Summer Student Programme 2010

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DESY summer student project

Absolute intensity monitor calibration for sFLASH

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Abstract

A nondestructive radiation detector unit at the FLASH Facility at DESY provides the radiation monitoring (pulse energy and statistical properties). Detection is based on three wide dynamic range micro-channel plates (MCP) which detect scattered radiation from a thin gold mesh passed by the photon beam. A main feature of the MCP-based detector is that it is capable to cover the dynamic range of the radiation intensity for commissioning a free electron laser (from spontaneous emission to SASE).

During my summer student programme participation at DESY my project goal was the absolute calibration of the detector, i.e. to extract a final calibration formula from measured data that converts the ADC output into photon flux energy

Due to time constrains (late arrival) not all goals were reached.

Contents

1. Introduction

MCP

A micro-channel plate (MCP) is a planar component used for detection of particles and impinging radiation (ultraviolet radiation and X-rays). It is closely related to an electron multiplier, as both intensify single particles or photons by the multiplication of electrons via secondary emission. However, because a microchannel plate detector has many separate channels, it can additionally provide spatial resolution.

A micro-channel plate is a slab made from highly resistive material of typically 2 mm thickness with a regular array of tiny tubes or slots (microchannels) leading from one face to the opposite, densely distributed over the whole surface. The microchannels are typically approximately 10 micrometers in diameter (6 micrometer in high resolution MCPs) and spaced apart by approximately 15 micrometers; they are parallel to each other and often enter the plate at a small angle to the surface (~8° from normal).

Each microchannel is a continuous-dynode electron multiplier, in which the multiplication takes place under the presence of a strong electric field. A particle or photon that enters one of the channels through a small orifice is guaranteed to hit the wall of the channel due to the channel being at an angle to the plate and thus the angle of impact. The impact starts a cascade of electrons that propagates through the channel, which amplifies the original signal by several orders of magnitude depending on the electric field strength and the geometry of the micro-channel plate. After the cascade, the microchannel takes time to recover (or recharge) before it can detect another signal.

The electrons exit the channels on the opposite side where they are themselves detected by a single metal anode measuring total current. [3]

General layout of sFLASH photon beamline

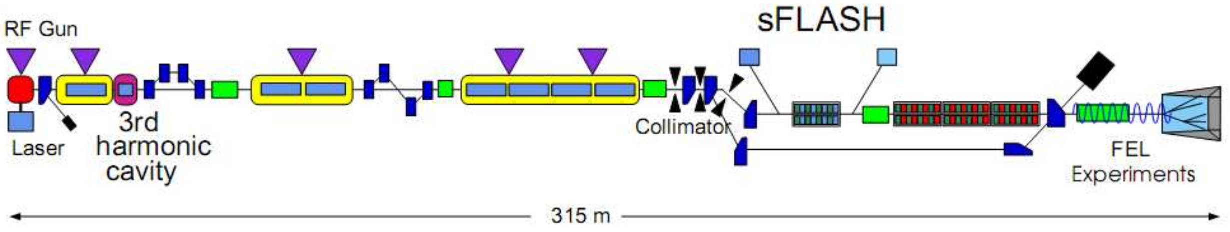

Figure 1: Layout of the FLASH facility. [1]

The free-electron laser FLASH at DESY is working in the SASE regime producing sub-10 fs XUV pulses down to 6.5 nm. The facility is based on a 1GeV superconducting linear accelerator and a 27m-long chain of fixedgap undulators. During a major upgrade of the machine starting in autumn 2009 several new components were installed in order to improve the shot-to-shot fluctuations and the longitudinal coherence and to increase the electron energy to 1.2GeV. Thus, now FLASH is capable to deliver intense photon flux close to the carbon K-edge at 284 eV (4.4 nm). A third harmonic cavity allows to produce 200 fs long electron bunches (few kA of peak current) and thus longer radiation pulses where more modes will contribute to the FEL radiation. A way to improve the longitudinal coherence of the radiation is to seed the electron beam with high-order harmonics of an optical laser generated in a gas target and to use undulators as an amplifier. Since direct seeding at 160 nm has been already achieved at SCSS, the aim of a project called sFLASH (seeding FLASH) is to demonstrate direct seeding at shorter wavelengths and in addition to use this radiation for pump-probe experiments

