A FAST SWITCHING MIRROR UNIT FOR FLASH

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Abstract

Switching mirrors are used to provide several beamlines with Free Electron Laser or synchrotron radiation from one source. Since most users do not need the nominal bunch train density, a fast switching mirror is a method to supply many experimental groups. So far, the switching process has a duration of several minutes. A feasibility study at DESY analyzes possible ways of permanent switching at half of FLASH's bunch train frequency of 1 to 10 per second. A first prototype with highest demands on repetition accuracy of the position (below 1 μm) and yawing of the mirror (about 1 arcsec) has been tested. In the course of the work several technical concepts from industry like Programmable Logic Controllers or Position-Velocity Streaming found their way into beamline technology, thus allowing fast proceedings in development.

INTRODUCTION

The state of the development of Free Electron Lasers (FEL) allows to provide external experiments with the outcoming photon beam. At the FLASH facility at DESY Hamburg, biochemical, material scientific and other physical experiments are supplied with an intense radiation with a wavelength down to 6.5 nm. The VUV and soft X-Ray radiation is deflected into five beamlines by silicon mirrors at grazing incidence. 94 to 96 per cent of the incoming radiation are totally reflected at a covering layer with a roughness smaller than 0.5 nm rms over the full mirror length [1]. By the use of these mirrors it is possible to build more than one experiment into a hall. These mirrors have to be carefully adjusted in order to minimize their influence on the beam position at the target. At present, this alignment can be done only from time to time.

The peak current of the FEL of several thousand Ampere cannot be supplied at all times - a pulsed operation is absolutely necessary in order to protect the accelerator from damage. This is achieved by splitting the electron beam into bunches with a separation of 1 μs and the alignment of up to 800 bunches in a bunch train. These trains are shot with a repetition rate of up to 10 per second, and each bunch produces an FEL pulse in the undulator (cf. fig 1). Pump and probe experiments can usually be done within one bunch train. That is why it is natural to consider the possibility of a switching mirror, that moves periodically so that *every second bunch train is deflected*.

For the feasibility study, the task is to move the mirror into

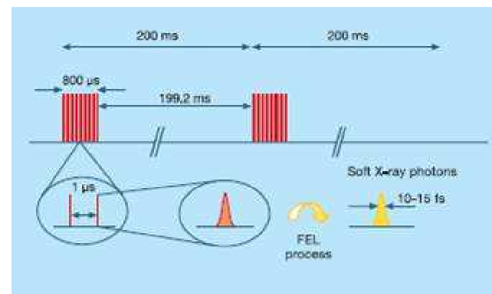

Figure 1: Time scheme of the electron bunches at FLASH, taken from [1].

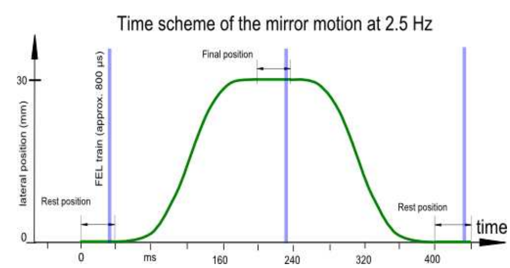

Figure 2: Time scheme of the motion of the mirror.

the beam with a stroke of 30 mm at a grazing angle of 3°, thus ensuring that the beam can pass the chamber if the mirror is off center. The time span for such a motion is smaller than the duration between two bunch trains, i.e. 200 ms for 5 Hz. Further on the motion of the mirror has to be synchronized to the machine's time scheme, as shown in fig 2. In the last year the use of linear motors, Programmable Logic Controllers (PLC) and the interface to the FLASH beamline control system (DOOCS) have been prepared in order to establish a toolkit which enables one to quickly develop and to implement off-the-shelf solutions for this kind of motion and communication problems. This work is a collaboration with HASYLAB, BESSY and the department of mechanical engineering at DESY Zeuthen. We describe our methods as well as the first measurements of an elaborate construction.

