GAS SCINTILLATION BEAM PROFILE MONITOR AT COSY JÜLICH *

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Abstract

The interaction of ion beams with the surrounding residual gas leads to photon emission by the excited residual gas atoms and molecules. These photons in the visible spectrum range can be used to monitor the transverse beam profile. We therefore use a multichannel photomultiplier (PMT) together with an optical imaging system. Measurements at COSY synchrotron of the Forschungszentrum Jülich are presented. The usability of the method is discussed by comparing to measurements at the iThemba LABS beamline and the beamline of the JESSICA experiment, a neutron spallation source test setup at COSY.

INTRODUCTION

The knowledge of the beam position and the transverse profile is essential for the successful operation of an accelerator facility. Due to thermal reasons high beam energy and/or high beam currents limit the use of traditional intersecting methods like wire scanners or secondary electron emission (SEM) grids. At synchrotrons non destructive methods are preferred to monitor the circulating beam, as the beam passes the interaction region many times. Even a small influence per turn would add up, leading to possible beam loss. Several kinds of diagnostic devices, using the products of the interaction between the ion beam and the residual gas, are under development or in use. Usually the devices register the ions and/or electrons produced in collisions of the beam particles with the residual gas. A few attempts have already been made to use the emitted light of the excited residual gas particles in order to monitor the beam [1]. This method has the advantage of being insensitive to electric or magnetic fields. Also the spatial and time resolution is high, allowing a single pulse measurement. The principle limitations of this method are the low cross section for light production in the visible range and the small solid angle of the optical setup. This leads to an available count rate about three orders of magnitude lower, compared to profile monitors based on residual gas ionization. Nevertheless, a wide range of applications can still be covered with this method.

MEASUREMENT TECHNIQUE

The light emitted by the residual gas is focused by a glass lens onto a multichannel photomultiplier (PMT) array, as shown in figure 1. A Hamamatsu PMT (7260-type, 32 channels, 0.8×7 mm photocathode size, 1mm pitch size) was used for these measurements. The readout was performed using a 48 multichannel current digitizer, developed at iThemba LABS [3].

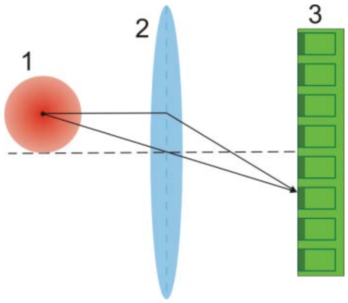

Figure 1: Measurement principle [2] (not to scale): The light from the interaction of the beam with residual gas (1) is focused by a glass lens (2) onto the multichannel photomultiplier (3).

PHOTON YIELD

While measuring the transverse beam profile using photons emitted by residual gas the only controllable parameters to influence the photon yield are the composition and pressure of the residual gas at fixed ion beam parameters. Although the increase of residual gas pressure is normally not standard practice at accelerators, this method has been successfully tested. While the residual gas mixture is given, the gas to be added can be chosen. Two gases are candidates for addition, N_2 and Xe, because both show strong light emission within the visible range and are also easily pumped out of the vacuum system.

Preliminary tests regarding the residual gas scintillation spectra were performed at a test bench [4]. A 20 keV He^+ beam passed an interaction region, where various gases could be added up to a total pressure of 10^{-3} mbar. A grid type monochromator together with a single channel PMT, that has a similar spectral response characteristics compared to the multichannel model, was used to measure the scintillation spectra. Since the ion source of the test bench uses He and H_2 is typically a dominating component of the residual gas in an accelerator, the scintillation spectra of these two gases were measured as well. The spectra are shown in figure 2

The results of the spectral measurements are in good agreement with [5]. The relative intensity at 424 nm (N_2) has been found to be less than expected. The overall results however clearly show that N_2 and Xe are

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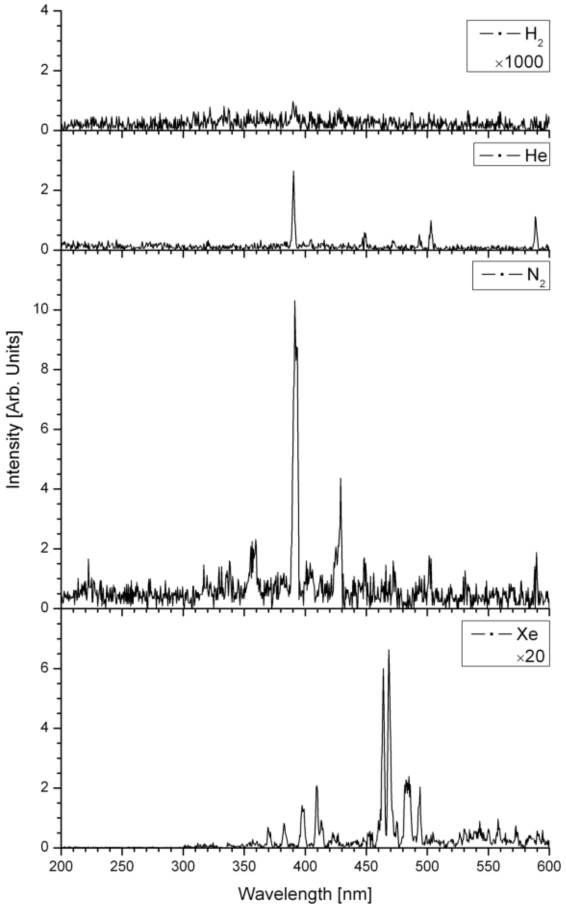

