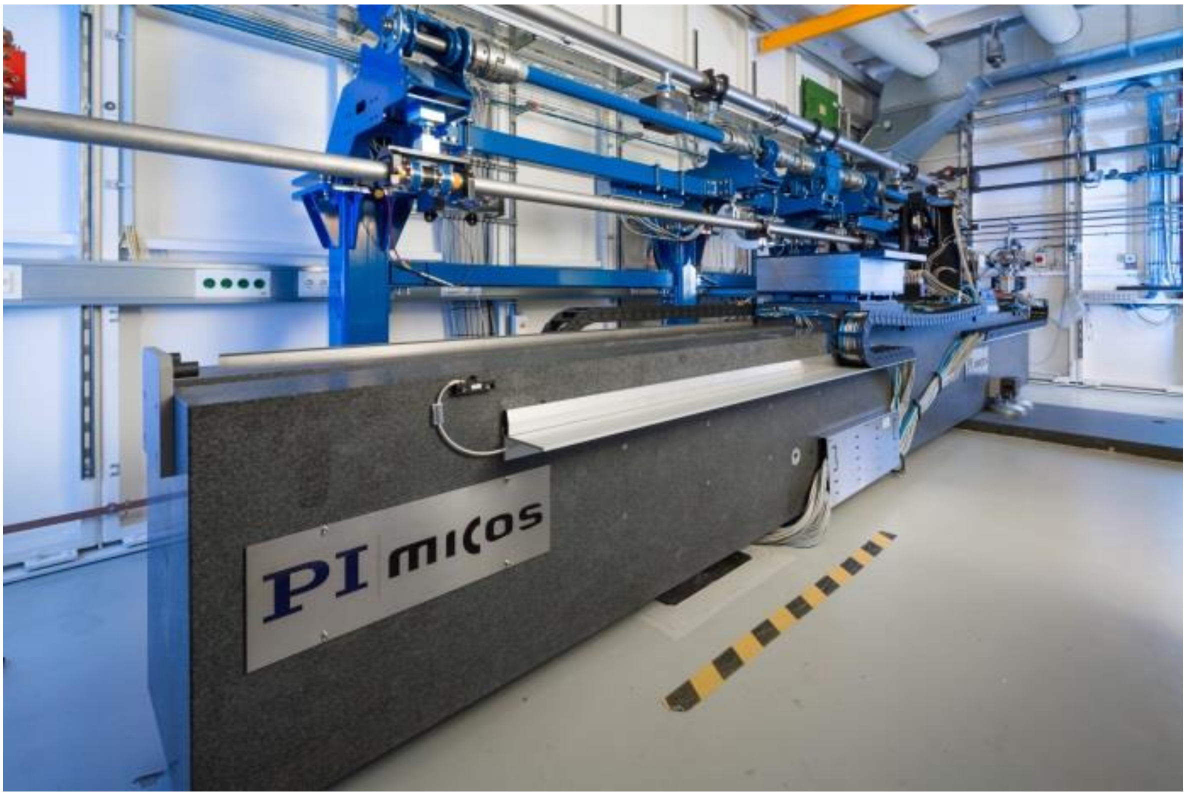
Tailor-Made Positioning Solution for Analytical Methods Performed on a Beamline

Mechanical System Approaches Limit of Technical Feasibility



Physik Instrumente (PI) GmbH & Co. KG_Auf der Roemerstrasse 1_76228 Karlsruhe, Germany
Tel. +49 721 4846-0, Fax +49 721 4846-1019 Email info@pi.ws, www.pi.ws

Nowadays X-ray and tomographic methods help detect very fine structures inside objects. For spatial resolutions down to 100 nanometers, diffractive X-ray optics are available today. However, various challenges have to be overcome to obtain a three-dimensional image with volume resolution in this range. It is a major challenge to achieve the extremely high mechanical accuracy and stability required for the alignment of the optics and samples in the X-ray beam and for the entire experimental setup. Even minute changes in temperature or vibrations could degrade the desired resolution. This is why the improvement of the X-ray optics must always go hand in hand with the mechanical perfection of the entire setup. If specialists work closely together, considerable progress can be made as shown by the example described below.

Fig. 1 At the X-ray light source PETRA III at the DESY research center (German Electron Synchrotron) in Hamburg, the Helmholtz-Zentrum Geesthacht - Center for Materials and Coastal Research (HZG) - operates the Imaging Beamline P05 (image: PI / HZG)

At the X-ray light source PETRA III at the DESY research center (German Electron Synchrotron) in Hamburg, Germany, the Helmholtz-Zentrum Geesthacht - Center for Materials and Coastal Research (HZG) operates the Imaging Beamline P05, which includes two experimental hutches, one for nanotomography (Fig. 1) and one for microtomography. Each name designates the attainable (spatial) resolution.

