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# FAST X-RAY BEAM INTENSITY STABILIZATION FOR ABSORPTION SPECTROSCOPY AND SPECTROMICROSCOPIC IMAGING

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*Abstract*

We have designed and implemented a hardware component called "Wedges" with a closed-loop feedback system to achieve a constant incident X-ray flux $I_0$ at the sample during spectroscopic measurement at the microXAS undulator beamline at the Swiss Light Source. Compared to existing approaches, the new system has several advantages, in particular when used in combination with mini-gap, in-vacuum insertion devices or microfocusing optics. The attenuation strength required to maintain constant I0 flux can be adjusted in a fast, steady manner by simple linear translations of two wedge-shaped attenuators.

## INTRODUCTION

The characteristics of synchrotron sources and beamline optics commonly result in systematic and random variations of the delivered photon flux. In X-ray absorption based measurements, for example, monochromator glitches [1] or the energy dependent gap size of small gap in-vacuum undulators [2] are intrinsic sources for changes in the $I_0$ flux. The measured signal intensity, I, has to be normalized by taking the ratio with $I_0$ to compensate for such variations in $I_0$. However, especially in the case of non-linear responses between the $I_0$ and I detectors, such normalization can introduce artifacts or signal distortions. Many types of x-ray experiments would benefit from a constant $I_0$ flux over the entire experimental parameter space.

Monochromator Stabilization (MOSTAB) is the current solution for most synchrotron beamlines with double crystal monochromators (DCM) to have a constant I0 from the monochromator output [3, 4]. The MOSTAB approach is acting on the relative alignment of the two monochromator crystals ('dynamic detuning') in order to stabilize beam intensity (or to maintain beam position). Obviously, any change in angular alignment of the monochromator crystals will not only result changes in the transmitted photon flux, but also induce deviations in the beam trajectory and photon energy distribution.

## BEAMLINE LAYOUT

The beamline layout and relevant components are shown in Figure 1. A minigap in-vacuum undulator (U19) serves as radiation source providing high brightness X-rays in the energy range from 4 to 23 keV. The photon flux delivered at 12 keV is > 1012 photons/sec, while the optical scheme employed used ensure an energy resolution of ΔE/E <10-4. The optical layout of the beamline is composed of several pairs of slits, a bendable toroidal, horizontally deflecting mirror and a DC monochromator (Figure 1). The toroidal mirror unit serves three main purposes: (i) to collimate the beam in the vertical dimension, (ii) to allow for dynamic demagnification in horizontal dimension, and to act as a low-pass filter with an energy cut-off of ~23 keV given by the Rh coating. The horizontal focusing corresponds to the first part of a two-step focusing strategy that offers two main advantages: a secondary source with flexible size adjustment by precision slits (the capability of dynamical focusing and the possibility of optimizing the overall acceptance of the subsequent microfocusing optical system. The fixed–exit double-crystal monochromator is equipped with three different pairs of crystals: Si(111), Si(311) for higher energy resolution and Ge(111) for higher flux throughput. The first crystal is for energy selection while the fixed-exit is controlled by a piezo device acting the second crystal.

In the experimental hutch, the micro-probe set-up is installed on a stable optical table. Achromatic focusing in the entire energy range of 4-23 keV is done with an elliptical shape mirror pair in the Kirkpatrick-Baez (KB) geometry (or KB mirrors) producing a beam of about 1.0

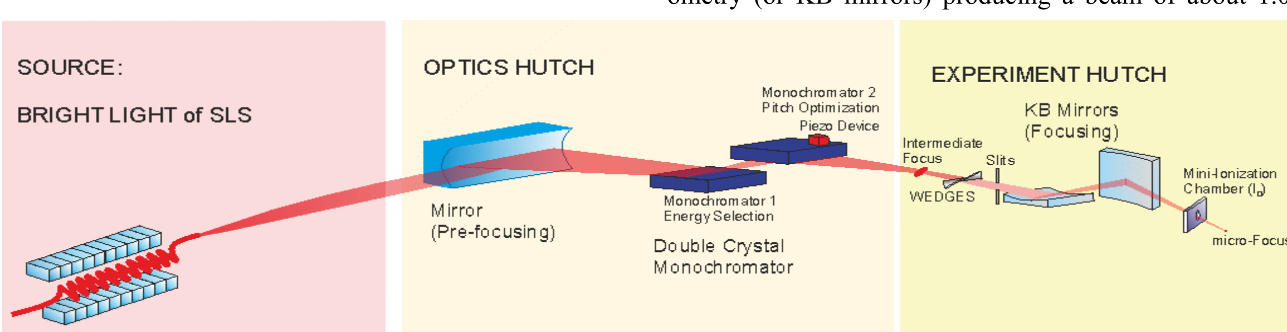


Figure 1: MicroXAS Beamline Layout.

