A FAST SWITCHING MIRROR UNIT AT FLASH

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Abstract

The **F**ree **E**lectron **Las**er at **H**amburg (**FLASH**) [1] facility at the **D**eutsches **E**lektronen-**Sy**nchrotron **(DESY)** is a linear accelerator operated in superconducting technology producing soft X-ray laser light from 6nm to 30nm. The light is created by **S**elf **A**mplified **S**pontaneous **E**mission (**SASE**). Several switching mirrors, located in the experimental hall, provide different beam lines with laser light. The switching procedure lasts up to one hour and is performed at intervals of days or sometimes weeks. Since the experiments would be sufficient even with a lower repetition rate, the beam trains may be distributed between two beam lines with a frequency of up to 2.5 Hz. The challenge lies in the precise repetition accuracy of position (few µm) and angle (about 1 arcsec) of the mirror.

INTRODUCTION

FLASH provides unique experimental opportunities to investigate the atomic structure and properties of materials, nanoparticles, viruses and cells. The extremely intense short-wave laser pulses produced by FLASH are in high demand by users; the facility is consequently always overbooked. The beam is separated into so-called trains with a repetition frequency of up to 10 Hz. Silicon mirrors - located in large vacuum vessels - deflect the light into different beam lines, but unfortunately, limit the beam supply to one experiment for days or even weeks. A possible solution to this problem would be a fast switching mirror unit that moves the mirror into the beam. The motion of the mirror is started with a machine trigger that is being synchronized with the trains. Depending on the time structure of the beam trains and on the demands of the user, the mirror can be moved freely back and forth up to a frequency of 2.5 Hz. Figure 1 shows the test set-up supported by the adjustment table and the vacuum vessel (original FLASH components).

Perpendicular to the beam, a new high precision fast moving linear motor is implemented. The aim of this project is to move the mirror to a well-defined position with a high speed and precision, i.e. the error of the mirror is only a few µm in position and about 1 arcsec in angle. A dummy mirror made of polished aluminium replaces the original silicon mirror.

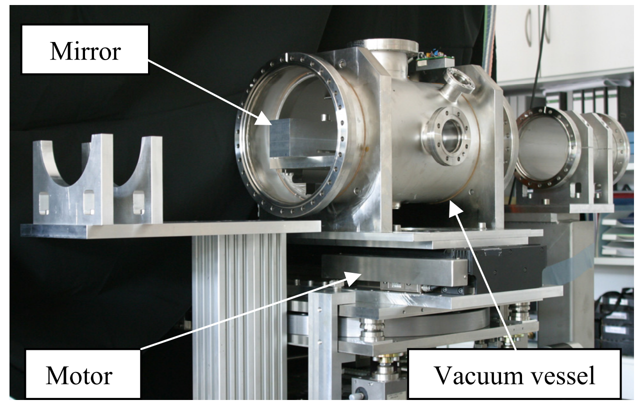


Figure 1: Test setup with vacuum vessel and drive system.

THEORETICAL CONSIDERATIONS

Positioning of the Mirror

As explained above, a photon beam shall be transported to different experiments using a fast moving mirror. The synchronized time scheme of the mirror position and the photon beam is shown in Figure 2. It can be seen that it contains dynamic motion periods and two positions where the system is in steady state. The motion of the beam in both steady-state positions (i.e. rest and final position) is shown in Figure 3. Note that since the duration of the photon beam is 0.8 ms, it is crucial that the mirror position is static during this time.

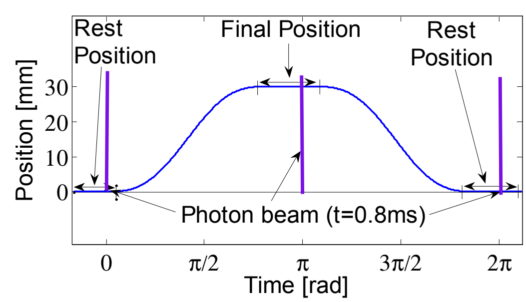


Figure 2: General time scheme of the motion of the mirror.

