DEVELOPMENT OF BEAM POSITION AND PROFILE MONITOR BASED ON LIGHT RADIATION OF ATOMS EXCITED BY THE BEAM PARTICLES

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Abstract

Particle beam position and profile monitor based on registration of the light radiated by residual gas atoms is being developed by collaboration JINR – Forschungs-zentrum Jülich. Proposed device and first experiments have been performed at Nuclotron (JINR) and COSY (FZJ) accelerators are presented in this report.

INTRODUCTION

Interaction of ions moving in an accelerator chamber produces ionization and excitation of residual gas molecules and, as a result, generation of low-energy electrons and ions as well as radiation of light and ultraviolet photons. All these constituents can be used for nondestructive beam diagnostics. There are methods of such a diagnostics based on registration of electrons or/and ions of ionized residual gas [1-3]. One of the first attempts in application of light radiation of atoms excited by the beam particles was reported in [4]. Recently the interest to this principle was increased. The methods of construction of beam position and profile monitors were proposed in [5-7]. However these methods are applied very rarely and are not developed properly. At the same time the diagnostics based on the residual gas luminosity has several **advantages** comparatively to the methods based on registration of ionization particles:

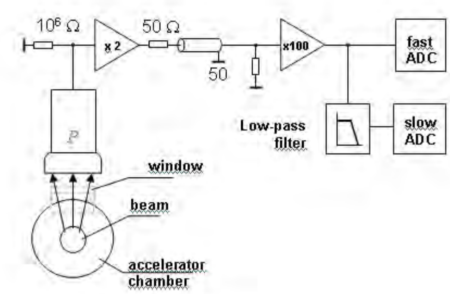
- Insensitivity to external electric and magnetic fields of a high level where an application of ionization methods is very limited.
- The spatial resolution of the method is not limited by the beam intensity: the beam space charge field does not influence a photon trajectory.
- The spatial resolution can be easily varied with optic lenses. The time resolution of ~200 ps can be obtained. It is at least by one order of magnitude better than the resolution of electron-based diagnostics systems and by 3 orders better than ion-based systems.
- The photomultipliers (PMT) are significantly more resistive against injurious exposures like the bright light, the beam and secondary particles than microchannels plates (MCP), which are applied usually for electrons and ions registration.

The main **disadvantage** of the photon registration method is its rather low sensitivity because atomic excitations cross-section is smaller than the ionization one. However, this disadvantage practically does not limit application of the method under specific conditions.

TEST OF PRINCIPLE

The preliminary measurements of light radiation intensity of residual gas atoms excited by the circulating beam ions were performed in the warm area of the ring at superconducting synchrotron Nuclotron [6, 8] at JINR (Dubna) as well as at COSY (Juelich) [9] to estimate the sensitivity of the method.

Light at Nuclotron (Fig. 1) was observed by single channel photomultiplier tube FEU-110 at the distance of ~100 mm. The diameter of the photocathode is of 60 mm. Residual gas pressure was at the level of 10^{-8} mbar in accelerator chamber. The single-bunch beam was injected into the ring at the energy of 5 MeV and accelerated up to 1.2 GeV. Beam intensity of $^{2}H^{+}$ and $^{12}C^{6+}$ ions was at the level of ~ $10^{8} \div 10^{9}$. The light intensity "steps" for every pass of the bunch are distinguished in signals.



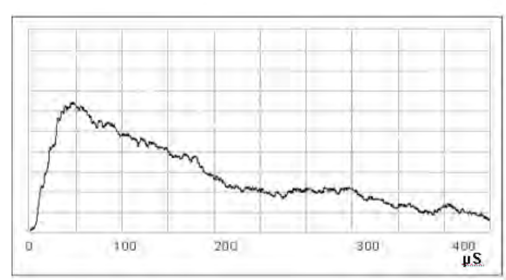


Figure 1: Scheme of light intensity tests at Nuclotron and measured signals.

Light at COSY was observed by multianode photomultiplier tube Hamamatsu H7546 at the distance of ~100 mm. All 64 anodes of PMT of 2x2 mm^2 size were connected together. Residual gas pressure was of the order of 10^{-8} mbar in accelerator chamber. Beam intensity of 45 MeV proton beam was at the level of 10^{10} p/bunch. Light signals were registered by digital oscilloscope and are presented at Fig. 2

The results of measurements and mathematical data acquisition have shown the feasibility of the beam monitoring system based on the lig possible scheme of beam position and profile monitor is shown at Fig.3. It should be remarked, that under high vacuum conditions or at low beam intensity the sensitivity ignificantly increased. One can do it applying a gas or vapour jet, which produces local enhancement of residual gas concentration.