Figure 2: Scintillation spectra of H_2, He, N_2 and Xe in the visible range. The intensity scaling is common to all four measurements. For comparison the results for Xe and H_2 are multiplied by a factor of 20 and 1000 respectively.

promising candidates to boost the overall photon yield for a given total pressure. For further experiments N_2 is used, as the photon yield of Xe is slightly lower combined with a much higher price.

PROFILE MEASUREMENTS AT THE CYCLOTRON BEAMLINE

The scintillation profile monitor (SPM) was used to measure profile and position of the 3.14 MeV protons at the iTemba LABS transfer beamline. To verify the correct operation of the SPM, the beam was transversely shifted by a steering magnet. The beam position was derived from the beam profile and plotted together with the position reported by a standard beam position monitor (BPM) just downstream the SPM. Both results are in good agreement, as shown in figure 3. During the measurements, the PMT was operated at only $^2/_3$ of the maximal voltage, leaving room for about two orders of magnitude lower beam intensities or lower pressure.

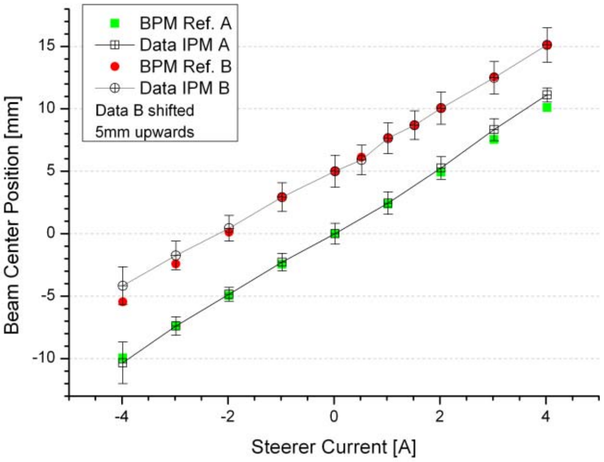

Figure 3: Beam position measured with the scintillation profile monitor (SPM A,B) and with a reference BPM at the 3.14 MeV iThemba LABS beam transfer line versus steerer current (beam current 300 µA, residual gas pressure ~ 10^{-5} mbar).

PROFILE MEASUREMENTS AT COSY

With the given residual gas pressure, residual gas mixture, the parameters of the optical system, and the PMT quantum efficiency, the calculated count rate is only 3 – 6 counts per second, depending on the proton energy within the synchrotron. Under these circumstances the signal to noise ratio is rather poor, making a reasonable measurement impossible. One possible compromise is, adding e.g. N_2 to the vacuum system near the SPM, as mentioned earlier.

Figure 4 shows the result of the profile measurement during a whole machine cycle, which in this case lasted 72 s. At injection the beam was located at its center position and was then accelerated to 1.7 GeV/c. About three seconds later the beam is displaced intentionally. The beam profile and also the center position could be successfully monitored throughout the complete cycle. During this first test the vacuum conditions were locally changed to achieve a better signal to noise ratio by manipulating the function of a vacuum pump to release deposited gas. This way the vacuum conditions could not be held stable over a long time, giving rise to variations of the overall intensity.

SCINTILLATION CROSS SECTION

Cross section calculations for the emission of photons in the visible range and a broad beam energy range are based on results from [1]. These data and the calculated cross sections obtained from our own measurements are summarized in figure 5, together with an adapted progression, derived from the Bethe formula as well as a low energy supplement based on [6].

In addition to the measurements described above, data was taken at an external beamline at COSY (JESSICA) [8]. The extracted beam passed through an enclosed chamber, where the gas composition and pressure could

