ADJUSTABLE OPTICS FOR A NON-DESTRUCTIVE BEAM PROFILE MONITOR BASED ON SCINTILLATION OF RESIDUAL GAS

V. Kamerdzhiev, A. Pernizki, K. Reimers[#], FZ-Jülich, Germany

Abstract

The scintillation profile monitor (SPM) is being developed at COSY in addition to the existing ionisation profile monitor (IPM). Contrary to the IPM it does not require in-vacuum components, making it a robust and inexpensive instrument. The SPM is suitable for high intensity operation rather than operation with low intensity polarised beams. A multichannel PMT is used to detect scintillation light. The rate of detectable scintillation events is about three orders of magnitude lower compared to the rate of ionisation events. To boost the photon yield, small amounts of nitrogen are injected into the SPM vacuum chamber. An adjustable light focusing system is being built to optimise the SPM performance for different machine operation modes. The new system allows using a variety of optical components ranging from single lenses to high-grade camera objectives. Cylindrical lenses are considered to further boost the sensitivity by better fitting the beam image to the detector geometry. The latest experimental results and the new design of the optical system are presented.

INTRODUCTION

The cooler synchrotron COSY is equipped with a low energy electron cooler and a stochastic cooling system. While the electron cooler is typically used at injection energy stochastic cooling is operated at higher energies. A 2 MeV electron cooler built by BINP is expected to be installed in a few months. The new cooler will allow electron cooling in the entire energy range of COSY [1].

Non-destructive beam diagnostics, in particular profile monitors are essential for the operation of circular accelerators with beam cooling. At COSY two profile monitors are installed. The ionisation profile monitor (IPM) relies on the beam particles ionising residual gas. The IPM is routinely used and delivers beam profiles with high sensitivity down to $1{\cdot}10^8$ protons in the ring at typical vacuum pressure of $1{\cdot}10^{-9}$ mbar [1]. It provides beam profiles in both transverse planes. The IPM became a very valuable tool for setting up beam cooling. However, high cost and components prone to aging triggered a search for alternatives.

The scintillation profile monitor (SPM) detects light emitted by the residual gas atoms and molecules after their excitation by the beam particles. This method is typically used in beamlines [3, 4]. The SPM is a robust and inexpensive instrument aimed at operation at high beam intensities. At COSY the much lower event rate compared to the IPM is coped with by creating a local pressure bump. Nitrogen [5, 6, 7] is injected directly into the SPM vacuum chamber using a commercially available piezo-electric dosing valve. The vacuum chamber is blackened inside to avoid light reflections. It is equipped with two DN100 viewports for light extraction and two DN40 ports for vacuum monitoring and gas injection. A 32-channel photomultiplier (PMT) is used to detect scintillation light.