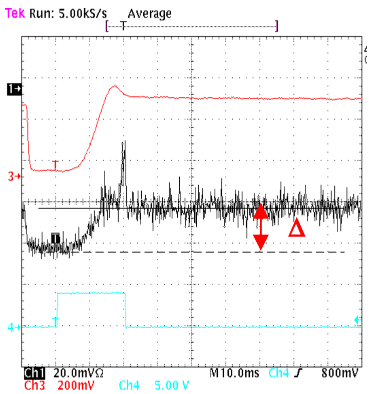


Figure 2: Signals of light intensity measured at COSY ring, *p*= $6{\cdot}10^{-8}$ *mbar*, $4.7{\cdot}10^{10}$ *p*, Δ= *21.2 mV*

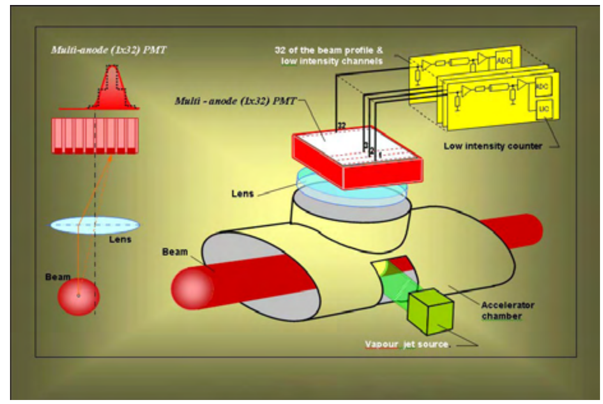


Figure 3: Scheme of beam position and profile monitor

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EXPERIMENTS WITH GAS TEST CHAMBER IN EXTRACTED BEAM

The jet generator in vacuum chamber of accelerator for test of light radiation of different kinds of atoms and molecules with circulating beam is relatively complicated and rather expensive device. Therefore at the first stage of experiments test gas chamber was constructed (Fig. 4). It could be filled with any gas or some another luminescence substance at the desired pressure and placed into the extracted beam of accelerator. The single-pass beam crosses the chamber volume through the folia installed at the end-caps of the chamber. The chamber was equipped with quartz glass window for light registration to provide as large as possible spectrum range of light. The movable light shield is placed in front of glass window to separate the parasitic light generated in the quartz window body (background) from the light generated in gas of the internal volume of the chamber.

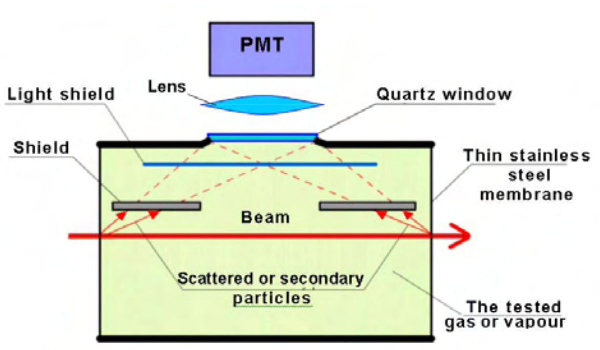

Figure 4: Scheme of gas test chamber

The target was designed and produced at JINR (Dubna) and installed in Jessica beam line at COSY (Juelich) Fig. 5. The proton beam of ~10^{10} intensity at the energy of 1.2 GeV of ~4 cm diameter of ~100 ns duration has passed through the gas target filled with N_2 of pressure from 10^{-3} to 10^{+3} mbar.

Image of the beam was projected onto MPMT (1 line of 32 pixels of 7x0.8 mm^2 size of 1 mm pitch) located at 50 cm distance from the beam via the lens of 10 cm focusing distance

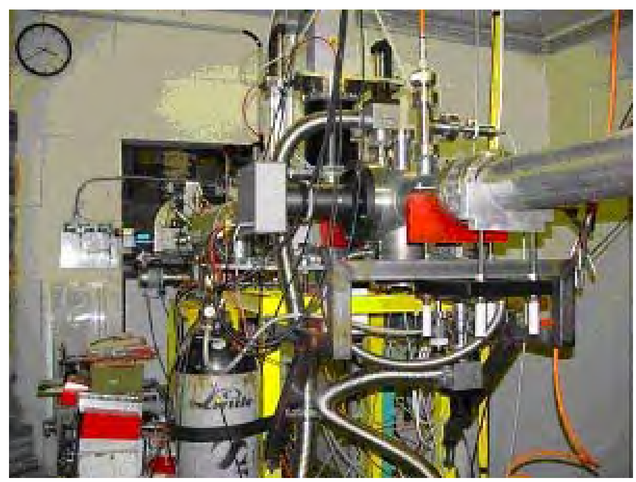

Figure 5: View of gas test chamber at JESSICA beam line

32 pixels of MPMT were divided into 8 separated groups of 4 interconnected pixels. Signals of these 8 groups were amplified by preamplifiers, located by MPMT which was designed and produced at COSY. These signals were registered by two Tektronix oscilloscopes.

The signals from 8 groups of anodes at the pressure of N_2 of 16 mbar are shown in Fig.6 and corresponding to them beam profile is given in Fig. 7. Fig.8 shows profiles of two beams, which were shifted one relatively to another one by ~10 mm.

It is necessary to notice that the level of background in area of the beam was too high due to products of interaction of the beam particles with the target, used for JESSICA experiment. Therefore the proper level of N_2 pressure was limited by 5x10 $^{-1}$ mbar at the acceptable ratio of light signal to the background at those of level of ground.