THEORETICAL CONSIDERATIONS

One can now calculate the influence of a change of each of the six degrees of freedom (three translations and three rotations) of the mirror, according to the law of reflection. Seen from the user's perspective, a small translation will lead to a parallel offset of the outgoing beam that is in-

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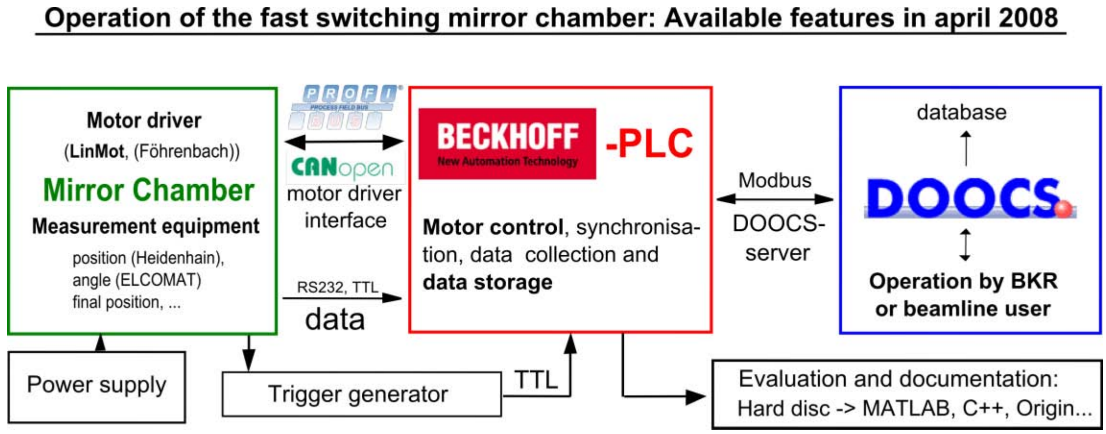

Figure 3: Communication scheme of all components.

dependent of the distance from the mirror. An error in the angle will however lead to an offset that grows proportional to the distance.

In table 1 the calculated errors are presented. The yawing γ, a small change in the angle of incidence, is by far the most critical error. Due to the special alignment (grazing incidence), the influence of the errors of the other angles is reduced. A misalignment of the motor position leads to a horizontal offset which is almost two times higher. α denotes the angle of grazing incidence (here: $3°$), x the direction of the beam, y the direction of motion and z the normal to ground. The nodding ν denotes a small rotation around the beam axis and ρ a small rotation around the axis of motion. From this point of view it becomes clear that it is more important to reduce the clearance of the guiding and the vibrations induced by the motor rather than to tune the feedback so stiff that the position error stays small. Pretuning of the feedback loop is done in accordance to the method of Ziegler and Nichols [3], whereas the fine tuning is done empirically by the evaluation of the recorded position time series y(t). The mass of the system and the dry friction are entered as feedforward parameters.

PRESENT APPROACH

In the recent years one has made good experience with low clearance linear guidings for the linear support of beamline equipment. Particularly for the TTF Wire Scanner [2], a rather compact linear guiding together with a slot curve drive an a stepper motor had been chosen. In this drive there are two ball bearings which add their clearance to the position of the moving slide. In addition the masses that we will have to move are considerably higher than those moved by the wire scanner, the weight of the mirror itself is already about 4.5 kg. On this account we decided to drive the slide with linear motors which are state-of-the-art.

The task is then to tune the controller and the feedforward in order to achieve highest possible positioning accuracy and minimal possible vibrations. Note that the most critical quantity, the yawing of the mirror, is not yet in a feedback loop. Instead we try to limit the clearance of the angles by making use of a stiff construction and reduced incoupling of vibrations. In figure 3 one can see the communication scheme of the machine. A Beckhoff PLC is used for general control, communication and data acquisition. It is also used to synchronize measurement and motion according to a trigger signal. The elaboration of this control system has been a substantial part of the work of the last year.

At present, two different setups are pursued. One is shown in figure 4: A motor from the LinMot company drives a mirror clamping trough bellows. A linear guiding supports the clamping from outside and a linear encoder (Heidenhain MT 60K) is mounted below the slide. It returns the position with a resolution of 100 nm. This construction from our facilities has a comparatively low moving mass (around 24 kg), however the motor controller has no notch filters available and the mounting suspension of the mirror has to be guided through bellows, resulting in a resonance frequency of less than one kHz. First measurements are presented below. Another approach is to move the whole existing mirror chamber with a very strong and compact linear motor from the Föhrenbach company. This would require only small changes in the existing construction but it means one would have to move a mass of about 80 kg in accordance to the above mentioned time scheme. Such a setup with a test mass is in preparation. This construction can be designed very stiff as there is no bellows between the motor and the mirror. Further on the motor controller has integrated notch filters to avoid the excitation of mechanical resonances. However the large momentum of up to 30 kg$\frac{\mathrm{m}}{\mathrm{s}}$ leads to large vibrations in the ground that will have to be compensated. We use an analog acceleration sensor ADXL320 to measure the vibration spectrum of the motion and on the ground via a Fourier transform with a bandwidth of 0 to 2.5 kHz.

