PROGRESS WITH THE SCINTILLATION PROFILE MONITOR AT COSY

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Abstract

After successful demonstration measurements with the Scintillation Profile Monitor (SPM) at COSY, a dedicated vacuum chamber with two vacuum windows and supporting vacuum ports was installed in the COSY synchrotron. The chamber is blackened inside to suppress light reflection. Since residual gas pressure is too low to support reliable profile measurements based on beam induced scintillation, a piezo-electric dosing valve was installed allowing fast injections of defined amount of nitrogen. A 32-channel photomultiplier is used to detect light. Beam profile measurements and first experience are reported.

INTRODUCTION

Beam profile monitoring is essential for emittance control and general performance optimization in an accelerator. Unlike linear accelerators the beam emittance in a circular machine can be determined using non-destructive techniques only. At COSY [1], a machine equipped with electron cooler and stochastic cooling system, profile data is vital for studies of the cooling process. A joint effort by the beam instrumentation groups at GSI, Darmstadt and COSY, Jülich resulted in an Ionization Profile Monitors (IPM) being operational at ESR [2] and COSY [3]. The IPM was designed to be the standard profile monitor for the future FAIR [4] machines. The IPMs real time performance together with high sensitivity and resolution make it a very valuable instrument. However, high cost and the presence of components prone to aging in vacuum, trigger the search for alternative methods. A profile monitor utilizing scintillation of residual gas offers a viable alternative to an IPM for certain beam conditions [5, 6]. The gas atoms and molecules are excited by the beam particles and emit visible light shortly after the excitation [7]. After passing a vacuum window the light is focused by an optical system and is detected by a multi-channel photomultiplier or an image intensified camera. Measuring the photon distribution allows reconstructing the initial beam profile.

SPM IN A PROTON SYNCHROTRON

Challenges

Compared to the ionization event rate, the rate of scintillation events is expected to be three orders of magnitude lower [8]. The reasons are the lower scintillation cross section and the geometrical factor. Nearly all ions/electrons can be collected in an IPM but only a fraction of light reaches the detector in the SPM [8]. Furthermore, vacuum conditions in a proton synchrotron like COSY cause the scintillation signal to disappear in the background noise.

At average COSY vacuum of 10^{-9} mbar no SPM measurements are possible. When internal targets (mostly hydrogen) are in operation the residual gas pressure can reach values beyond 10^{-7} mbar in the target region of the machine. Unfortunately this pressure bumps cannot be used for profile measurement. Nitrogen was found to be the most suitable gas [7, 9]. To increase the signal to noise ratio a local nitrogen pressure bump is introduced.

Advantages

A scintillation profile monitor does not require any vacuum parts except for vacuum windows which makes it a simple, inexpensive and robust instrument. Being based on light, the technique is insensitive to the electric and magnetic fields in the vacuum chamber (e.g. beam space charge). Furthermore, the light can be transported outside the accelerator tunnel if necessary. This is particularly important for high intensity machines where high radiation levels make installation of electronics in the tunnel difficult.