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(H) x 1.0 (V) µm$^2$ spot size on the sample (monochromatic beam). The wedges are housed inside a vacuum box with the multi-layer mirrors of the beamline (used for pump-probe experiments) and positioned about 2.5 meters away from the KB mirror box. Scattering from the wedges are limited by slits in front of the KB mirror box. Incident X-ray flux of the microfocus beam from the KB box is counted by a mini-ionization chamber (S-2274B with 5 x 10 mm$^2$ opening produced by OHYO KOKEN KOGYO Co., Ltd) before the beam hits the sample. Different detectors are present for fluorescence, diffraction and transmission measurements.

## WEDGE DYNAMIC ATTTENATORS – SYSTEM DESCRIPTION

### *Concept*

Two wedge-shaped absorbers produce a spatially uniform attenuation preserving the beam shape without changing the beam trajectory. The attenuation length can be modified by changing the relative overlap of the two wedges (transversal alignment of the wedges with respect to the beam direction) as shown in Figure 2. The wedges are mounted on linear positioners. The direction of motion and the velocity of the wedge actuators are simply linked to the deviation from the $I_0$ set point by an ultrafast closed-loop algorithm.

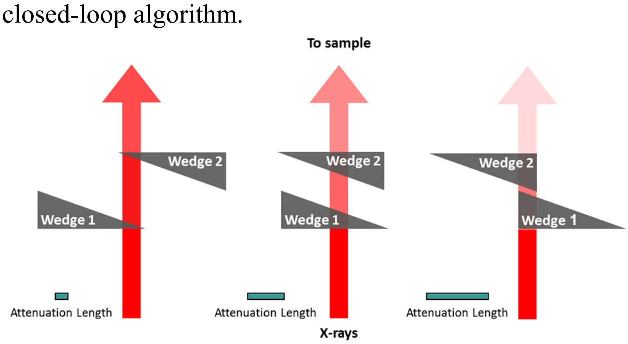


Figure 2: Attenuation length at different wedge positions.

### *Mechanical Part*

The two wedges were made from boron carbide ($B_4C$) ceramic with 4mm thickness (purchased from Goodfellow). Due to the hardness of the $B_4C$ material, it had to be diamond-grinded into the wedge shape (Stecher Ceramicparts GmbH).

The motion system is mainly a combination of a powerful in-vacuum linear ironless motor from Aerotech (constant force of 18.3 N) and a compact linear rail from Schneeberger AG. On the surface of the rail an optical 100 um pitch linear scale is engraved. The rail is equipped with low vibration carriages including a sin-cos encoder reading head. These components are mounted on an aluminium support (Figure 3).

### *Feedback Loop*

Incident X-ray flux is counted by the mini-ionization chamber before the sample position. A FEMTO© current amplifier converts the current from the ion chamber into a

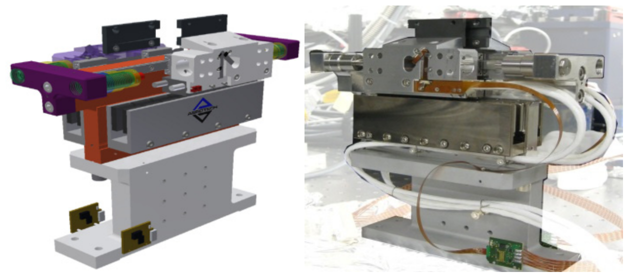

Figure 3: Design and photo of the system.

voltage between 0 to 10 VDC. The feedback loop basically takes this voltage signal “current value” coming from the amplifier ($I_0$). The “set value” is produced by an analog output of the control sysem. With the “current value” and” set value” the Aerotech controller calculates a ultrafast hardware based position profiling and generates the modulated current for the motor. This ultrafast closed loop implementation is called “autofocus” and corresponds to a standard implementation of this controller.

## DYNAMICS AND PERFORMANCE

The moving mass of the axis is around 50 g. With a countinous force of 18.3 N it is theoretical possible (in open loop) to accelerate the wedge up to 366 m/s$^2$. With a travel range of 50 mm a max speed of ~4.2 m/s is feasible for a full range step within a time of 20 ms.The response time of the system was tested using the output of the $I_0$ chamber as the current value and the value of the analog output from control system as the set value at ~7.2 keV. By changing the set point it is possible to measure the response behaviour of the current value and the whole closed loop system. The data are acquired directly on the Aerotech Controller with a sample rate of 2 kHz which gives a time resolution of 0.5 ms. Figure 4 shows the step response time of a 20% drop. It shows that the current value reaches an error bandwidth of +/-1% of the set point within **~40 ms** (Figure 4) and for a drop of 80% **~60 ms** (Figure 5).