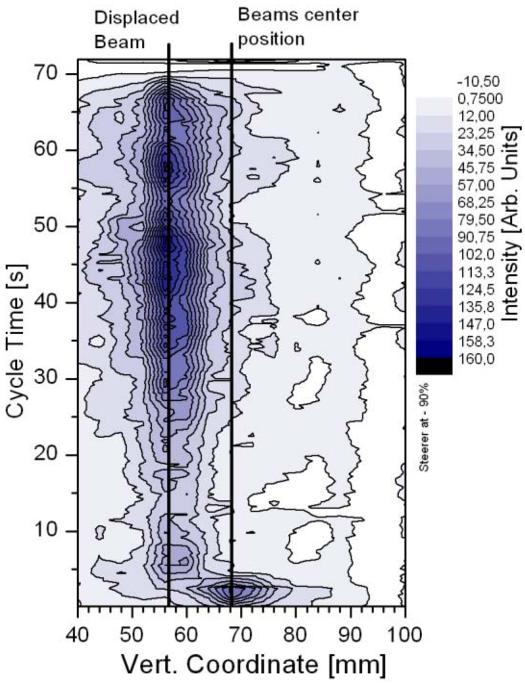

Figure 4: Beam profile versus time for a 72 s machine cycle. The beam is injected at its central orbit and then displaced. The BPM reference showed 13 mm displacement. The vacuum conditions were changing during the cycle.

be freely chosen, without affecting the vacuum system of the accelerator.

The data acquisition at the JESSICA beamline and the iThemba LABS have been performed using amplifiers equipped with automatic gain control (AGC), in order to boost the signals for transport via long cables out of the radiation area. Because of the AGC, only a mean value of the amplification factor is known, leading to an uncertainty in the cross section calculations, which can be seen in the discrepant results in figure **5**.

The measurements at COSY were performed with a different data acquisition hardware, which is described in the section ‘measurement technique’. The use of this hardware results in a better knowledge of the measurement parameters. This allows a more exact calculation of the cross section, reflected in figure **5**.

CONCLUSIONS

The method of beam profile measurements based on residual gas scintillation has been evaluated. Good profile measurements results were achieved at the JESSICA beamline, despite a high radiation background. As a further development for areas like this, the light could be transported out of the radiation area with a proper optical system. Also the experiments at iThemba LABS showed a use case, when non-disturbing beam profile measurements are required. For both cases a simple, cost effective and easily maintainable system is presented. The only component which has to be assembled in vacuum is a viewport, all other components are outside the vacuum system.

For use in synchrotrons with ultra high vacuum conditions and particle energies corresponding to the minimum of the scintillation cross section, the system is beyond its limits. Here profile measurements are only possible when the conditions are changed by intention, e.g. increasing the pressure inside the vacuum system. A system based on residual gas ionization [9, 10] might be the better choice, as the event rate for ionization is about three orders of magnitude higher. Such a system usually has the disadvantage of being realized through a very complex and costly apparatus.

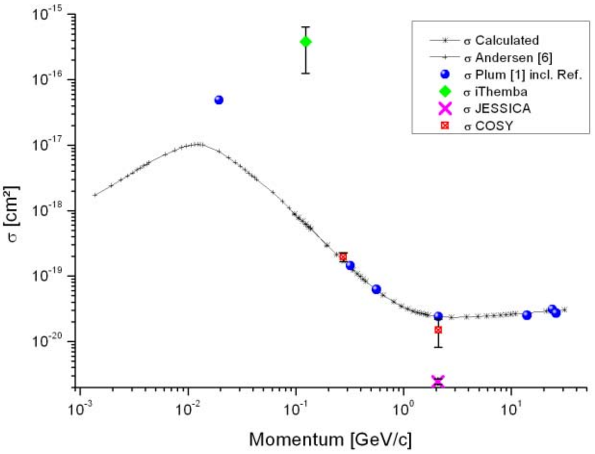

Figure 5: Cross section calculated from beam profile measurements, shown together with values from [1] and [6] as reference. Error bars represent statistical error only.

REFERENCES

[1] M.A. Plum et al., Nucl. Instr. Meth. A492 (2002), p. 74.

[2] N. I. Balalykin et al., WEHP42, Proceedings of RuPAC XIX, Dubna, 2004.

[3] iThemba LABS Annual Report 2008, p. 50.

[4] C. Boehme et al., Beam Instrumentation Test Facility, IKP Annual Report 2009, Forschungszentrum Juelich, t.b.p.

[5] Ralchenko, Yu., Kramida, A. E., Reader, J. and NIST ASD Team (2008). NIST Atomic Spectra Database (version 3.1.5). National Institute of Standards and Technology, Gaithersburg, MD. [2010, March 1] http://physics.nist.gov /asd3

[6] H. Andersen and J. Ziegler, Hydrogen: Stopping Powers and Ranges in All Elements Vol. 3, Pergamon Press 1977.

[7] J. Dietrich et al., First Beam Profile Measurements Based on Light Radiation of Atoms Excited by a Particle Beam, AIP Conf. Proc. 773, 184 (2005).

[8] N.I. Balalykin et al., WEHP42, Proceedings of RuPAC XIX, Dubna 2004.

[9] C. Boehme et al., Beam Test of the FAIR IPM Prototype in COSY, Proceedings of DIPAC2009, Basel, Switzerland.

[10] C. Boehme et al., Nondestructive Beam Instrumentation and Electron Cooling Beam Studies at COSY, Proceedings of IPAC2010, Kyoto, Japan, t.b.p.