AN IONIZATION PROFILE MONITOR FOR THE DETERMINATION OF THE FLASH AND PITZ BEAM PARAMETER

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Abstract

Accurate measurements of beam parameters, like position and profile, are essential to operate the accelerators FLASH and PITZ successfully. As one contribution to their beam diagnostics, a specific Ionization Profile Monitor (IPM) was developed and tested in both accelerators in order to prove its usability. Currently, one horizontal and one vertical oriented IPM are installed at FLASH, and one vertical oriented IPM is installed at PITZ. The aims of this paper are to give an overview of the installed IPMs and to present the first successful operation.

MOTIVATION/INTRODUCTION

The Free-electron Laser facility at Hamburg (FLASH) is a linear accelerator with a total length of 315 m and it is producing soft X-ray laser light with a wavelength variable from 4.2 to 60 nm. The Photo Injector Test facility at the DESY location in Zeuthen (PITZ), on the other hand, has a total length of 22 m and is used for the development and optimization of electron sources. The test facility can generate electron bunches with a charge from 1 nC up to several nC, whereas the nominal charge of FLASH and PITZ is 1 nC [1].

In order to operate an accelerator, like FLASH and PITZ, successfully, accurate information of the position and profile are important during the survey of the beam. Currently, several different beam position diagnostic tools are implemented: wire-scanners [2] and fluorescent screens that are linked with camera readout. However, the main disadvantage of these measuring methods is the partial or total destruction of the beam. Since an online analysis of beam parameters would be advantageous especially during measurements, an Ionization Profile Monitor (IPM) is seen as a promising solution in such a case [3]. The operating principle of an IPM is a non-invasive method of beam analysis and can be summarized as the detection of ions that are generated by interactions of the beam with the residual gas. Since 1988, this type of monitor has been used at DESY in numerous charged particle and ion accelerators [4]; however, they have not yet been applied as a beam diagnostic device in photon and electron beams.

As a result, a project has been started to investigate a potential use of IPM at such facilities for the first time. References [3] and [5] show first results indicating that the monitor is able to determine the relative position and the spatial profile of the photon/electron beam with the precision of better than 50 μm. The aim of this research paper is to present first results of the operation of two different IPM designs, which have been developed at DESY Zeuthen and were installed into the FLASH and the PITZ facility.

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DESIGN AND WORKING PRINCIPLE OF THE DEVELOPED IPM

As part of this project, two different design types of an IPM have been developed, the box-IPM and the grid-IPM, and their internal structure can be seen in figure 1. However, since the design of both types and their working principle are already explained in detail in [3] and [5], only an overview is given below.

In general, the working principle of an IPM is based on the detection of secondary particles that are generated if a photon or electron beam is passing through an IPM device and ionizes the residual gas in the beam line. Before the created ions and electrons can recombine, they are accelerated vertically with respect to the beam under the influence of a strong homogeneous electrical field and thus moved towards a high spatial resolution detector, the Micro-Channel Plate (MCP) [6]. A MCP is an image intensifier with high gain, high resolution and also a distortion-free image conversion. A CCD camera (FLASH: [7], PITZ: [8]) is then used to record the images of the MCP for further analysis.

The initial motivation of designing such IPM can be summarized as follows: a) the internal design of an IPM should be as simple as possible and b) standard components should be preferred in order to reduce the costs and to simplify the fabrication. In addition, the following factors had to be considered during the design process: the fixed width of the selected MCP, the fixed diameter of beam pipe and that all components can be used in ultra-high vacuum.

Both IPM designs have in common that they consist of a cylindrical chamber that is built around the vacuum beam pipe. The MCP and an electrode called the "repeller plate" are installed perpendicular to the beam direction, but in opposite direction.

At first, a box-IPM (figure 1.a) was designed that uses 17 additional electrodes between MCP and repeller plate to realise the strong homogeneous electrical field. Nevertheless, since the voltage supply for these electrodes and the assembly of all parts are very complex, another type of IPM, the grid-IPM, was designed that uses only 4 grids at FLASH and 2 grids at PITZ, respectively. The reduction from 4 to 2 grids is caused by the fact that PITZ uses a larger beam pipe diameter compared with FLASH, resulting in less spare space for grids between MCP and repeller plate. In both types, the voltage applied to the individual electrodes/grids depends on the voltage of the repeller plate, which can be adj usted up to 4 kV, and decreases linearly in accordance with the distance from the repeller plate and the distance to the MCP.