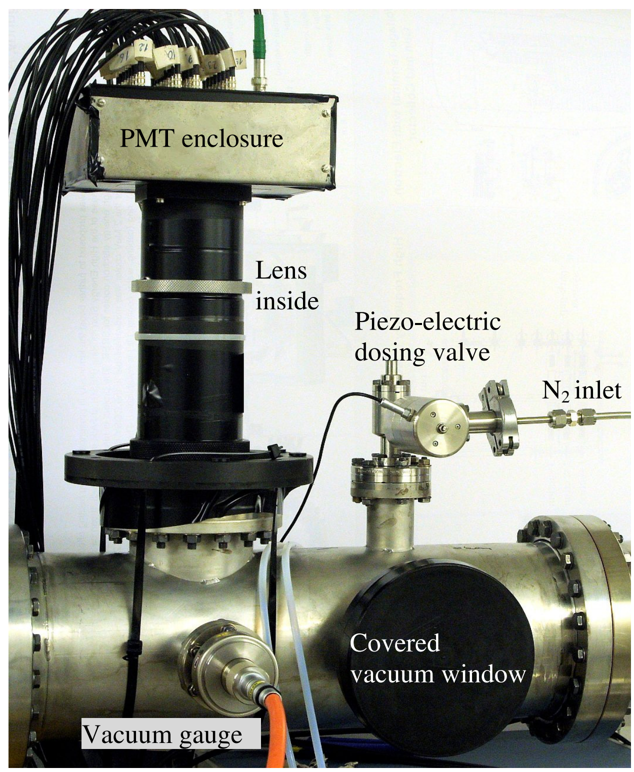

Figure 1: A photograph of the SPM installation in COSY. Shown is the vacuum chamber with two vacuum windows for light extraction and two vacuum ports for N_2 injection and vacuum measurement. On the upper flange a simple one lens optical system and a multi-channel photomultiplier are installed for horizontal beam profile measurements.

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The Setup

The SPM vacuum chamber installed in COSY has a length of 508 mm (Fig. 1). The inner diameter of 150 mm corresponds to the inner diameter of COSY beam pipe in straight sections. To avoid possible light reflection the inner surface of the vacuum chamber was acid cleaned to increase the roughness and then blackened by chemical treatment. The chamber is equipped with two DN100 vacuum windows and two DN40 vacuum ports for pressure measurement and gas inlet. To create local pressure bumps a commercially available piezo-electric dosing valve is used. The piezo stack is driven by a 1 kV power supply purchased from the same company. After passing the vacuum window the light is focused by a lens and detected by a 32-channel photomultiplier. The SPM is currently equipped with one detector only measuring horizontal profiles. The calibration in mm is based on the assumption that the vertical position of the beam corresponds to the geometrical center of the vacuum chamber. The PMT readout is done by a 48-channel picoammeter module developed by iThemba Labs, South Africa [6]. The module design is based on a commercially available low noise switched integrator chip. The PMT power supply and readout module as well as dosing valve power supply are controlled and/or read out over local Ethernet. The latter requires an Ethernet to RS-232 converter. The control and data acquisition software is written in LabView.

Measurement Procedure

Although the dosing valve is specified for pulsed operation with pulse width up to 20 ms the power supply does not work reliably with pulse widths below 100 ms. Since the pulsed operation was not possible, the measurements, presented in this paper, were done by slowly (few seconds) ramping the voltage using the RS-232 interface of the valve power supply. The vacuum reading is shown in Fig. 2.

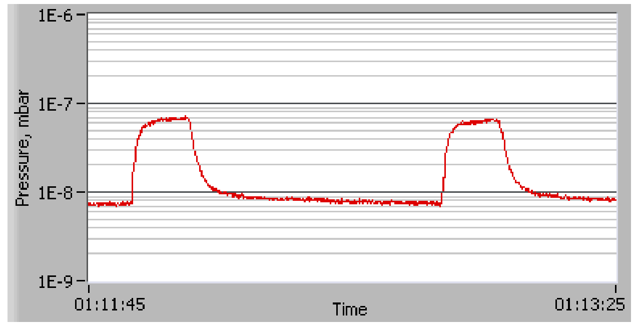


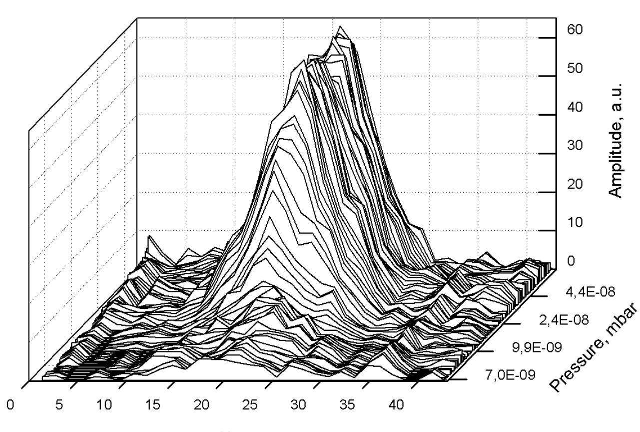
Figure 2: Vacuum reading during the profile measurement. Time interval of 100 s is shown.