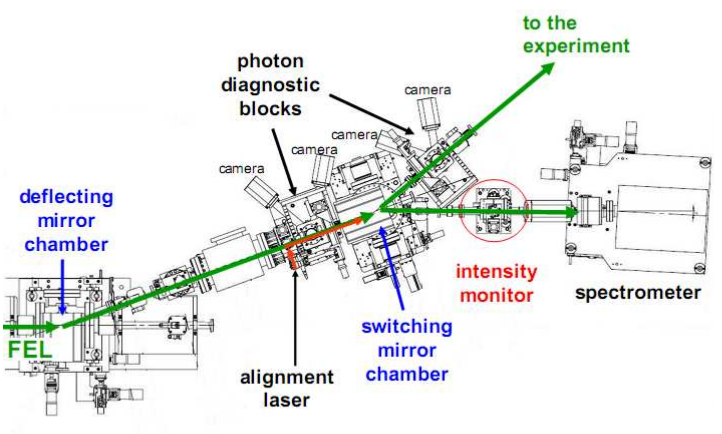

Figure 2: Layout of the diagnostic branch. The FEL radiation, coming from left, is deflected by the first mirror, then passes through the diagnostic unit. After that a further mirror allows to send the beam either to the XUV-spectrometer or to the experimental hutch. [1]

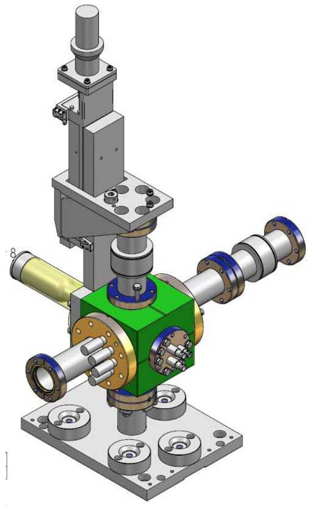

Figure 3: Intensity monitor. [1]

in a dedicated beamline. The layout of the FLASH facility is illustrated in Figure 1
During the summer student program I was working with diagnostics located in the corresponding branch of sFLASH. (Figure 2)
The gold mesh is placed at the center of the intensity monitor (Figure 3 and 4) at 45° with respect to the seeded FEL beam. Three MCPs are used: one is at 45° with respect to the mesh (90° with respect to the FEL beam), the other two MCPs have a hole in the middle to be place on axis with respect to the photon beam. The first holed MCP detects the radiation scattered backward from the mesh and the second holed one detects the radiation scattered forward (see Figure). Due to the geometry, the detection efficiency of each MCP is different at the same photon energy, hence increasing the dynamical range of detection.[1]

Calibration

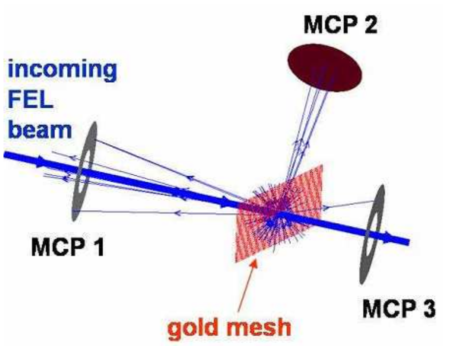

Figure 4 Schematic layout of the intensity monitor. The detector contains 3 MCPs mounted at different geometry with respect to the photon beam in order to increase the dynamic range of detection. [1]

Thin gold wires of a mesh scatter a tiny fraction of the incident radiation onto an MCP. The MCP amplification coefficient can be easily tuned in a wide range by changing the voltage which is applied to the MCP assembly. These features make an MCP a perfect detector for monitoring XUV radiation. A specific feature of MCPs is a nonlinear, nearly exponential dependence of the gain on the applied voltage, so special efforts have to be made for a calibration procedure [2]

2. Getting the MCP gain

In order to get the MCP gain depending on the input voltage I performed a series of measurements with all 3 MCP-s. The MCP output was measured with different applied voltages at constant photon flux. Around 400 measurements were taken for each MCP applied voltage/MCP output/photon flux, in order to get enough statistics. (see Figure)
At high MCP voltages (over 1825V) the distribution of data becomes rather big, which limits the monitor performance for these settings.

