Design of a Large Offset Monochromator at PETRA III

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Abstract

For the beamlines of the new synchrotron radiation source PETRA III at DESY, monochromators with specific features are under development. To achieve a compact arrangement of a canted undulator beamline, one option is to shift one of the two beamlines 1.25 m upwards. This is needed to arrange the experimental hutches of one beamline on top of the hutch of the other beamline. This will be realized with a large offset monochromator (LOM) installed behind the high heat load monochromator (HHL). The energy range will be 5.4 keV to 29.4 keV with an energy step resolution of 10 meV. The beam position stability at the experiment must be better than 10 μm . The photon intensity losses have to be kept as low as possible. Additionally the LOM will narrow the energy bandpass transmitted by the HHL (Si 111) by using Si 311 and Si 511 crystal sets. For low frequency distortions like thermal and mechanical drifts an active stabilization of the crystal positions using piezo driven actuators is realized. We aim for a novel approach using a visible laser-based stabilization system. The laser beam is fed into the optics of the LOM so that it points parallel to the x-ray beam but with a horizontal offset. Therefore, the laser light will always be reflected in the same direction as the x-rays. To monitor the exact position and direction of the laser beam three position sensitive detectors for the optical laser will be mounted between and after the crystals of the LOM. Using these signals a piezo feedback system keeps the position and direction of the laser beam constant with an accuracy of 1 μm and 0.3 μrad . As the x-ray beam is exactly coupled to the optical laser beam the same accuracy is expected for the x-rays with no loss of intensity due to the stabilization system.

1. Introduction

At the new synchrotron radiation source PETRA III at DESY some neighbouring beamlines are fed by two canted undulators. The beams are emitted from the undulators with 5 mrad separation. This limits the space between the neighbouring beamlines dramatically. Because of this, one option is to shift one of the two beamlines 1.25 m upwards. This is needed to arrange the experimental hutch of beamline P08 (High resolution diffraction) on top of the hutch of beamline P09 (Resonant scattering/diffraction). This will be realized with a large offset monochromator (LOM) installed in beamline P08 behind a high heat load monochromator (HHL). The resonant scattering beam passes the hutch without any manipulation. The high-resolution diffraction beam is monochromatized by the cryo-cooled HHL and is offset vertically by the LOM.

We have to deal with a beamline length of 60 m and a precision of the beam position at the experiment of 10 μm . Because of this and many degrees of freedom concerning our mechanical setup we designed a stabilization system which guarantees the beam position at the experiment. We decided not to monitor the x-ray beam itself but a laser beam following the same optical path. Using this approach the x-ray beam is not attenuated by position monitors.

Fig. 1: Overview of the optics hutch showing the high heat load monochromator (HHL) and the large offset monochromator (LOM).

2. Purpose and specification of the LOM

The specification of the beamline asks for an energy range from 5.4 keV to 29.4 keV with an energy step resolution of 10 meV. The beam position stability at the experiment must be better than 10 μm . The intensity losses have to be kept as low as possible. Additionally, the LOM is used to increase the energy resolution in comparison to the HHL, which is equipped with Si 111 crystals. For photons with energy 29.4 keV the Bragg reflex of Si 111 has a width of 4 eV FWHM compared to 300 meV of Si 511, for example.

Fig. 2: Main components of the LOM.

Fig. 3: Si 311 and Si 511 crystals mounted on an assembly consisting of goniometer, lateral drive and piezo table.

2.1 mechanical setup

The mechanical design fulfilling this specification is shown in figures 2 and 3. Two pairs of crystals (one pair of Si 311 and one pair of Si 511) will be used to cover the whole energy range and to increase the energy resolution. The energy range in combination with the large vertical beam offset demands for a relative crystal movement of roughly 3 m in longitudinal direction. This is implemented by longitudinal movements of 1.5 m for each crystal (see Fig. 2). The Bragg angle of the crystals is positioned by a high precision goniometer. For fine-tuning the pitch axis of the piezo table (see Fig. 3) is provided. The piezo table will also be used to correct the roll and height deviations caused by the linear crystal drives and the goniometer. The precision of all mechanical components beneath the piezo table are specified such that all deviations can be compensated by the piezo table. Further we can reach the specified energy resolution of 10 meV even at high energies as the piezo table enables us to perform steps down to 50 nrad. The linear axis is mounted on a rigid steel bar. This bar can be preadjusted by micromovers from outside the vacuum vessel [1].

2.2 x-ray detectors

After the first crystal a simple metal foil detector is used to measure the intensity of the x-ray by photo effect. After the second crystal there are two x-ray beam position monitors. One is situated directly behind the LOM and the other approx. 20 m behind. The working principle is the detection of back-scattered light emitted from a metal foil with four pin diodes. The resolution of these monitors is specified as 2 μm .

