# A POWER SWITCHING IONIZATION PROFILE MONITOR (3D-IPM)

H. Breede, L. V. Vu, M. Sachwitz, H. Grabosch, DESY, Zeuthen, Germany

## *Abstract*

FLASH at DESY in Hamburg is a linear accelerator to produce soft x-ray laser light ranging from 4.1 to 45 nm. To ensure the operation stability of FLASH, monitoring of the beam is mandatory. Two Ionization Profile Monitors (IPM) detect the lateral x and y position and profile changes of the beam. The functional principle of the IPM is based on the detection of particles, generated by interaction of the beam with the residual gas in the beam line. The newly designed IPM enables the combined evaluation of the horizontal and vertical position as well as the profile. A compact monitor, consisting of two micro-channel plates (MCP) is assembled on a conducting cage along with toggled electric fields in a rectangular vacuum chamber. The particles created by the photon beam, drift in the homogenous electrical field towards the respective MCP, which produces an image of the beam profile on an attached phosphor screen. A camera for each MCP is used for assessment. This indirect detection scheme operates over a wide dynamic range and allows the live detection of the clear position and the shape of the beam. The final design is presented.

## INTRODUCTION

To ensure a smooth operation of the free electron laser FLASH at DESY Hamburg, numerous detectors for the precise measurement of the electron and laser beam are necessary. The great advantage of the here described Ionization Profile Monitor (IPM) is an undisturbed determination of the position and intensity distribution of the laser beam.

## MEASURING PRINCIPLE OF AN IONIZING PROFILE MONITOR (IPM)

The FLASH laser beam with a variable wavelength from 4.1 to 45 nm is located in an Ultra High Vacuum (UHV) beam pipe. Despite the vacuum a certain amount of residual gases still exist. If the laser beam hits a residual gas atom, it becomes ionized and charged electrons and ions are created. By means of a homogeneous electric field, these electrons and ions can be deflected in a rectilinear way towards the micro-channel plate (MCP). Here, the impacting particles create an avalanche of secondary electrons in the micro tubes of the MCP and are being visualized on the phosphor-screen see Figure 1). These results in an image of the intensity-dependent laser beam profile (see Figure 2).

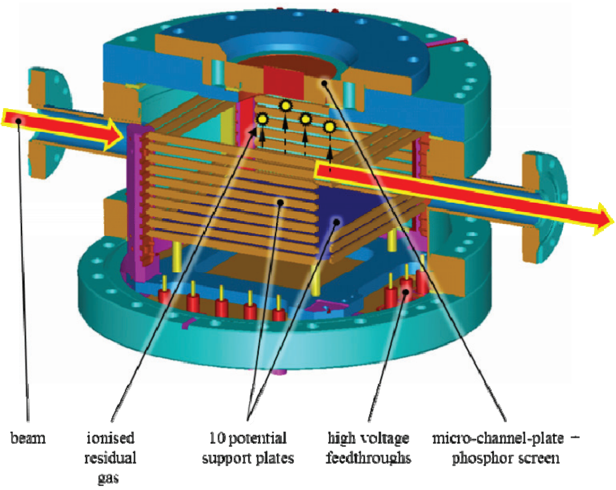

Figure 1: Conventional set up [1].

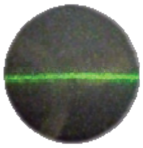

Figure 2: Image of the FLASH laser beam [1] [2].

## CONVENTIONAL SET UP

Figure 2 shows an IPM module for the laser beam position measurement as implemented in FLASH [1] [2]. Problems and disadvantages of this design are the following:

- The large size of the monitor (approx. 400 mm x 300 mm x 200 mm) results in an insufficient homogeneity of the electrical field applied. Therefore the exact path of the electrons or ions from the origin of creation to the MCP is unknown and the spatial resolution is in the order of about ±50 microns.
- The size makes the IPM harder to manufacture and more expensive due to the high number of high voltage feedthroughs.
- To detect the horizontal and vertical parameters of the laser beam (3D) two consecutive detectors have to be implemented with perpendicular orientation to each other demanding large space.
- To take a look at the single bunches rather than just examining the whole train, the IPM needs a time resolution of at least 100 ns, the conventional set is not capable of.