In the nanotomography hutch, X-ray optics for three-dimensional micrographs with resolutions around 100 nm are used, that consist of up to many hundreds of diffractive lenses, which were developed at the Institute of Microstructure Technology (KIT) at Karlsruhe, Germany. The setup also includes microscopy optics for visible light, used for further magnification of the X-ray micrographs and their transfer to a camera.

The Instruments Must Meet High Standards

With the aim to carry out as many different experiments as possible, the HZG provides two different X-ray optics configurations: An imaging setup, in which the sample is positioned in front of the objective optics (Fig. 2), and a cone-beam setup, in which the sample is placed in the diverging beam behind the optics.

In both cases, high mechanical stability and precision positioning are essential in order to obtain micrographs of high quality. This is why the instruments used for the experiments at the P05 beamline must meet very high standards.

However, thanks to the close cooperation of the clients with the engineers and developers from PI (Physik Instrumente), this complex task could be solved in a practice-oriented manner.

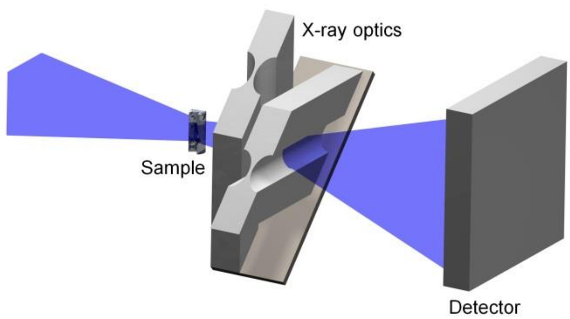


Fig. 2 Different X-ray optics configurations are possible: The one shown here is an imaging setup in which the sample is positioned in front of the optics (image: HZG)

Physik Instrumente (PI) GmbH & Co. KG_Auf der Roemerstrasse 1_76228 Karlsruhe, Germany
Tel. +49 721 4846-0, Fax +49 721 4846-1019 Email info@pi.ws, www.pi.ws

After all, this company has valuable know-how and many years of experience especially in the "Beamline Instrumentation" field of application.

The aim of the team of specialists, coordinated by PI miCos, is to develop application-specific solutions that go beyond offering individual components and include system integration as well as the complete instrumentation.

On the Beamline P05, they once again demonstrated these capabilities. A particular challenge was how to configure the control, which was based on an industrial controller. The challenge consisted in controlling almost 50 axes independently of one another while ensuring collision protection. The entire system was finally integrated into the TANGO interface customary for beamlines.

The Base: Granite Platform Supported by Air Bearings

To minimize the effect of vibrations and securely fasten the individual components and stabilize them, relative to one another, a granite base 6.8 m in length forms the basis of the instrument. Another four moving granite platforms driven by linear motors are arranged on this base on air bearings.

This makes it possible to position all components with high speed and precision: The sample stage, the X-ray optics, and the detector. The substructure itself, which weighs several tons, is also mounted on air bearings. This allows the entire assembly to be moved out of the X-ray beam with minimal effort when the second experimental station is to be used, while maintaining a stable position as soon as the air flow is switched off (Fig. 3).

A particular challenge was the construction of the sample stage, since it had to be mechanically stable in the range below 100 nm, in order to achieve the required spatial resolution. To this end, several positioning systems have to work hand in hand with maximum precision, to ensure that always the same volume element is investigated when the sample is rotating.

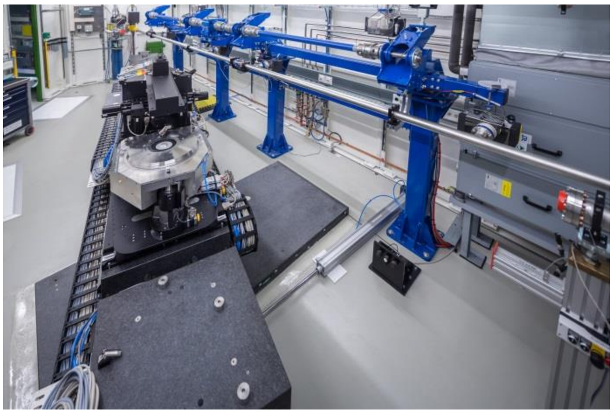


Fig. 3 The substructure, which weighs several tons, is mounted on air bearings. This allows the entire system to be moved out of the X-ray beam with minimal effort, while maintaining a stable position as soon as the air flow is switched off. The picture shows the assembly in the parking position outside the beam (image: PI / HZG)

Complex Sequences during Sample Positioning

The basis of sample positioning is a horizontal positioning unit which moves the sample stage into the beam. It has a travel range of 20 mm, can be subjected to a load of 300 kg and works with a repeatability of 30 nm.

