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LUMINESCENT DIAGNOSTICS OF LOW INTENSITY PROTON BEAMS AT INR RAS LINAC

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Abstract

INR RAS linear accelerator is a high-intensity accelerator, mostly used for rare isotopes production and neutron experiments. However low-intensity beam research is also presented at INR linac and requires appropriate diagnostics, such as luminescent diagnostics, which is implemented at a new proton irradiation facility. Important experimental results of beam position, size and intensity measurements during accelerator run are discussed.

INTRODUCTION

INR RAS linear accelerator is a high-intensity accelerator mostly used for isotopes production and neutron experiments. However low-intensity experiments such as irradiation of materials and proton therapy are also presented and require diagnostics that can provide information about beam parameters such as position, size and pulse charge (C/pulse) (or pulse intensity measured in particles/pulse). System of luminescent diagnostics is an appropriate one.

Luminescent diagnostics is one of the oldest methods of obtaining beam position and size and is already used for more than a century as a particle detector [1]. At INR linac system of luminescent diagnostics is implemented at the proton irradiation facility and consists of luminescent screen, CCD camera and software designed for image processing. Figure 1 shows a layout of its components.

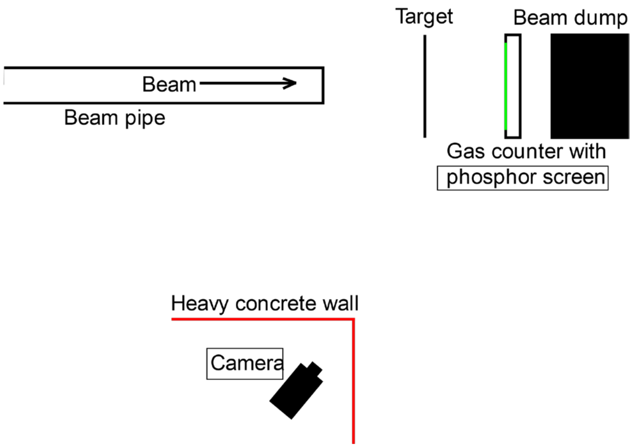

Figure 1: Layout of luminescent diagnostics components at INR PIF.

While passing through the scintillator screen, beam particles interacts with luminophore molecules which emit light. This makes feasible to measure beam position and size. Moreover, for many scintillators amount of emitted light is linear to pulse charge in a wide range of beam intensities, which makes luminescent diagnostics appropriate for measuring beam charge.

DESIGN FEATURES

Phosphor screen is a P43 luminophore molten with Kapton™ which is attached to multianode gas counter, another diagnostics method on proton irradiation facility (Fig. 2). Phosphor screen is 100*100 mm^2 and has coordinate grid on it.

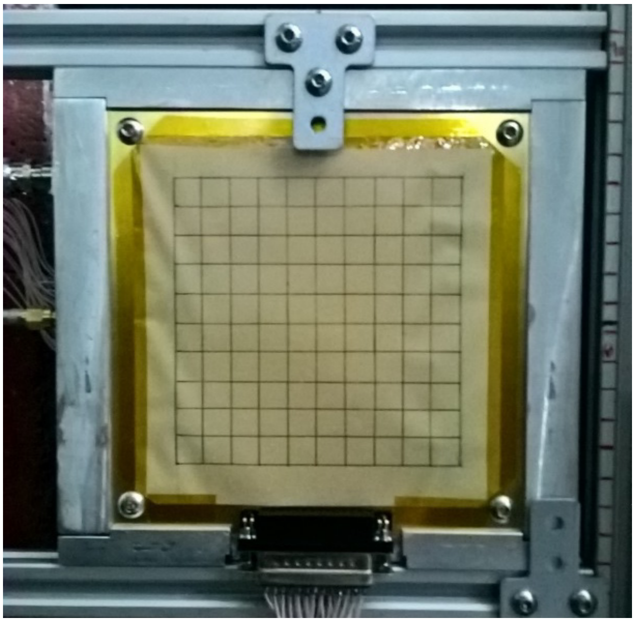

Figure 2: Phosphor screen.