It is important to note that an IPM can only be used in a vacuum environment with pressures of 10^{-6} mbar or less to prevent flash-/sparkovers on the supporting points and in the individual micro-channels of the MCP due to the larger number of particles.

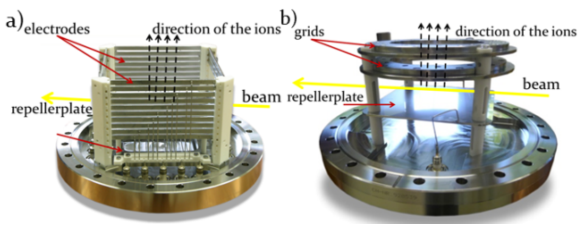

Figure 1: IPM designs; a) box-IPM, b) grid-IPM (PITZ).

MEASUREMENTS AT FLASH

Introduction

Figure 2.a sh ows schematically the position of the installed IPM station at the FLASH facility. It can be seen that it is approximately 259 m behind the gun. Taking into account a divergence of the photon beam in t he range 100–150 µrad behind the undulators [1], the full width at half maximum (FWHM) expected at t he position of the IPM (i.e. 26 m downstream) sh ould be in the range between 2.6 and 3.9 mm.

The IPM station and its corresponding coordination system are shown in figure 2.b. While the box-IPM maps the z-y-direction, the grid-IPM displays the z-x-direction. The beam conditions and the IPM settings that were used for the measurements are shown in the appendix in table 1 and 2.

Comparison Grid-IPM and Box-IPM

This section studies the spatial resolution of both IPM designs under the same conditions in order to point out possible weak points in the design of one type. Several series of measurements have been recorded an d after a detailed analysis, a pot ential impairment could be detected. In accordance with all res ults, figure 3 s hows the recorded camera image of one particular example for both IPM devices.

While the box-IPM in figure 3.b shows a plane surface where the ions of the beam are displayed as a "point-to-point" image and indicate a natural noise behaviour on the „flat top", the grid-IPM shown in figure 3.a exposes the structure of the grid within the recorded image resulting in high intensities (hot spots) on the „flat top". Further analyses showed that it corresponds exactly to the structure declared by the manufacturer of the grids (wire gauge: 33.5 µm, distance: 284 µm) [9].

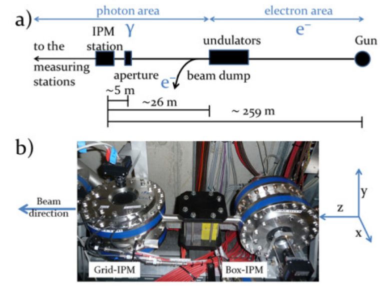

Figure 2: Installed IPM devices at FLASH; a) position in beam line, b) installed IPMs with orientation.

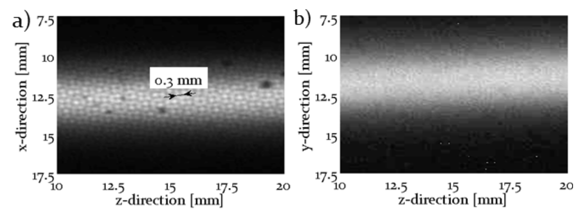

Figure 3: Recorded images of one particular photon beam; a) grid-IPM, b) box-IPM.

Since such a beam surface indicates image distortions, the measuring of beam parameters, like position and width, becomes falsified. This leads to the conclusion that the wire gauge of selected grids should be much smaller than the determined camera resolution of 49 µm in [3].

Measuring Accuracy of Both IPM Types

To test the accuracy of the installed IPM devices, several apertures are driven into the beam line to get a defined beam diameter. A series of measurements has been recorded an d a t ypical 3D- & y-profile of a beam can be s een in figure 4. The results of its analysis are presented in the appendix in table 3.

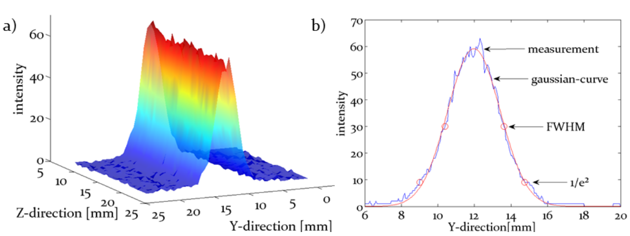

Figure 4: Beam at FLASH; a) 3D-profile, b) y-profile.