After further processing the data with Origin software I determined an MCP gain at different light intensities (deuterium lamp and undulator emission). (Figure)
Measurements outside the shown data range were not useful because of the high background level at low input voltages, and signal processing limitation at high output voltages. Thus on the plot we see the actual working range of the MCP-s at two different photon fluxes (deuterium lamp and spontaneous undulator radiation).

After extrapolating the MCP gains with exponential growth formulas ($\mathrm{y} = y_0 + \mathrm{a} \cdot \mathrm{e}^{(x/t)}$), I found that the MCP gains vary at different photon fluxes. For instance: “t” parameter for MCP2 is 56,86 at deuterium lamp light intensity measurement, unlike 45.87 value for undulator spontaneous emission light.
The background noise level and MCP output saturation at 1,1V cause a nonlinear gain in logarithmic scale which changes for different photon fluxes.
Consequently, the MCP settings have to be carefully adjusted to measure a wide range of pulse energies. However, I obtained the requested MCP gain formulas for different levels of measured photon fluxes.

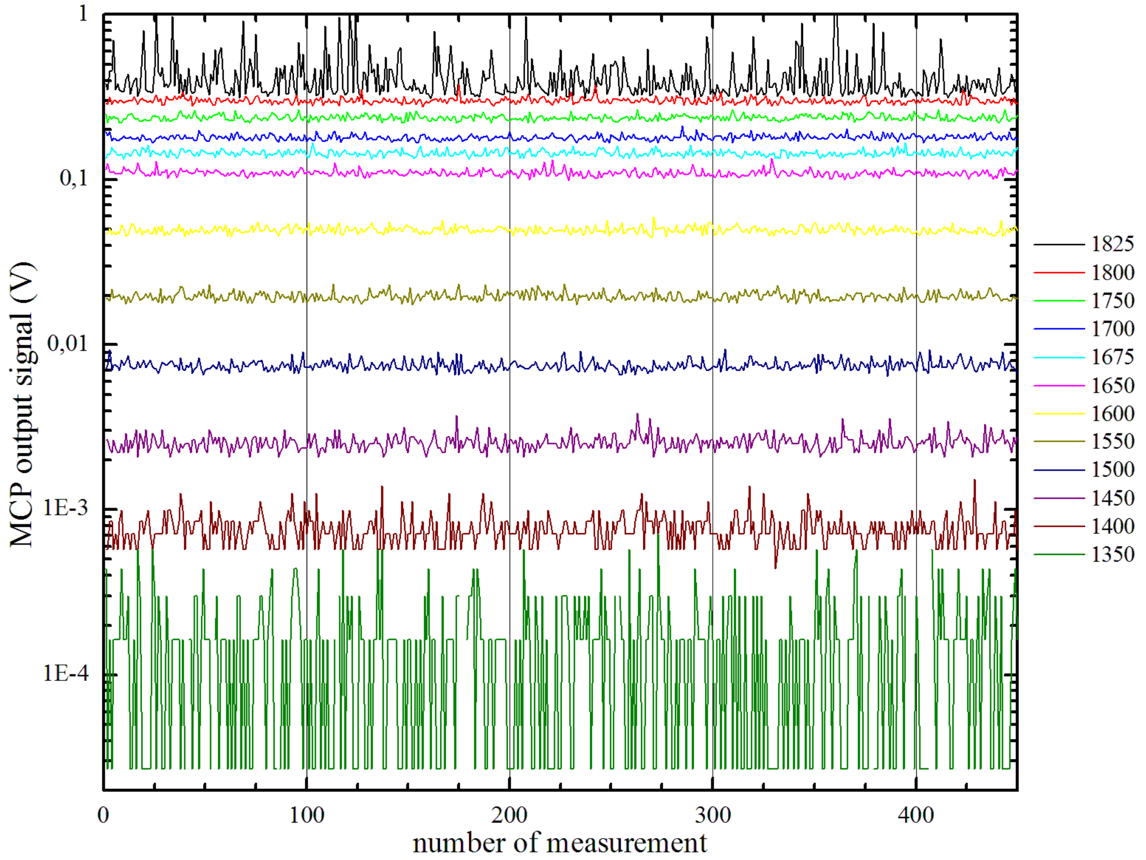

Figure 5: The measured MCP2 response with different applied voltages at identical photon flux parameters

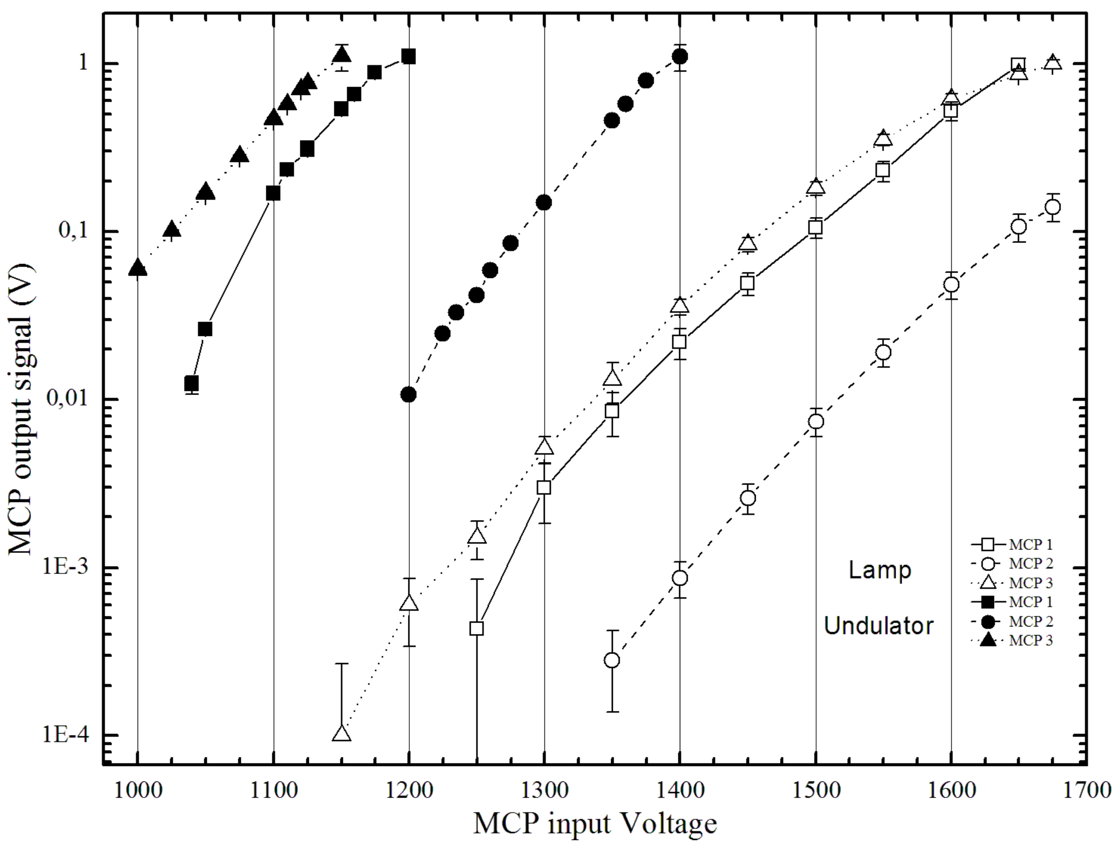

Figure 6: The measured MCP gain at two different pulse energies

3. Calibration formula calculation.

To receive the final formula for pulse energy calibration depending on input and output voltage I followed the idea to use experimental data, which was taken by the previous summer student Marek Oja.[4]

In this study MCP output voltages were measured in parallel to the calibrated gas monitor detector (GMD) data at FLASH.