What drives this high-precision positioning unit are stepper motors combined with high-resolution optical linear encoders. When driven accordingly, this allows closed-loop step sizes of a few nanometers. The precision crossed roller guides and ball screws used also contribute to the high positioning accuracy.

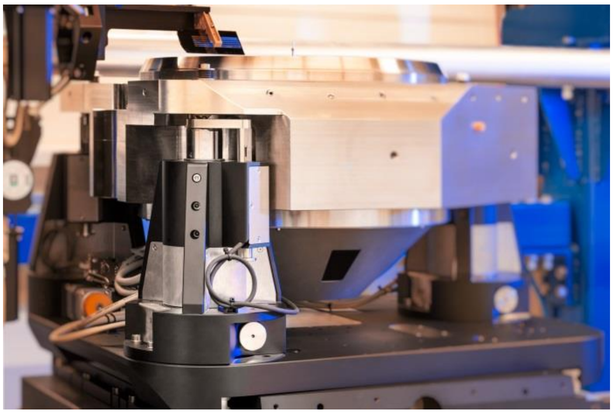


Fig. 4 The Z lifting stage performs the height adjustment, tilt correction, and orthogonal alignment, relative to the beam (image: PI / HZG)

Physik Instrumente (PI) GmbH & Co. KG_Auf der Roemerstrasse 1_76228 Karlsruhe, Germany
Tel. +49 721 4846-0, Fax +49 721 4846-1019 Email info@pi.ws, www.pi.ws

This displacement unit is equipped with three lifting elements which perform the height adjustment, tilt correction, and orthogonal alignment, relative to the beam (Fig. 4). It is based on three identical, symmetrically arranged, and position-controlled stepper motors, combined with worm gears and spindle drives. Mounted on this Z stage is an air-bearing supported rotation stage (Fig. 5).

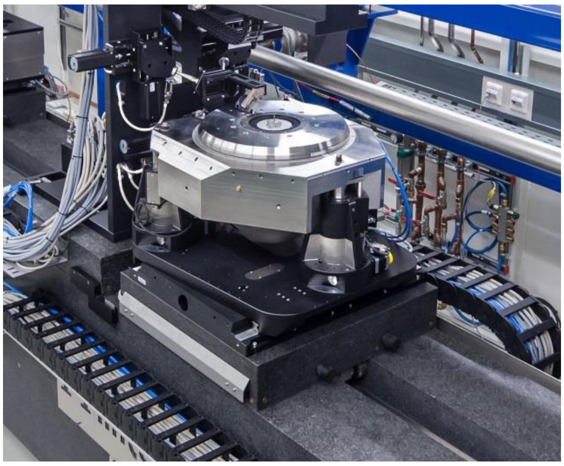


Fig. 5 Mounted on the combined tilt and Z stage is an air-bearing supported rotation stage. It rotates at a velocity of up to 36 °/s and works with flatness deviations of less than 100 nm at a resolution of 0.5 µrad (image: PI / HZG)

In developing this stage, the designers had to go push the limits of technical feasibility: What was required was a really "pure" rotary motion of the sample with minimal wobble, radial runout or eccentricity.

Only in this case can sharp pictures over 360 degrees be made which all refer to the same volume element and can all be clearly assigned when reconstructing the picture. This is why the rotation stage, which rotates at a velocity of 36°/s, works with flatness deviations of less than 100 nm at a resolution of 0.5 µrad. The air bearing does not produce any friction, which over time would lead to a deterioration of these values.

Parallel Kinematics for the Sample Holder and the Optics

The actual sample holder is located in the aperture of the rotation stage on the moving platform of a six-axis parallel kinematic machine (Fig. 6).

The SpaceFAB clearly makes work easier for the researchers, since the small samples - only a few 10 to 100 micrometers in size - plus the holder can initially be inserted into the stage with low precision.

They can then be aligned automatically using software commands. Thus, no additional mechanical components are required for correct alignment.

The samples are positioned with six degrees of freedom. Essential features are the freely selectable pivot point of the parallel-kinematic system and its high stiffness.

A six-axis parallel-kinematic machine of this type is also used for the positioning of the optics. In nanotomography, which allows three-dimensional micrographs with resolutions below 100 nm, this machine is used to align compound refractive lenses (CRL) in the beam with high precision.