As expected from the above IPM comparison, the grid-IPM shows 50 t o 100 % higher RMS values for the deviation from centre of grav ity than the box-IPM, indicating a redu ced resolution. Nevertheless, it can be seen that both IPM show very good results:

a) without an aperture the measured FHWM of the beam lies in the expected range (i.e. between 2.6 an d 3.9 mm),
b) the $1/e^2$-values of t he beam correspond well with the aperture.

MEASUREMENTS AT PITZ

Since IPMs have not yet been applied as a beam diagnostic device at an electron facility, one grid-IPM station has been installed into the PITZ facility for test purposes. Its position within the PITZ beam line is shown schematically in figure 5.

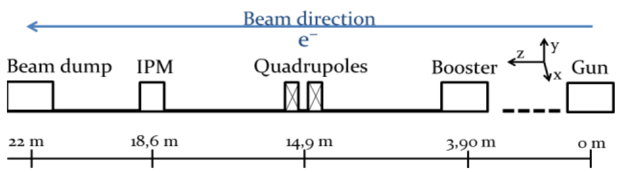

Figure 5: Position of installed grid-IPM at PITZ.

In contrast to a photon beam, an electron beam shows some characteristics that have to be considered beforehand: a) an electron beam is accompanied by dark current, and b) calculations pointed out that an electron beam produces a lower number of ions with respect to a photon beam. Both cases have in common that they complicate the measurement of beam parameters because the ratio between signal and noise becomes too low for an analysis.

Measurements and calculations showed that point a) could be reduced by changing machine parameters (e.g. a reduced booster power) and point b) could be compensated by increasing the vacuum pressure in the IPM area and the number of pulses. The optimal machine and IPM parameters found through several test series are shown in table 1 and 2. One example of a recorded beam, plus its analysis are shown in figure 6. It can be seen that the beam is clearly visible and that it shows a proper Gaussian profile.

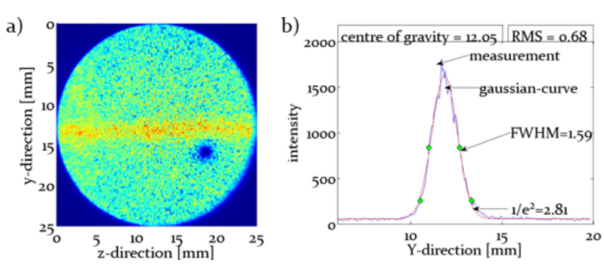

Figure 6: Beam at PITZ; a) recorded image of MCP (miscoloured), b) analysed beam parameters.

CONCLUSION

This paper presents first results of an operation of IPM devices at FLASH and PITZ. Extensive measurements showed that both IPM types are capable of permanently analyzing a photon and an electron beam without distortion or even influence. Since a linear correlation between measured and real beam position occurs, it therefore enables an easy online diagnostic tool.

The comparison of both presented IPM types indicated that the wire gauge of the mounted grids in a grid-IPM should be much smaller than the camera resolution to avoid characteristic distortions.

APPENDIX

Table 1: Machine Parameter Settings

FLASH		PITZ	
photon beam energy [eV]	150	electron beam energy [MeV]	20
wavelength [nm]	13.3	booster power [MW]	3
charge [nC]	0.6	charge [nC]	1
number of pulses	10	number of pulses	120
repetition rate [kHz]	1,000	vacuum [mbar]	$3.1 \cdot 10^{-7}$

Table 2: Settings for IPM and MCP

Parameter IPM	FLASH	PITZ
Repeller plate [V]	3,000	2,000
MCP Input [V]	0…-150	0…-200
MCP Output [V]	0…2,000 (max.)	0…2,000 (max.)
MCP Screen [V]	6,000	6,000

Table 3: Measured Beam Parameters at FLASH

Beam measurand	Apertures			
	none	5 mm	3 mm	1 mm
Box-IPM				
- RMS of deviation from centre of gravity [mm]	0.017	0.023	0.019	0.033
- FWHM-mean [mm]	3.4 ±0.11	3.11 ±0.17	2.41 ±0.14	0.74 ±0.14
- 1/e²-mean [mm]	6.4 ±0.45	4.9 ±0.39	3.72 ±0.49	1.66 ±0.57
Grid-IPM				
- RMS of deviation from centre of gravity [mm]	0.031	0.037	0.046	0.058
- FWHM-mean [mm]	2.7 ±0.16	2.53 ±0.21	1.97 ±0.18	0.81 ±0.25
- 1/e²-mean [mm]	5.13 ±0.15	4.43 ±0.64	3.28 ±0.51	1.69 ±0.53

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