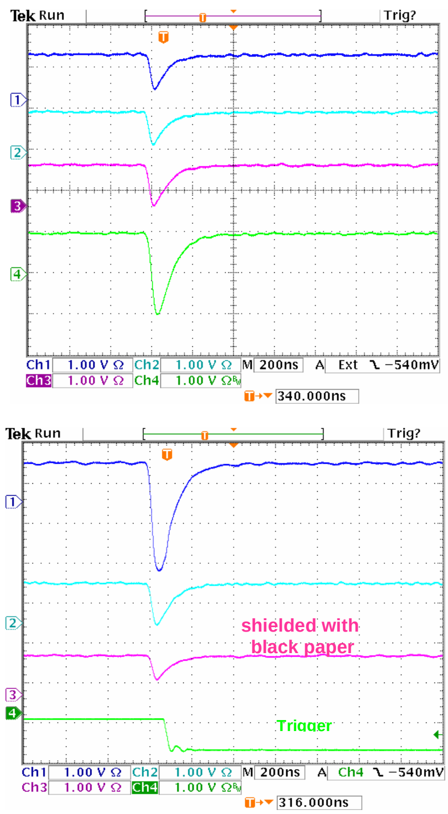

Figure 6: Oscillogrammes of light signals registered at pressure of N_2 of 16 mbar.

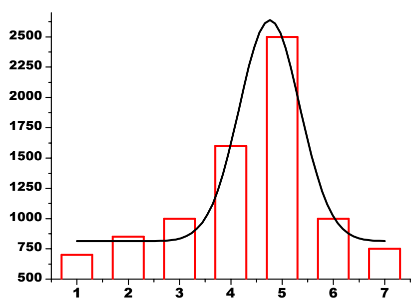

Figure 7: Gauss fit of registered beam profile

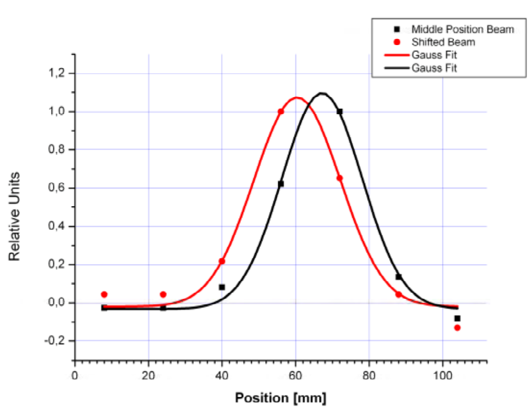

Figure 8: Two shifted beams

SUMMARY

- Nondestructive method of beam diagnostic system based on light radiation of atoms excited by the beam particles has the advantages - insensitivity to external magnetic and electric fields and, as a consequence, to the beam space charge fields. It allows to get higher spatial and time resolution.
- Multichannel photomultipliers are appreciably more resistive against injurious exposures like the bright light as well as beam and secondary particles than microchannels plates (MCP) which are applied usually for electrons and ions registration.
- N_2 can be considered as possible scintillation substance.
- However it is necessary to increase the sensitivity of the device. Additional researches are necessary for this goal. More effective scintillating substances are required to use them in gas or vapour jet generator, which produces a local enhancement of residual gas pressure. The level of background has to be reduced. Also development of convenient optic system and mathematical methods of data acquisition is necessary.

ACKNOWLEDGEMENTS

We are grateful to teams of Nuclotron and COSY accelerators and their leaders A.Kovalenko and R. Maier as well as to JESSICA collaboration for the possibility to provide measurements and for their interest and support of the work.

REFERENCES

1. G. Budker, Ya. Derbenev, I.Meshkov et al., Atomnaya Energia, v. 40, № 1, 1975; Particle Accelerators, vol. 7, 1976.
2. V.Mikhailov, V.Rezvov et al, Proc.of the 13-th Int. Conf. "Cyclotrons and their Application", Vancouver, Canada, 1992, p.473.
3. V.Kamerdzhiev and J.Dietrich, IKP Annual Report 2001, Jül-3978.
4. R.G. Bikmatov, L.G. Boriskin, V.I. Kudelaynen, I.N. Meshkov, V.V. Parkhomchuk, Atomnaya Energia, v. 24, № 1, 1967.
5. O.I. Brovko, I.N. Meshkov, A.N. Parfenov, Patent № 2212690, priority of 27.07.2001, Moscow, Russia.
6. O.I. Brovko, et al., Proc. of the International Workshop Relativistic Nuclear physics: from hundreds of MeV to TeV. (Varna, Bulgaria, September 10-16, 2001), published by JINR, Dubna, 2001. vol. 1, pp.89-94.
7. M.A.Plum et al., Nucl. Instr. Meth. A492 (2002), p.74.
8. A.D. Kovalenko. Proc. EPAC' 94, v. 1, p.p. 161-164. London, 1995.
9. J.Dietrich et al., IKP Annual Report 2002, Jül-4052