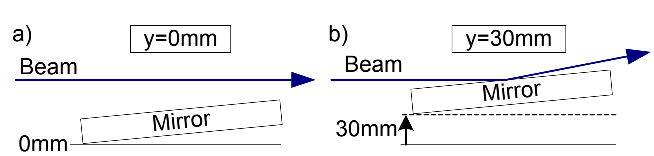


Figure 3: Beam motion in a) rest position (y=0mm) and b) final position (y=30mm).

Positioning Error

As the mirror moves into the center of the beam, a positioning error of the motor (i.e. in *y*-direction) will result in a beam displacement that is seen by the beamline user, as shown schematically in Figure 4.

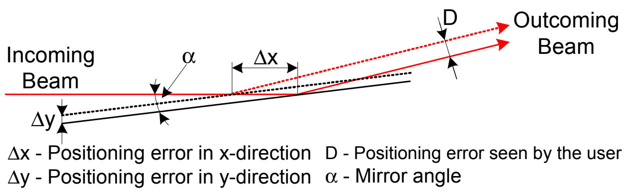


Figure 4: Positioning error of the mirror; y=30mm.

As exemplified in Figure 4, the lateral positioning error D can be determined with either Δx or Δy as an input:

$$\mathrm{D} = \sin(2 \cdot \alpha) \cdot \Delta x = 2 \cdot \cos^2(\alpha) \cdot \Delta y \qquad (1)$$

Angle Error

Since the mechanical forces on the vacuum vessel can reach large values when the motor accelerates or decelerates (especially at high motion frequencies), an angle error can occur due to the limited stiffness of the system.

Since a vertical angle displacement has very little influence on the beam, further investigation is not required [2]. A horizontal angle displacement γ, on the other hand, has a strong influence on the beam position because the angle error becomes $2*\gamma$ in the beam deflection angle.

MIRROR CONTROL

Main Control Block

A simplified block diagram of the mirror control is shown in Figure 5. It can be seen that it consists of a vacuum vessel, a linear drive and a control system with a reference curve generator. A position encoder is used to measure the absolute position of the vacuum vessel, and this value is used as feedback signal in the control system. The inputs of the mirror control are the system trigger, the frequency of motion f and the total stroke y_{max} that is constant (i.e. $y_{max}=30mm$) in our system setup.

The vacuum vessel is driven by a linear motor, the PFLG 230, from Föhrenbach that has a step precision of 0.1 µm and a positioning accuracy of ±1 µm.

An IndraMotion MLD from Bosch Rexroth [3] is applied to function as the main control block since it merges drive functions, motion control and processing logic in one device.

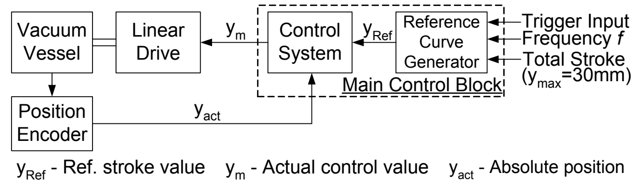


Figure 5: Simplified block diagram of mirror control.

Measurement Setup

A caliper (here: Heidenhain LC 483 [4]) is mounted next to the motor to measure the actual position of the mirror. Its measuring steps are 100 nm and the absolute position values are read by the IndraMotion controller via an EnDat 2.2 interface.

The angle deviation of the mirror is measured in the motor test system by an autocollimator, which is an ELCOMAT 3000 [5] in our setup. This device has a resolution of 0.01 arcsec and a measuring accuracy of ±0.1 arcsec.

Reference Time Response Curve

While one main focus of this project lies in getting a fast mirror speed, it is crucial to have low mechanical forces at the endpoint resulting in a low system overshoot. This can be achieved using a reference stroke response curve that uses optimized jerk, acceleration and velocity curves. As a result, this project employs a sloped sine line (Helling-Bestehorn) as shown schematically in Figure 6. Since the jerk is represented here as a cosine function, it results in smooth changes in the acceleration and velocity curves, with the result that fewer vibrations are induced into the drive.