The angle measurement is taken synchronously with the final position with an electronic autocollimator ELCOMAT

Table 1: Beam misalignment due to positioning errors of the mirror as seen by the beamline user.

Cartesian error:	Δx	Δy	Δz
horizontal:	$\sin 2\alpha \cdot \Delta x$	$2 \cdot \cos^2 \alpha \cdot \Delta y$	0
vertical:	0	0	0

Angle error:	Yawing γ	Nodding ν	Rolling ρ
horizontal:	2γ	0	0
vertical:	0	$2 \cdot \sin\alpha\cos\alpha \cdot \nu \approx 0.1\nu$	$2 \cdot \sin^2 \alpha \cdot \rho \approx 0.005\rho$

3000 which delivers a horizontal and a vertical angle value every 40 ms with a noise of 0.2 arcsec rms.

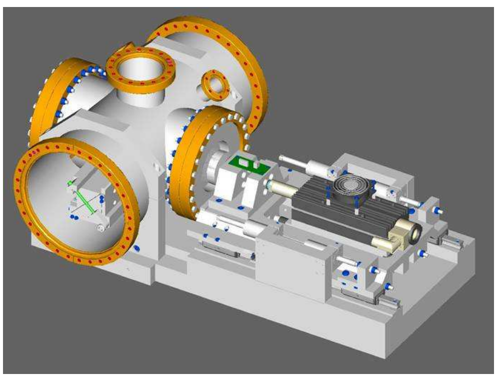

Figure 4: Current design of the Switching Mirror Chamber (LinMot version).

FIRST RESULTS

We measure the Y position accuracy by averaging over 1500 final positions and calculating the standard deviation. For the angles' measurement one has to take into account that the autocollimator vibrates due to the motion of the motor. A mounting of the device on a different stand is not possible, as the stands will vibrate against each other. Instead we take a mirror that is glued to the very massive wall of our laboratory as reference and make two measurements: 1.) The device against the wall while the motor is running, 2.) the autocollimator against the moving mirror. Both measurements are then approximated as normal distributions and are deconvoluted. Thus we obtain the standard deviation of the (hypothetical) measurement of the moving mirror against the reference mirror
(cf. table 2).

The misalignment seen by the user is calculated via the formulae in table 1. All errors refer to a confidence interval of 95 $\%$ (2σ). The errors lie beyond our demands. (Compare: The FLASH beam diameter is $\approx$ 3 mm.) Tuning may reduce the Y position error, but for the angle errors we have reached the lower limit of this construction.

Table 2: Measured beam misalignment as seen by the beamline user.

	accuracy	**user's view**
Y position:	$\pm 3\ \mu$m (2σ)	$\pm 6\ \mu$m
Yawing:	± 0.6 arcsec (2σ)	$\pm 6 \frac{\mu \mathrm{m}}{\mathrm{m}}$
Nodding:	± 3 arcsec (2σ)	$\pm 1.5 \frac{\mu \mathrm{m}}{\mathrm{m}}$

FUTURE OPTIONS

During the next weeks, tuning of the controllers and measurements, especially of the Föhrenbach motor, will proceed. The above results show that at a distance of up to 20 m to the experiment the horizontal spread will be more than 0.2 mm. This may be insufficient as direction-sensitive devices like monochromators will get out of tune. Thus it is being investigated whether it is possible to close the feedback loop for the yawing angle. A possible choice is a laser and a four quadrant photodiode as yawing detector and voice-coil or piezoelectric actuators to add a very small shift to the mirror clamp. The PLC would act as controller. Another step is a mechanical blocking in the final position, which can be used for demonstration but which is also an obstacle if one has to tune the stroke. A mirror clamping that allows for the support of a mono-crystalline mirror is being developed. At the moment we pursue FEM calculations and interferometer measurements of the test clamping seen in figure 4. Therefore a dummy mirror made of aluminium with a surface roughness of better than 50 nm will be used as optical mirror to measure the deformation of a clamped mirror with an interferometer at BESSY.

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