CCD camera which is used for image registration is hidden behind heavy concrete wall to decrease camera irradiation during PIF operation. Basler acA780-75gm [2] monochrome camera with 75 mm focal length lens is used for image registration. Camera is connected with a PC in a control room by a GigE standard cable. There is an interesting fact that cable length is 130 m, which is considered inappropriate for Gigabit Ethernet standard, however camera still works correct with this limit exceed.

SOFTWARE FEATURES

Camera is displaced non-perpendicularly to luminescent screen plane and luminophore image is distorted. To solve this problem a LabVIEW [3] program was written to make an image correction. It uses several

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affine transformations and requires preliminary calibration. Stages of correction are presented in Fig. 3.

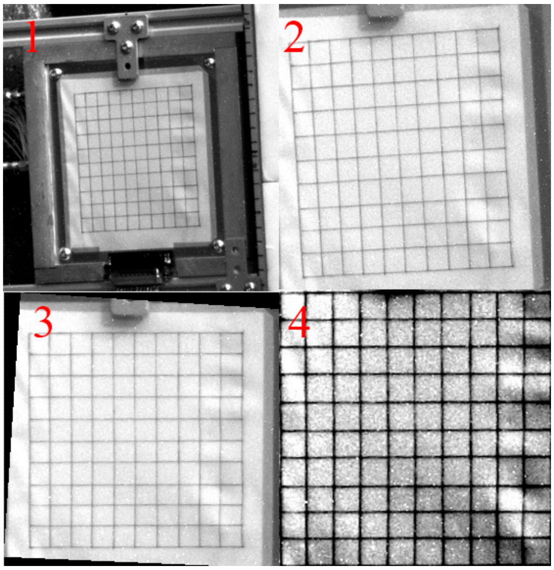
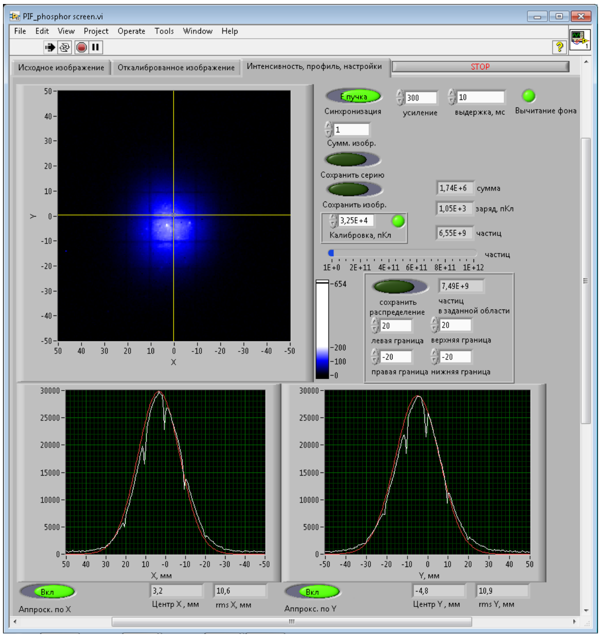


Figure 3: Image correction procedure. Numbers show consequent images of luminescent screen during preliminary calibration.

After image correction software obtains information about beam position, size and pulse charge and output it on desktop frame, which is presented in Fig. 4.


PIF_phosphor screen.vi

Интенсивность, профиль, настройки

Синхронизация: E пучка
усиление: 300
выдержка, мс: 10
Вычитание фона
Сумм. изобр.: 1
Калибровка, пКл: 3,25E+4
сумма: 1,74E+6
заряд, пКл: 1,05E+3
частиц: 6,55E+9
частиц в заданной области: 7,49E+9
левая граница: 20
верхняя граница: 20
правая граница: -20
нижняя граница: -20
Аппроск. по X: Вкл
Центр X , мм: 3,2
rms X, мм: 10,6
Аппрокс. по Y: Вкл
Центр Y , мм: -4,8
rms Y, мм: 10,9

Figure 4: Software desktop frame.