3. Laser stabilization system

For low frequency distortions like thermal and mechanical drifts an active stabilization of the crystal positions is mandatory. This could be done by monitoring the beam intensity behind each crystal and

Fig. 4: The laser beam passes a crosshair. From the intensity profile which is observed by a camera the position of the beam relative to the crosshair can be calculated.

then controlling the Bragg angle to stabilise the beam intensity at a value of about 80% of the maximum, using the well known Mostab algorithm [2]. This technique would cause an overall intensity loss of about 50%, including intensity losses due to the intensity monitors.

To minimize these losses a laser-based stabilization system for the monochromator crystals is implemented. The laser beam enters the monochromator parallel to the x-ray beam and is reflected at the surface of the crystal which is partly coated with a highly reflecting layer. The laser light will travel through the monochromator on a parallel path with a horizontal offset to the x-ray beam. Thus, it is affected by changes of the crystal positions exactly as the x-ray beam. By stabilising the laser beam using 3-axes piezo stages (see Fig. 3) the x-ray beam is automatically stabilised.

3.1 Laser position monitors

We use 3 subsequent laser position monitors, which calls for semi-transparent optical devices. The first monitor between the two crystals is a diffusive glass panel with a crosshair. Its lines are 0.5 mm thin. Using a beam splitter like for the second and third monitors is not possible as the angle of incidence changes by ± 33 degree for the first monitor. This is due to the large travel of the crystal when changing the energy of the beam. We apply a method which was formerly developed for an alignment laser system in the front end [3]. The laser beam passes through the crosshair and images are captured by a digital camera. The principle is sketched in Fig. 4. This data is used to calculate the beam position relative to the crosshair. By evaluation of the attenuation due to the crosshair in vertical and horizontal direction the beam position can be specified with a resolution of 2 μm .

The laser beam is reflected on the second laser position monitor by a semi-transparent mirror. The position of the beam is measured with a resolution of 0.4 μm by a CCD detector. Finally the beam is reflected by a mirror on the third detector which is identical to the second one. The distance between these two position monitors is approx. 20 m.

3.2 Control system

Each crystal stage of the LOM is equipped with three piezo actuators. These devices act on the height, pitch and roll of the crystals, respectively. We get horizontal and vertical position from the crosshair detector. We use this information to compensate deviations by controlling the pitch and roll piezo of the first crystal. The height piezo settles at a position which compensates the height deviation of the linear

axis. For the second crystal we have more information concerning the beam path. As two position detectors are installed after the second crystal we can easily calculate the angle and height deviation of the beam and can determine how far the three piezos of the second crystal have to be moved.

4. Results

As the setup of the LOM is not finished yet we tested our stabilization approach with the HHL. It is equipped with three piezo actuators for the second crystal. As for the LOM these actuators affect the pitch, roll and height of the crystal. For our experimental setup we replaced the crystals of the HHL by mirrors to guide the laser beam. The laser position detectors were mounted behind the HHL at distances 0.3 m and 2.8 m. The results were promising and a drift compensation of the laser positions was put in practice. We achieved a standard deviation of $0.6\text{ }\mu\text{rad}$ for pitch and roll and $1.1\text{ }\mu\text{m}$ for the height. The long term mean value of the deviation from the set point of pitch and roll is in the range of 1 nrad and the mean value of the deviation from the set point of the height is approx. 50 nm . In our preliminary setup the laser beam passes through air and not through vacuum. Hence, we observed high measurement noise which limited the ability to compensate vibrations or shocks. Nevertheless, the systems main purpose is to guarantee long term stability. We assume that we can reach smaller standard deviations of the controlled parameters in the final setup as the laser beam travels completely in vacuum and more effort will be spent on mechanical stability of the final setup.

The profile of the beam which passed the crosshair detector has an almost symmetrical intensity profile. If the position of the beam is measured with a laser position monitor while moving the crosshair a change of the detected position at the laser position monitor is seen. This side effect is due to the not perfectly symmetrical beam profile. A change of the position of the crosshair by $1\text{ }\mu\text{m}$ leads to a change of the position at the laser position monitor of $0.15\text{ }\mu\text{m}$. As we try to keep the position of the laser beam relative to the crosshair constant by controlling the piezos of the first crystal, we are confident that there will be negligible error in the measured position at the laser position monitor.

5. Conclusion

We presented the development of the LOM for a high resolution diffraction beamline at PETRA III. Several demands have to be fulfilled like high intensity of the x-ray beam, a narrow energy distribution of the photons, beam stabilization and horizontal beam offset by 1.25 m . The Bragg peaks of Si 311 and Si 511 are narrow enough to reach the specified bandwidth of the beam. For the realisation of beam stabilization and high intensity we decided to develop a laser stabilization system which enables us to stabilise the x-ray beam without monitoring it directly. Because of that we omit the attenuation due to x-ray position monitors. The challenges are the measurement of the laser beam position with 3 subsequent detectors and the appropriate control of the piezo actuators of the crystal stages. We have to take care that the first measurement, where the beam passes a crosshair on a glass panel, does not influence the following measurements. This is done by choosing the right thickness of the glass panel and of the cross hair lines. Further we compensate the angular depending displacement of the laser beam due to the glass panel. The system will be tested in the first half-year of 2009.

References

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