I extracted straight line extrapolation formulas ($Y = A + B \cdot X$) for these data and found Slope (parameter $A \pm A_{err}$) and Intercept (parameter $B \pm B_{err}$) errors for each fit (Figure7). For better perceiving of these dependences I decided to plot them in 3d with respect to MCP input voltage. The data is rescaled to new ADC configuration, which is currently in use.

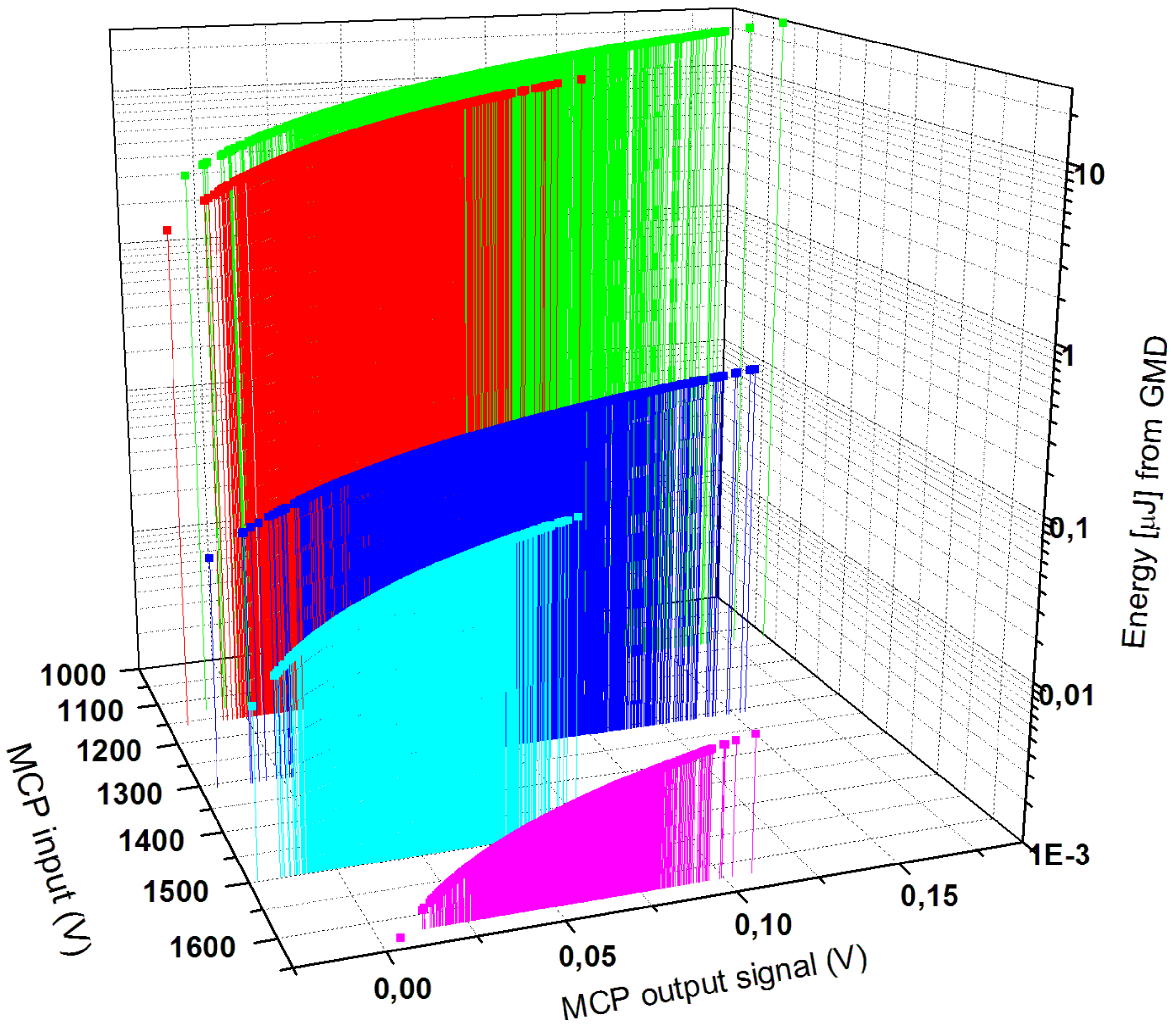

Figure 7: Straight line approximations of photon energy, measured with GMD with respect to MCP2 applied and output voltages.

