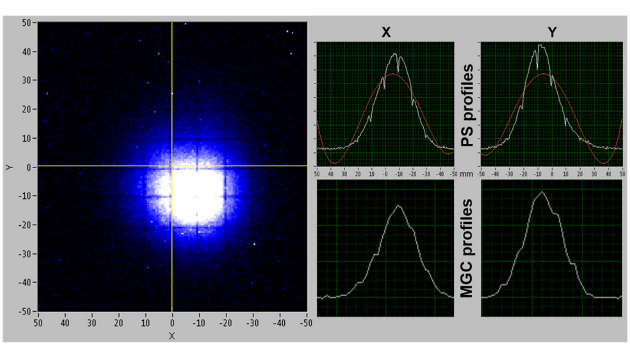

Figure 9: Beam cross-section at the PS and postprocessing profiles from the PS image and from MGC data.

Moreover, PS shows 2D beam cross sections and reveals images of irradiated targets with an ability to observe an internal density distribution (Fig. 10).

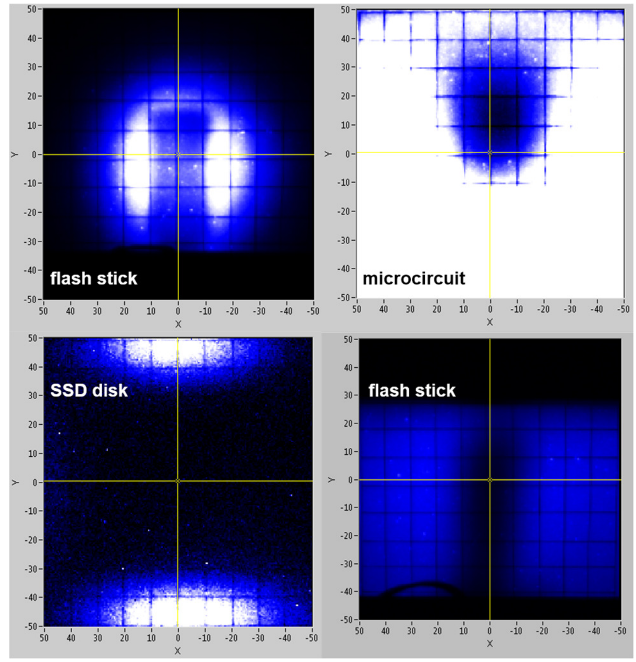

Figure 10: Images of "shadows" from beam irradiated objects at the phosphor screen.

After calibration a pulse particle count is also available by a software summation of image pixels intensities. The light yield remains linear in a full range of PS operation. However, a threshold sensitivity of PS is 10^7 p/cm^2, while MGC can provide both current and profile measurements with beam densities down to 10^5 p/cm^2 due to a special differential signal read-out with a reference interference channel (Fig. 2). One extra stripe operates like an antenna for interferences from different linac equipment near PIF. This signal is subtracted then from the profile signals of the regular stripes, so one can obtain a spatial sensitivity better by two orders of magnitude.

CONCLUSION

A new proton irradiation facility was constructed at INR RAS linac. To provide the beam diagnostics in a full range of operation parameters three devices were used:

- beam current transformer – 10^{10}÷10^{12} p/pulse,
- phosphor screen – 10^8÷10^{11} p/pulse (10^7÷10^{10} p/cm^2),
- gas counter – 10^7÷10^{11} p/pulse (10^5÷10^{10} p/cm^2).

The limits of use are connected with the saturation and aging effects for high-density and with interferences and signal-to-noise ratio for low-density beams. The energy limit ~21 MeV relates to the finite thickness of MGC.

The results of test operation and real measurements show the necessity of a further PIF diagnostics upgrade: a new luminescent screen with better surface uniformity and light yield, a gas-filled hermetical design of the gas counter, as well as an improvement of a radiation shield for CCD-camera and other back-end electronics.

REFERENCES

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