As preliminary measurements have shown, the pressure bump extends only a few meters upstream and downstream of the dosing valve thus the impact on the average pressure in the machine is negligible and the SPM can be considered non-destructive. This was also confirmed by Schottky measurements as no frequency shift due to the local pressure bump could be observed. The SPM data acquisition software records and displays graphically the currents in individual PMT channels, beam current as measured by the beam current transformer and the pressure at the SPM location. Offset subtraction features help to compensate for background signals due to voltage dependent PMT dark currents. Online Gaussian fits are performed to determine beam width, position and intensity.

MEASUREMENT RESULTS

Figure 3 shows the measured profiles and corresponding Gauss fits for different pressures. The measurement was carried out at beam intensity of $1.3 \cdot 10^{10}$ protons in the machine and PMT voltage set to 750 V. Reasonable profiles were observed at pressures starting at $2 \cdot 10^{-8}$ mbar.

The data shown in Fig. 3 was acquired with internal beam targets being disabled to avoid additional signal background due to beam losses hitting the PMT.



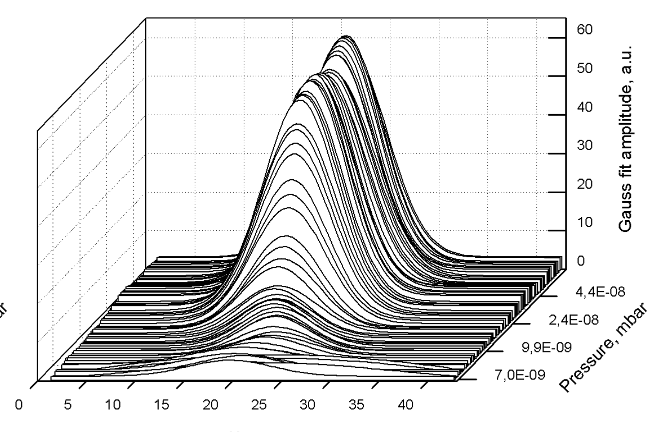


Figure 3: SPM proton beam profiles (left) and corresponding Gauss fits (right) shown as a waterfall plot. Pressure axis also represents the time axis. 80 Profiles corresponding to 8 s time interval are shown. Beam parameters were: 3350 MeV/c, $1.3 \cdot 10^{10}$ protons circulating in the ring. PMT HV was set to 750 V.

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SUMMARY

The measurements performed at COSY have shown that a profile monitor based on scintillation of residual gas can be successfully used in a proton synchrotron. At COSY conditions a pressure bump was necessary at the monitor location to boost the scintillation event rate. The pressure bump was realized by injecting small amounts of pure nitrogen into the vacuum chamber by means of a piezo-electric dosing valve. Such a procedure was shown to be non-destructive for the beam. Some profile measurements were performed while experiments were taking data. Assuming the pressure bump is less than one order of magnitude profile measurements can be carried out for beam intensities higher than $5 \cdot 10^9$ particles in the ring. One should avoid operating devices capable of light generation such as residual gas analyzers, titanium sublimation pumps or even ion pumps in the proximity of the SPM. An SPM is a very robust and inexpensive instrument as it does not contain any vacuum components.

OUTLOOK

To better use the resolution capability of the multi-channel PMT and to be able to compensate for a beam position offset a motorized zoom lens with variable focus can be used. The theoretical calibration of the SPM should be verified by simultaneous IPM measurements. Turn-by-turn measurements may be possible if faster PMT readout electronics and higher pressures are used.

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