## A NEW DESIGN OF THE IONIZATION PROFILE MONITOR

In order to tackle the challenges described above the following design is proposed:

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- Unification of the separate horizontal and vertical monitors with an alternating homogeneous electric field.
- A special cage protects the area of interest from electrical stray fields to ensure an optimal homogenous electric field.
- Decreasing the size of the device to 203 mm × 218 mm × 246 mm while at the same time reducing the applied electrical voltage with the appropriate low cost feedthroughs.
- With the Finite Element Method (FEM) a comparison of different residual gas particles is performed concerning their trajectories in the electric field.
- This procedure offers an optimization of the design by simulating the trajectory of the particles in the electrical field with the deflection caused by the inhomogeneity of the field. Varying the CAD monitor model helps finding out the best possible determination of the laser beam position.

Following the principles described above in figure 3 the resulting new design of a 3D detector is presented. The inner cage with a measure of 100 mm × 100 mm × 100 mm consists of equally sized pads, plates and two 28 mm diameter holes for the passage of the beam. Figure 3 shows that 30 different electrical potentials are needed to achieve a homogeneous field in two directions.

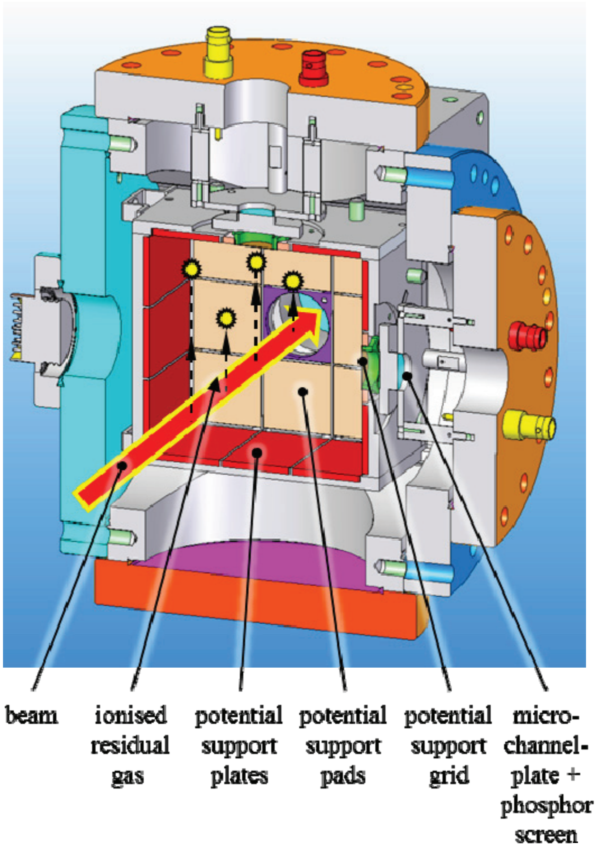

Figure 3: Design of the 3D ionization profile monitor.

### Device Specifications

The following special components were chosen:

- 1x stainless steel block with measures 140 mm × 203 mm × 203 mm
- 1× 41-time electrical feedthroughts with plugs and cables
    - W-MPC2-41-DE-CE-SSG [3]
- 2x grid bonded in a ring washer by Precision Eforming
    - MN49 bonded to 20mm SS Frame [4]
- potential support plates and pads consisting of stainless steel
- an inner retainer of the cage consisting of MACOR by MCI UG [5]
- a pulse generator for generating an alternating orthogonal electrical field
    - A-GBS-MATRIXPULS 1×25 by GBS ELEKTRONIK GmbH
    - with a frequency of 100 kHz [6]
- 2x micro-channel-plate and P47 phosphor screen assembly by HAMAMATSU
    - F2222-27P227 [7]
    - Emission range 375 - 600 nm
- 2x special coated sight glasses for optimal transmission
    - VPCF40DUVQ-L-BBAR2 [3]
    - Fused Silicia with anti-reflective coating
- a Camera especially for the emission range of the phosphorscreen
    - Basler acA2500-14gm with an Aptina CMOS MT9P
- an Objective especially for the emission range of the phosphorscreen and the small distance to this screen
    - Schneider Kreuznach Makro-Symmar 5.8/80

The time difference between a photo of the horizontal and the vertical view should be as fast as possible in order to get a complete snapshot of the beam profile at a specific moment.

### Temporal Resolution

The selected camera offers a shutter frequency of 12 pictures. This means that 12 times per second the position and the profile of the beam can be measured. The time between the horizontal and the vertical measurements of the profile is limited to the time of fly of the ions and the intensity of light of the screen. A $N^{2+}$ Ion needs 1 µs from the middle of the assembly to the screen. The intensity of the light is unknown and it has to be tested. Certainly, the shutter time is much longer than the time of fly. But a shutter time of 400 µs is realistic, resulting in a complete profile measurement of the beam every Millisecond.