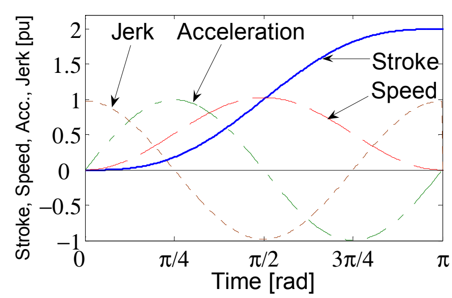


Figure 6: Reference stroke response using a sloped sine line (Hellhorn-Bestehorn).

RESULTS

The test setup shown in Figure 1 has been connected with the control system and all measurement devices. Particularly with regard to the required accuracy, the reference stroke response and the horizontal angle error of the final test system are tested in this section.

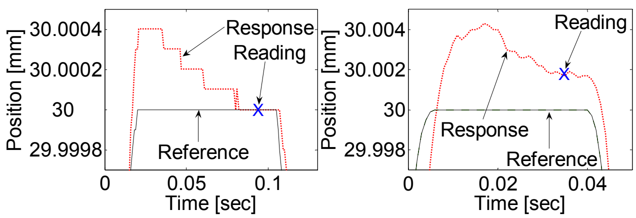
Reference Mirror Position Response

The reference stroke response of the vacuum vessel and the preset reading points are shown in Figure 7 for two particular motion frequencies; a) f=0.4Hz and b) f=2.5Hz.

Note that the shown reading points also represent the time period when the photon beam is turned on.

It can be seen that the test case in Figure 7.a shows a very good response with low overshoot and no positioning error in the reading point.

The test case in Figure 7.b, on the other hand, shows an extreme case with still a low overshoot (0.013%) but a positioning error of 1.5 µm in the reading point. However, it has been shown in further studies that even after hundreds of runs this error value is relatively constant with an accuracy of 1.5±0.2 µm. According to (1), the misalignment seen by the beamline user becomes ±0.4 µm with the result that even a setup with such a high frequency still meets the required accuracy.



a) f=0.4Hz b) f=2.5Hz

Figure 7: Mirror stroke response.

Horizontal Angle Measurement

The most sensitive positioning parameter is a possible misalignment of the angle of the mirror in the horizontal plane. As described before, a frequency of 2.5 Hz is the extreme case. As a result, the angle distortion is investigated in this section for this particular frequency. Using the ELCOMAT 3000 autocollimator, we obtain an angular distribution at the final position as shown in figure 8. Here, an intrinsic noise of the autocollimator and the environment (mostly air disturbances) measuring 0.2 arcsec has to be subtracted. The distribution around the nominal deflection angle of 3 degrees is almost Gaussian, as can be seen in figure 9. The standard deviation of the fitted Gaussian is about 0.6 arcsec and fulfils the required accuracy.

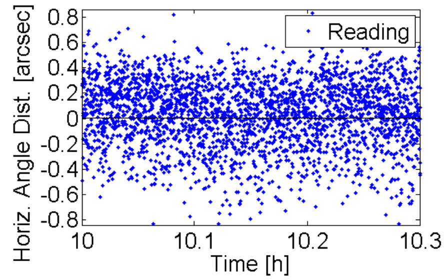


Figure 8: Horizontal angle disturbance; f=2.5Hz.

Given that the experiments are typically about 20 meters downstream of the deflecting mirrors, the resulting misalignment, as seen by the user, is about 100 µm at a beam diameter of around 3 mm.

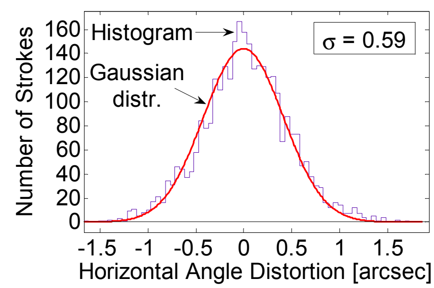


Figure 9: Gauss distribution; f=2.5Hz.

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