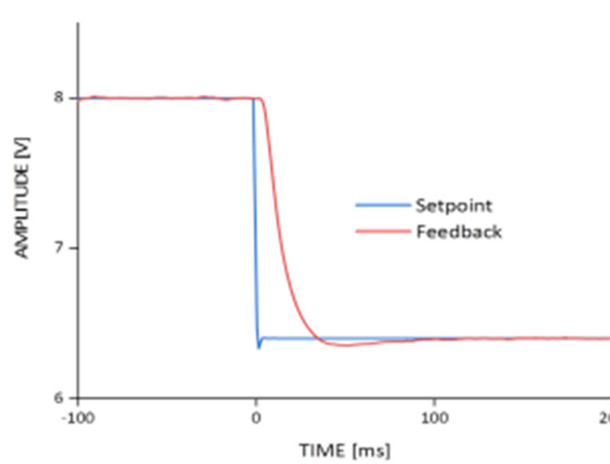


Figure 4: Step Response Time of a 20 % drop.

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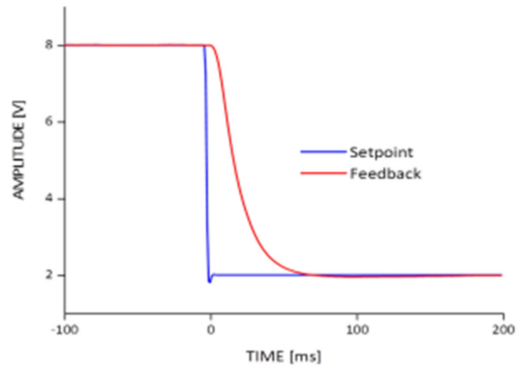


Figure 5: Step Response Time of a 80% drop.

## I0 MEASUREMENT AT DIFFERENT SETPOINTS

During an energy scan the wedge can remove different artifact like glitches and non-linearities. Figure 6 shows the $I_0$ measurement without and with the wedge operated at different set point voltages. Energy range was at ~17.33 keV with a prominent glitch.

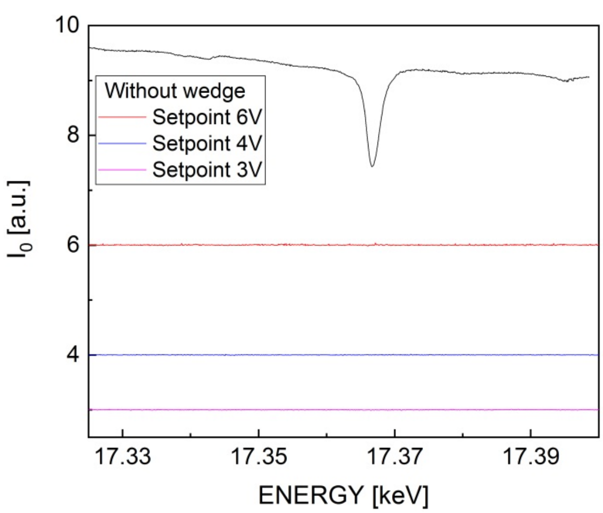


Figure 6: $I_0$ during Energy @ different set points.

## BEAM POSITION & SIZE

By using this system it is important to realize that the beam size and position is not changed by the wedge. Based on knife-edge scans with a nano test pattern the position deviation at different attenuation factors turns out to be < 40 nm from the average beam center position. The beam size during the scans is changing by < 100 nm. Both numbers are within the typical measured errors. In contrast to the MOSTAB system, we can conclude that the wedge system does not affect beam size nor beam position.

## CONCLUTION

We have designed and implemented a hardware component called **"WEDGE"** with a closed-loop feedback system to achieve a constant incident X-ray flux $I_0$ at the sample during spectroscopic measurement at the microXAS undulator beamline at the Swiss Light Source. Compared to existing approaches, the new system has several advantages, most pronounced when used in combination with mini-gap, in-vacuum insertion devices or microfocusing optics. The attenuation strength required to maintain constant $I_0$ flux can be adjusted in a fast, steady manner by simple linear translations of two wedge-shaped attenuators.

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