### *Optical Limits of Measurements*

In order to have a very short shutter time a special optical system is needed. Different lenses, glasses and cameras where compared. The following Table 1 shows the relative spectral emission, transmission and spectral response of the chosen parts and the optical system.

Table 1: Signal Intensity of the Optical System

| | Phosphor-screen<br>Hamamatsu<br>F2222-27P227 | Inspection Glass<br>Vacom<br>VPCF40DUVQ-L-BBAR2 | Objektive<br>Schneider<br>Kreuznach<br>Makro-Symmar<br>5.8/80 | Camera<br>Basler<br>acA2500-14gm | relative Light-absorption<br>with Makro-Symmar and AcA2500-14gm |
|---|---|---|---|---|---|
| wave-lengh in nm | rel. spectral emission in 1 | rel. transmission in 1 | rel. transmission in 1 | rel. spectral response in 1 | rel. trans-mission of light relating 25 nm |
| 350 | 0,00 | 0,90 | 0,00 | 0,00 | 0,00 |
| 375 | 0,10 | 0,90 | 0,66 | 0,00 | 0,00 |
| 400 | 0,70 | 0,90 | 0,85 | 0,48 | 6,43 |
| 425 | 0,95 | 0,90 | 0,95 | 0,56 | 11,37 |
| 450 | 0,95 | 0,90 | 0,95 | 0,60 | 12,18 |
| 475 | 0,80 | 0,90 | 0,96 | 0,61 | 10,54 |
| 500 | 0,70 | 0,90 | 0,97 | 0,61 | 9,32 |
| 525 | 0,55 | 0,90 | 0,97 | 0,60 | 7,20 |
| 550 | 0,35 | 0,90 | 0,97 | 0,58 | 4,43 |
| 575 | 0,22 | 0,90 | 0,97 | 0,55 | 2,64 |
| 600 | 0,12 | 0,90 | 0,97 | 0,50 | 1,31 |

**Relative signal intensity of the beam photo relating to the sender:** **48,11%**

The chosen parts leads to a signal intensity of 48,11% because of unavoidable transmission and response losses. Semiconductor detectors these avoid.

## FEM ANALYSIS

To analyse the homogeneity of the electric field and to determine the trajectory of different particles obtained with the design described above, a FEM analysis was carried out using ANSYS 14 modules workbench [8] and classic [8]. In the simulations different variations and possible future developments of the design were included directly from the CAD-model.

### *Potential Ratios*

Simulation studies performed with the ANSYS 14.5 workbench module package proved the potential ratios, as can be seen in Figure 4, to be optimal for a homogeneous electric field and hence for a straight flight of particles. Since the MCP has a diameter of merely 20 mm, only in the marked “area of interest” the electric field must be homogeneous. Also, the expected beam variation in X or Y is below ± 5 mm. Homogeneity in a larger space does not result in a higher spatial resolution.

The electrically conductive potential supporting points are assumed as being an ideal conductor with equal potential at any point. The permittivity of the ceramic was assigned to ε = 6 and of the vacuum to ε = 1.

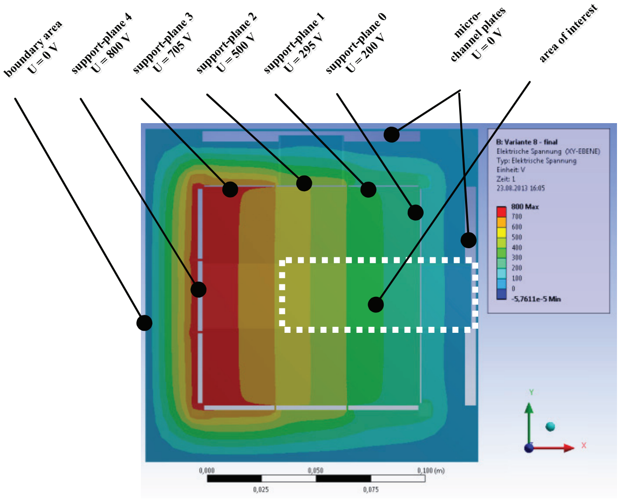

Figure 4: Equipotential lines of the electrical field [8].

## CONCLUSION

The first prototype of a 3D-IPM is currently under construction and will be completed and tested in 2014. Before any test with a toggling electrical field, there will be tests with a rigid field. First practice tests are planned in 2015 at FLASH in DESY Hamburg site.

## REFERENCES

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