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NOVEL COMPREHENSIVE UHV LENS CHANGER AT THE PETRA III BEAMLINES P22, P23 AND P24

J. Raabe†, K. Ederer†, C. Schlueter, R. Grifone, D. Novikov
Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

Abstract

We present the design of a compact UHV-compatible X-ray transfocator for beryllium compound refractive lenses (CRL).

CRLs are nowadays commonly applied for beam focusing, collimation and aperture matching in a lot of experimental techniques based on synchrotron radiation. Aim of the current project was the development of a low-maintenance lens for the reliable use under ultrahigh vacuum conditions. We discuss two variants of the device, one designed for 2D lenses and the other one operating with 1D lenses. Precise and reproducible alignment is achieved by pneumatic actuators that press the lens stacks against a high precision prism. All actuators and position sensors are placed outside the UHV vessel. Alignment is facilitated by integrated beam monitors and alignment apertures. The transfocator construction allows an easy adaptation for any desired number of lens stacks. In the current version, the 2D lens changer adapts 12 stacks of up to 8 single lenses each, and the 1D variant – 8 single lenses or apertures.

INTRODUCTION

Refractive optics is of key importance for synchrotron beamlines aiming for micrometer and sub-micrometer beam sizes. Small dimensions of the lenses allow for very compact and cost effective solutions for beam focusing applications [1, 2]. Consequently, CRLs became widespread in the synchrotron community, particularly for hard X-ray beamlines.

Three new beamlines went into operation in the Ada Yonath hall at the high brilliance PETRA III storage ring at DESY (Hamburg, Germany) in 2017. At all beamlines compound refractive lenses are employed for in-vacuum X-ray beam focusing, collimation and conditioning [3].

In this project, great importance was attached to a robust and low maintenance design of the lens changing mechanics which was implemented with some minor variation at all three beamlines. Here we present a lens changer design, with particular emphasis on 2D focusing requirements at the In-situ and Nano Diffraction beamline P23 and at the Chemical Crystallography beamline P24.

LENS CHANGER DESIGN

The beamline optical configurations require the positioning of lenses in the optic hutches in an UHV environment, making a compact and scalable design, high reliability and low-maintenance operation as well as compliance with the stringent DESY vacuum guidelines key objectives of the design task.

Requirements

Basic specifications for the lens changer include :

- Main functionality: high precision for positioning of the lenses
    - with exact coaxial orientation of the lenses to the synchrotron radiation beam and to each other
    - high positional reproducibility
- UHV environment with extremely low residual hydrocarbon content
- Simplified adjustment mechanics with four motorized degrees of freedom for alignment with respect to the X-ray beam – y (horizontal, perpendicular to the beam), z (vertical), pitch and yaw
- all alignment mechanical parts should stay outside of vacuum for easy service and troubleshooting
- Integrated alignment screens
- CF-flange viewport(s) for inspection and alignment
- flexible remote control via a TCP/IP interface

Design of P23 Transfocator

The general design of the transfocator is comprised of a vacuum vessel with lens stacks, alignment prism, out of the vacuum support and positioning mechanics. Single lenses are stacked in groups depending on experimental requirements (i.e. energy, focusing conditions, photon flux optimization). To achieve optimal focussing at discrete energies one can select suitable combinations of lens stacks carrying different numbers of lenses [4].

The lens stacks are pressed with a spring sheet into a high precision prism. The prism is the core element of the design. It has very tight shape and position tolerances and serves as a reference plane for reproducible alignment and ensures exact positioning. The manufacturer we have chosen provides a permitted variance of the guide plane parallelism to the reference planes of 2µm over the whole length of a range [300…1000] mm.

The stacks are inserted into the beam path by a rotational lever mechanics pushed by pneumatic drives. The simple and robust layout inside the vessel allows for fast and reliable switching between different configurations.

For alignment and beam monitoring, pinholes and X-ray fluorescence screen are incorporated into the system.

The assembly is shown in Figure 1.