At first, beam profiles could be fitted with gaussian or parabolic approximation, but after further investigation with the help of SRIM [4] program it was found out that parabolic distribution of particles in beam pulse after passing through 1 mm of aluminum foil 1 m of air transforms into gaussian one. That is why now only gaussian approximation is available. Beam profiles at the outlet window and after travelling through air is presented on Fig. 5.

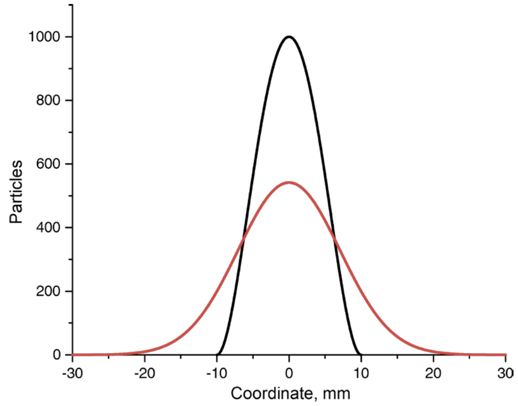


Figure 5: Beam (90 MeV) profiles at the outlet window (black) and after passing through 1 m of air (red).

An additional calibration with a help of reference diagnostics such as beam current transformer should be done for measuring pulse charge. Not only pulse charge but also beam density can be measured.

To eliminate external illumination there is an option to subtract background frame from image of luminescent screen. There is an example of subtraction in Fig. 6. It is possible to save one beam image and all parameters measurements or series of 50 sequential beam images. User can change gain and exposure of CCD camera, however the program will automatically recalibrate all parameters.

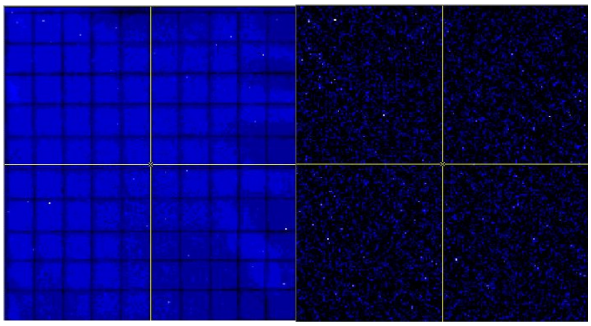


Figure 6: Image of luminescent screen with background illumination (left), the same image with subtracted background frame (right).

Components being used in luminescent diagnostics system make restraints on its accuracy and resolution. RMS errors of measurement of beam position and size were respectively determined as 0.92 mm and 0.45 mm. RMS error of pulse charge measurement is 3 %.

EXPERIMENTAL RESULTS

During accelerator runs in November 2017th and April 2018th system of luminescent diagnostics was used at the proton irradiation facility. During these runs it was used with beam energies from 20 to 209 MeV together with gas counter. It was used for beam control during irradiation of electronic components such as flash drives, microchips and solid state drives (Fig. 7).

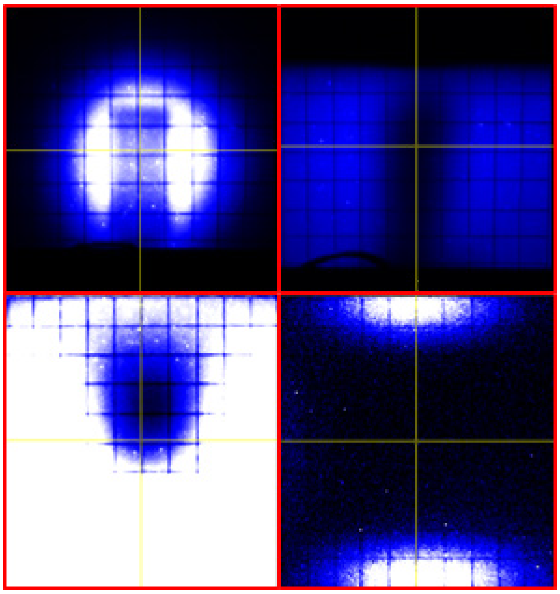


Figure 7: Beam images during irradiation of flash drives (first two images), SSD and microchip.