Here the Y axis is the energy from the GMD, and X is the MCP output signal. Thus I got $GMD = f(A, B, MCP_{out})$ (1) dependences with certain MCP_{in} values, where MCP_{in} and MCP_{out} are the applied and the output MCP voltages. Then I plotted A and B parameters depending on the MCP input value. Their behaviour was close to exponential as a sum of decaying functions (Figure8) and after some efforts I managed to extrapolate them with the following formulas:

$$A = A_0 + A_1 e^{-(x-x_0)/t_1} + A_2 e^{-(x-x_0)/t_2} + A_3 e^{-(x-x_0)/t_3} + A_4 e^{-(x-x_0)/t_4} + A_5 e^{-(x-x_0)/t_5} + A_6 e^{-(x-x_0)/t_6}$$

$$B = B_0 + B_1 e^{-(x-x_0)/t_1} + B_2 e^{-(x-x_0)/t_2} + B_3 e^{-(x-x_0)/t_3} + B_4 e^{-(x-x_0)/t_4} + B_5 e^{-(x-x_0)/t_5} + B_6 e^{-(x-x_0)/t_6},$$

with varying A and B. Here x denotes the MCP_{in} value.

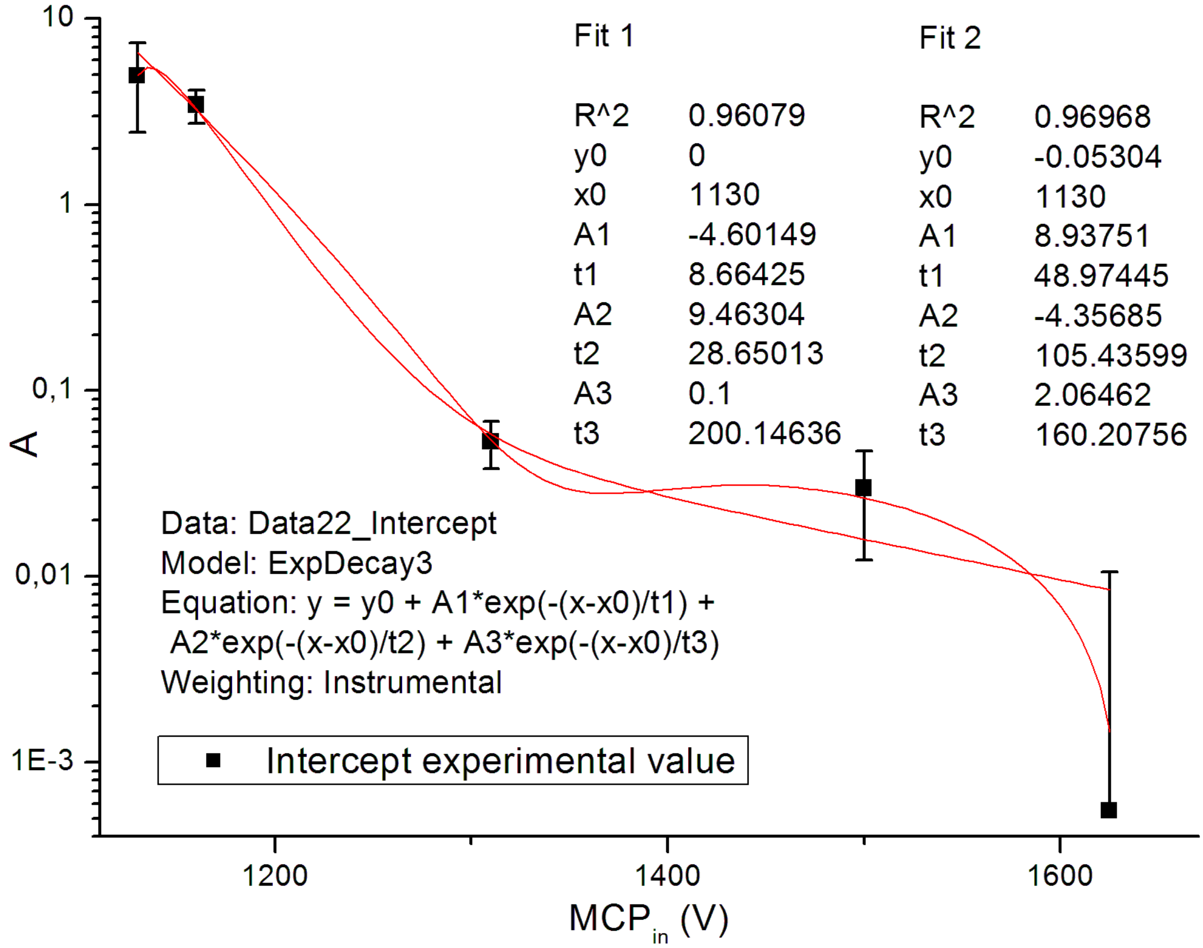

Figure 8: An example of intercept (B parameter) behaviour with respect to MCP input voltage, and two different fits with appropriate parameters. For calibration I used the average.

With the resulting coefficients I obtained the analytical dependences $A = f(MCP_{in})$ and $B = f(MCP_{in})$. By Substituting into the formula (1) we get GMD output as function of MCP_{in} and MCP_{out}: $GMD = f\left(MCP_{in}, MCP_{out}\right)$ (2). Formula (2) is the analytical fit of experimental data.

Calibration formula's prediction error calculation

As the experimental data that I was using for analytical extrapolation had some distribution, my formula needs to be provided with an error prediction allowance.

Formula's prediction error can be presented as $Y_{err} = A_{err} + B_{err} \cdot X$, where A_{err} and B_{err} are the fitting errors of Slope $\left(A \pm A_{err}\right)$ and Intercept $\left(B \pm B_{err}\right)$ of the MCP output voltage to the calibrated gas monitor detector (GMD) measurement dependences. Since parameters $A = f\left(MCP_{in}\right)$ and $B = f\left(MCP_{in}\right)$ are functions of MCP_{in}, then $A_{err} = f\left(MCP_{in}\right)$ and $B_{err} = f\left(MCP_{in}\right)$ are the functions of MCP_{in} as well. This is caused by different noise level and experimental data distribution of the MCP output voltage to the GMD value dependences.