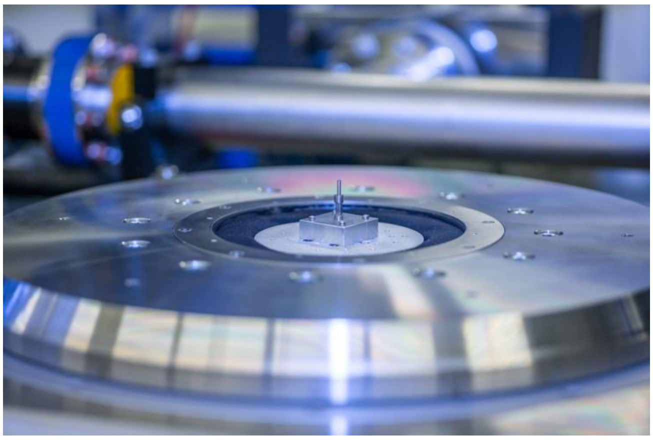


Fig. 6 The actual sample holder is located in the aperture of the rotation stage on the moving platform of a six-axis parallel kinematics (image: PI / HZG)

A wide range of areas, from industrial research to materials science and examination of bones in biology, can benefit from the investigation results obtained by means of these high-resolution tomographic methods on the Imaging Beamline P05.

The positioning solutions tailor-made by the "Beamline Instrumentation" specialists, used to align the small samples and optical components with high precision, make an important contribution.

Parallel-Kinematic Positioning Systems

PI's parallel-kinematic positioning systems offer a series of advantages over serially stacked assemblies, such as a lower moving mass, resulting in improved dynamics, less space required in combination with higher stiffness.

Thus, for motions with six degrees of freedom, either the strut length of the Hexapods can be changed - or in the SpaceFABs mentioned in the text - the angle can be varied if the strut length is constant.

The SpaceFAB principle is based on three XY stages that jointly position a platform using three struts of constant length and a suitable joint configuration (Fig. 7).

It is the principle of choice in particular when long distances have to be covered in the X and Y directions or a low-profile design is required.

Fig. 7 Assembly principle of a SpaceFAB: The principle is based on three XY stages that jointly position a platform using three struts of constant length and a suitable joint configuration (image: PI)

Physik Instrumente (PI) GmbH & Co. KG_Auf der Roemerstrasse 1_76228 Karlsruhe, Germany
Tel. +49 721 4846-0, Fax +49 721 4846-1019 Email info@pi.ws, www.pi.ws

Author

Dipl.-Phys. Birgit Schulze, Product Manager at Physik Instrumente (PI) GmbH & Co. KG

Helmholtz-Zentrum Geesthacht - Center for Materials and Coastal Research - in Brief

The Helmholtz-Zentrum Geesthacht – Center for Materials and Coastal Research – is part of the Helmholtz Association of German Research Centers, the largest German Scientific Organization, in charge of the development and operation of German and international large-scale research installations. This interdisciplinary research center was established in 1956. Until October 2010, it operated under the name of GKSS-Forschungszentrum Geesthacht GmbH. The research and development work at the Helmholtz-Zentrum Geesthacht is organized in the research divisions of the Helmholtz Association in different programs, one of which is materials research. Synchrotron radiation and neutrons allow researchers to carry out non-destructive investigations on materials and biological systems and to produce three-dimensional images in high quality. To this end, the Helmholtz-Zentrum Geesthacht operates test installations both at DESY in Hamburg at the PETRA III storage ring and at the FRM-II research reactor in Garching near Munich.

The PI Group in Brief

Over the last four decades, PI (Physik Instrumente) with headquarters in Karlsruhe, Germany, has developed into the leading manufacturer of positioning systems with accuracies in the range of only a few nanometers.

With four company sites in Germany and ten sales and service offices abroad, the privately managed company operates globally. More than 700 highly qualified employees all over the world enable the PI Group to fulfill almost any requirement from the area of innovative precision positioning technology.

All key technologies are developed in-house. This allows the company to control every step of the process, from design right down to shipment: precision mechanics and electronics as well as position sensors. The required piezoceramic elements are manufactured by our subsidiary PI Ceramic in Lederhose, Germany, one of the global leaders for piezo actuator and sensor products.

The PI miCos GmbH in Eschbach near Freiburg, Germany, is a specialist for positioning systems for ultrahigh vacuum applications and parallel-kinematic positioning systems with six degrees of freedom and custom-made designs.

Physik Instrumente (PI) GmbH & Co. KG_Auf der Roemerstrasse 1_76228 Karlsruhe, Germany
Tel. +49 721 4846-0, Fax +49 721 4846-1019 Email info@pi.ws, www.pi.ws