The limits of applicability of used luminescent diagnostics system were determined. If camera exposure is less than luminophore emission decay time light will not be collected by the camera entirely. Beam intensity was measured by luminescent diagnostics with different exposure while beam parameters was maintained the same. Figure 8 shows approximation of acquired data. Minimal exposure is 8 ms.

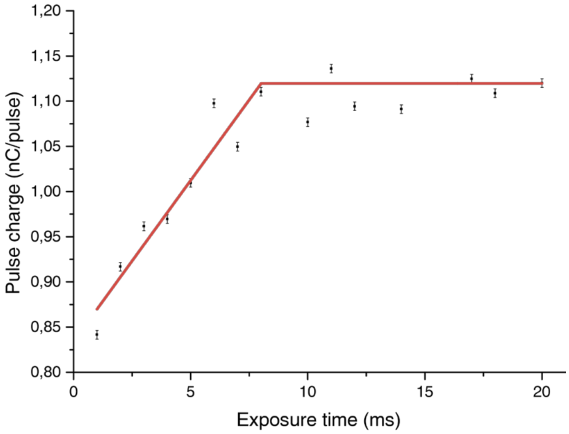


Figure 8: Dependence of measured pulse charge from camera exposure.

A problem of camera pixel saturation emerged while luminescent diagnostics was used, which led to an increase of pulse charge measurement error. Figure 9 shows that error significantly grows from pulse charge of 16 nC/pulse.

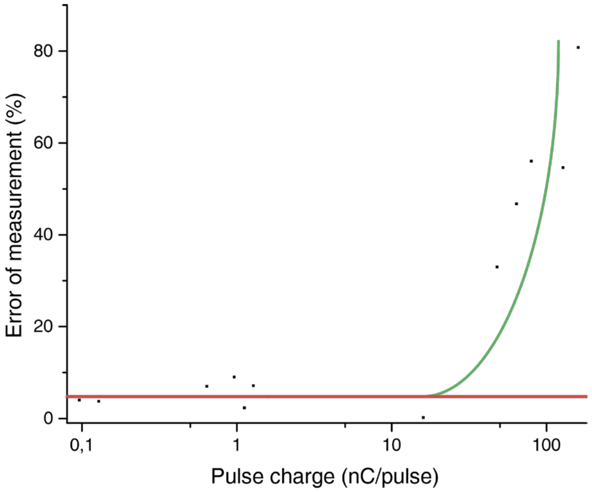


Figure 9: Dependence of pulse charge measurement error from pulse charge.

It is more correct to measure this limit not in pulse charge but in pulse charge density, but beam current transformer used as reference diagnostics cannot measure pulse charge density. Density limitation is equal to 1.6 C/(pulse*cm^2). This limitation can be diminished by camera gain range broadening. This software update has been already done but several verification tests are to be done in the nearest accelerator run.

CONCLUSIONS

Luminescent diagnostics, implemented at INR RAS linear accelerator, provides measurements of beam position, size and pulse charge in wide range of pulse intensities ($10^8 \div 10^{11}$ p/pulse or $10^7 \div 10^{10}$ p/cm^2) and full range of beam energies provided by linac. However, this system has limitations, which were measured. Some of them have already been diminished, but measurements of new values of limits are still to be done.

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[2] https://www.baslerweb.com/
[3] http://www.ni.com/ru-ru/shop/labview.html
[4] http://www.srim.org

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