I performed a fit of A_{err} and B_{err} the same way, like a fit of A and B.

After substitution of A_{err} and B_{err} into $Y_{err} = A_{err} + B_{err} \cdot X$, we get finally $GMD_{err} = f\left(MCP_{in}, MCP_{out}\right)$

4. Limitations of calibration formula usage

Due to fact, that my experimental data fits are based on a limited in number and range, the final calibration formula is usage-limited in the following aspects:

1) The fact, that GMD versus MCP_{in} dependence is close to exponential one would need many measurements (GMD vs. MCP_{out}) with small MCP_{in} steps, in order to allow for extrapolation in between known MCP_{in} values.
2) The same reason makes it difficult to use the calibration formula in a parameter range outside that used in this work, especially for lower MCP_{in}
3) I suggest to apply the MCP_{in} voltages, in order to achieve MCP_{out} values in a range of $0.2 \div 0.8$V. In this range calibration works within ?% precision.

5. Summary

The relative gain was measured and approximated for 3 MCPs which are included in an intensity monitor design for low and high FEL pulse energies.

Absolute calibration formulas were derived for MCPs 1 and 2 with error estimates.

The result of my work is the capability to obtain absolute pulse energies using known MCP input voltages and MCP output data. The benefit is that calculations can be performed automatically with computer algorithms.

The improvement of formulas reliability (error bars) could be done with more experimental data.

Contact me in case of questions or to improve the formulas by processing more reliable sets of experimental data: svitozar1@gmail.com

Acknowledgement

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