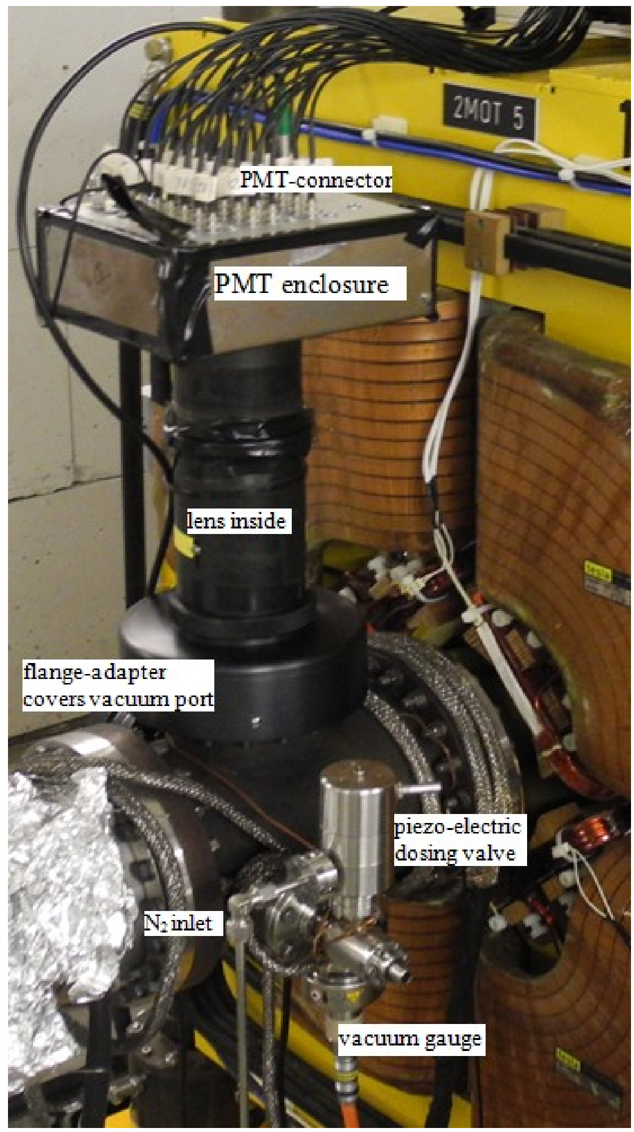

Figure 1: SPM installation in COSY. Shown is the vacuum chamber with the horizontal vacuum port for light extraction and the vacuum ports for N_2 injection and vacuum measurement.

A housing made of steel seals the electric connections and the backside of the PMT against incoming light and electromagnetic fields. All elements of the lens tube are blackened inside to reduce light reflection. The joints are sealed by tape to avoid light from outside of the chamber.

[#]k.reimers@fz-juelich.de

ISBN 978-3-95450-119-9

The lens is mounted on a sledge inside the lens tube. It can be moved by about 20 mm. Its position is fixed with two screws. The whole SPM has an overall height of about 450 mm above the flange (see Fig. 1).

This rigid setup bears disadvantages of mismatched profile measurement if the beam isn't crossing the field of focus. Readjusting the optics is time consuming as it has to be done by hand in the accelerator tunnel.

Upgrade

The newly designed twin drive optical system uses commercially available components. Each beam profile monitor has two linear drives. The PMT is placed on the upper, a lens or a lens system is placed on the lower drive. This setup allows matching the plane of focus to the beam position. Also, the scale of image can be adjusted to improve the resolution of the beam profile measurement. The vacuum chamber was made much shorter than the previous one. Its length has been reduced from 508 mm to 256 mm to fit with the length of the 2MeV cooler beam pipe. Correspondingly the in-air components have to fit within the available length.

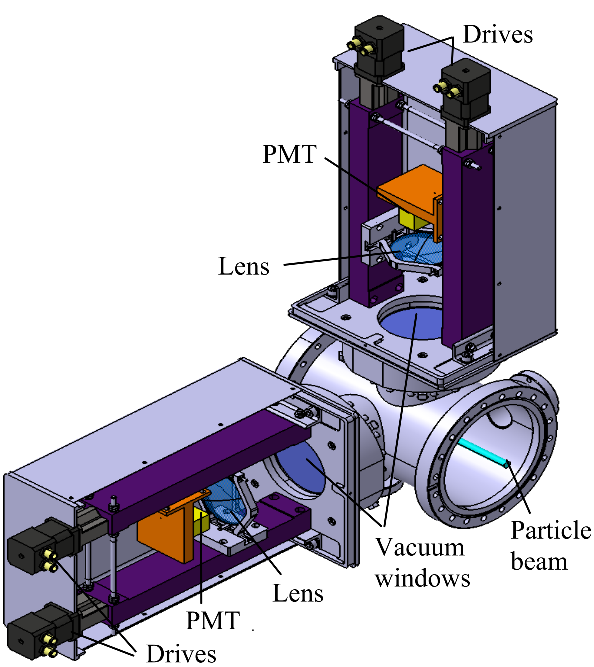

Figure 2: New SPM design.

The current data acquisition software written in NI LabView will be extended to control the linear drives by means of a commercially available stepper motor controller. The linear drives chosen are made by IGUS [8].