† jana.raabe@desy.de
† katrin.ederer@desy.de

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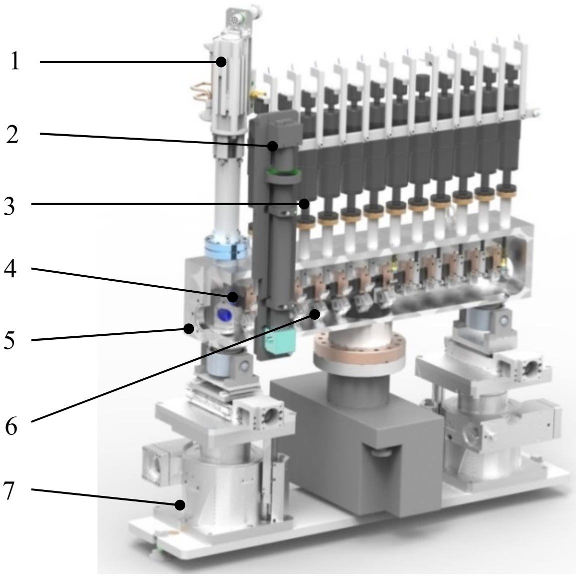

Figure 1: Rendered image of the 2D lens changer with fluorescence screen (1), camera and optics (2), pneumatically driven translation actuators (3), prism (4), UHV vessel (5), lens stack (6) and support construction (7).

Support Construction

The lens changer can be easily aligned in the beam by precise parallel kinematics, offering two translational and two rotational degrees of freedom.

The alignment of vessel and prism is done via a combination of two vertical and two horizontal individually driven translation stages placed under the UHV vessel (Figure 2). Two Huber Z-stages (5103.A20-90) are used to adjust height and pitch.

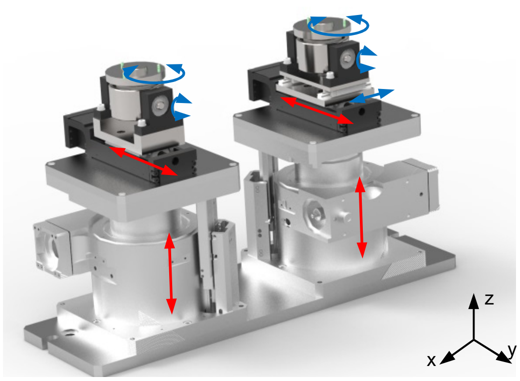

Figure 2: Rendered image of the support stage.

Two Misumi linear travels (LX3005-B1-A3038-125) adjust translation in y across the beam and the yaw rotation around the vertical z axis. Further rotational and translational rails and deep groove ball bearing compensate the angular and geometrical displacements (marked in blue) between vessel and ground plate that occur due to the movements.

Vacuum Chamber

The vacuum vessel consists of a base chamber and a sideward cover as shown in Figure 3. It has a length of 662mm, a width of 153mm and a height of 153mm. All inner components are arranged on the milled out rear panel and therefore positioned in a well controllable relation to each other.

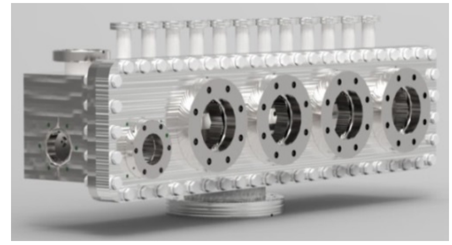

Figure 3: Rendered image of the vessel.

The cover has integrated viewports for easy inspection of the lenses. The main vessel components are sealed with a FKM O-ring seal (Viton®). The calculated groove filling was chosen to be as high as possible and lies between 84 and 98% which is in the specified tolerances to ensure optimal sealing. For high vacuum quality all parts went under a thorough cleaning process and assembly under ISO class 5 clean room conditions. Baking of the chamber is not necessary under these premises. Residual gas analysis shows that the system fulfills the DESY vacuum guidelines [5] and the emitted gas is free of hydrocarbons. A base pressure of 1.8x10-8 mbar was reached.

Furthermore DN40 CF Flanges are chosen to connect the chamber to other beamline components and a DN100 connects the Ion pump on the bottom. An additional DN40 viewport gives direct visibility onto the DESY standard diamond fluorescence screen incorporated into the system [6]. The CVD diamond screen with an integrated graphitized cross can be put into the center of lens axis immediately after the upstream port. The 12 DN16 flanges for the translational feedthroughs sit on the top of the vessel.

Positioning Mechanics

Details of the 2D mechanics are shown Figure 4. 2D lenses are delivered in circular metal frames. These frames are combined to firm stacks that exhibit cylindrical reference plane for alignment. The stacks are held loosely by a lever which can rotate in an lug. During the assembly the height of the lug is adjusted to ensure an optimal pivot point.