Cylindrical Lenses

A standard lens system only "translates" an area seen as an object to an area seen as an image. The sensor is a PMT with 32 pixels having the dimension of 0.8 mm x 7 mm and a pitch of 1 mm [9]. Due to vacuum chamber geometry, approximately 150 mm of beam length can be imaged by the SPM. An optical scaling factor in the current setup is about 0.5 (1/1.837) meaning that only a 14 mm long part of the beam is seen by the detector. Cylindrical lenses may be useful as they allow different light focusing along and across the beam axis leading to a significant boost of light intensity on the detector. The use of two cylindrical lenses oriented as shown in Fig. 3 corresponds to two optical lens systems having the same overall focal length but different lens positions and delivering different magnifications to the detector [10].

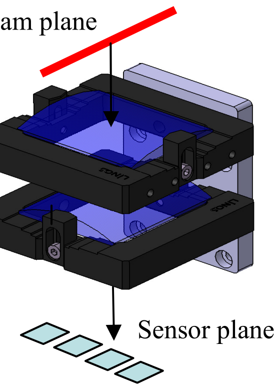

Figure 3: Cylindrical lens system for the SPM for one working distance. The upper lens compresses the beam image along the beam axis. The lower lens focuses the beam image across the axis (profile).

Operation of SPM

The calibrated optomechanics will allow refocusing step by step both transverse beam profiles. The horizontal beam profile will deliver the beam position to focus the vertical one, the vertical beam profile information will be used for focussing in the horizontal plane.

RESULTS

A 48-channel picoammeter electronics developed at iThemba Labs, South Africa [3] is used to read out the PMT. At typical vacuum pressure of $1{\cdot}10^{-9}$ mbar there is not enough light to be detected by the PMT. With the pressure bump to about $4{\cdot}10^{-8}$ mbar and beam intensities of $5{\cdot}10^{9}$ protons reasonable S/N ratio can be achieved. The local pressure bump doesn't impact the machine operation [2].

Figure 4 shows the measured profiles and corresponding Gaussian fits recorded simultaneously with the SPM and the IPM. The measurement was carried out with $6{\cdot}10^{9}$ polarized protons circulating in the machine and PMT voltage set to 750 V. The profiles were observed at the pressure of $8{\cdot}10^{-8}$ mbar. The horizontal profiles show a good match. As the PMT of the SPM only has 32 channels, the profile has lower resolution compared to the profile taken by the IPM. The IPM uses CCD cameras with 640 pixels per line.

ISBN 978-3-95450-119-9

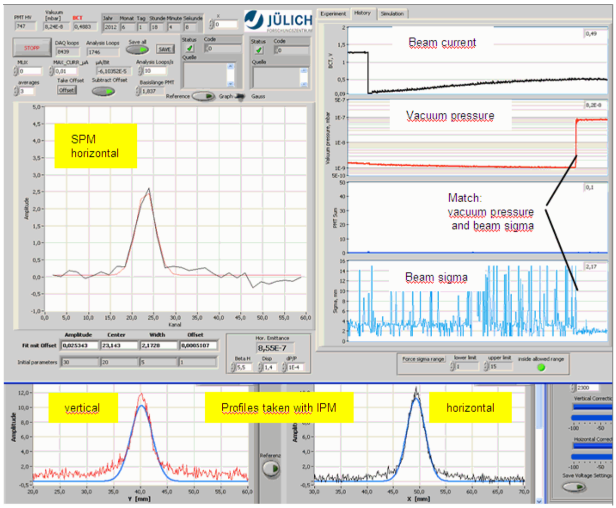

Figure 4: Comparison of horizontal profiles of stacked polarized proton beam taken by SPM and IPM at the same time. Only during gas injection enough scintillation events are available for profile measurement by SPM.

SUMMARY

The SPM is robust and inexpensive due to absence of vacuum parts. Good agreement of horizontal SPM and IPM profiles was achieved with current SPM setup. The new motorized optomechanical system promises enhancements in versatility and accuracy of the SPM.

The use of cylindrical lenses is regarded to increase the sensitivity of the SPM by boosting the photon number on the sensor.

ACKNOWLEDGMENT

The authors would like to thank J. Dietrich and I. Meshkov for initiating the project and valuable contributions. We are grateful to C. Böhme, L. Conradie and F. Becker for sharing their ideas and experience and F. Klehr for support with mechanical design

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