The stacks are pressed against the reference prism by pneumatic drives and the lever mechanism. For precision alignment a spring sheet pushes the reference planes of the lens stack into the prism planes. When removed from the beam, or in case of air pressure loss, the frames slide out of the X-ray path and a spring plate at the end of the travel ensures a gentle hold.

The insertion of a lens stack into the beam is implemented in two stages. In the beginning, there is no direct mechanical contact between the levers and pneumatic actuators: in a first step the force transmission is implemented in a contactless manner over repulsing permanent magnets built into the lever and the pneumatic drive tip. Under the magnet, adapted to the pneumatic drive rod,

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sits a small ball, so that in a second step the end of the rod has contact just in one point to the lever. This construction ensures both a damping of the mechanical impact by the drives and a self-aligning low contact motion transmission and allows avoiding complex adjustments in the force transmission mechanism.

The MDC linear feedthroughs with a travel length of 1 inch are mounted to the 12 DN16 flanges of the vacuum vessel (Model K075-ABLM-1).

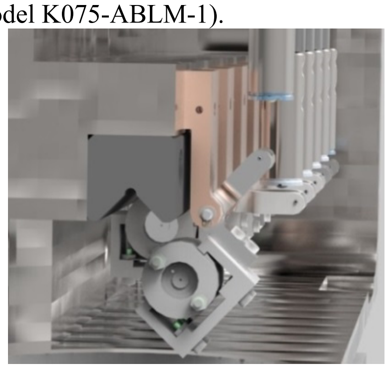


Figure 4: Detailed view on the 2D mechanics.

The 1D lenses differ from the 2D ones by a square holder form. The focusing direction of a 1D lens is parallel to one of the frame edges. Therefore, the lens changer prism is mounted under a 45° angle to align the rectangular lens frames in the vertical or horizontal planer (Figure 5). Extensions of the pneumatic drives press the lens stacks against the prism. Lateral stability of the stack holder is ensured by guide rails placed inside the vacuum vessel. [7ˈ

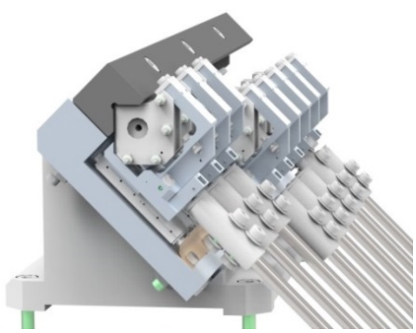


Figure 5: Detailed view on the 1D mechanics.

Alignment and Control

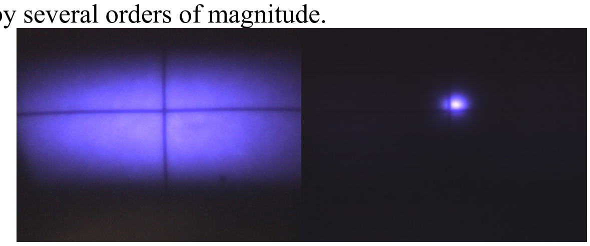
For easy alignment two built in apertures allow fast beam positioning parallel to the main axis.

According to the experimental requirements, different lens combinations can be set remotely from the beam line control cabin. A control box with an Acromag XT1112 16 channel I/O modules was designed to switch the FESTO valve terminal used for driving the pneumatic feedthroughs. Communication is facilitated via the ModBus protocol in the Tango middleware. The interface is fully integrated in the user software and allows for automated lens changes during experimental runs.

Example of Performance

First test for focusing showed good reproducibility and repeatability results for intermediate focus sizes, lens positioning in the prism and alignment by the parallel kinematic.

Figure 6 demonstrates the results of the first test of the 2D transfocator at beamline P23. Total beam intensity loss of about -40% was observed after focusing with a stack of 4 beryllium lenses with 500µm radius. After focusing, the flux density in the focal spot was increased by several orders of magnitude.



a) b)

Figure 6: Focused beam at 10.367keV.

CONCLUSION

We have presented two UHV compatible lens changer designs for 1D and 2D lenses for the use at synchrotron radiation beamlines. All active elements are placed outside the vacuum vessel, which allowed a compact vacuum chamber design and facilitates easy access for repair and maintenance work. Alignment aperture and fluorescent screens are integrated into the vacuum vessel. The design can be easily adapted for any number of lens stacks.

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