

Positioning Loads Accurately to the Micrometer

Hexapod at PETRA III



Since 2010, PETRA III (Fig. 1) is the most brilliant storage-ring-based X-ray light source in the world and it provides international scientists with excellent experimentation facilities. In particular, this benefits researchers investigating very small samples or those requiring tightly collimated and very short-wavelength X-rays for their experiments.

The high-energy radiation of up to and above 100,000 electron volts with high light intensity offers versatile capabilities, for example in the broad field of materials research for the inspection of welded seams, or for the examination of fatigue symptoms in workpieces. In some cases, this involves accurately positioning really heavy loads down to the micrometer. At the heart of the P07 beamline, which delivers the high-energy X-ray radiation required for materials research, is therefore a heavy-duty Hexapod. Thanks to its accuracy, it facilitates in-situ measurements of material properties under realistic process conditions.



Fig. 1 PETRA III offers scientists from around the world superlative experimentation facilities. In particular, this benefits researchers investigating very small samples or those requiring tightly collimated and very short-wavelength X-rays for their experiments, e.g. in the field of materials research (image: DESY/Reimo Schaaf)

Hexapods are parallel kinematic positioning systems (Fig. 2), now available in many versions with actuation travel lengths of up to a few hundred millimeters. With micrometer precision, they can position loads weighing from a few kilograms to a few hundred kilograms, or even several tons.

They can also do this in any spatial orientation, i.e. independently of the direction of installation. Their advantages compared with serial, i.e. stacked systems, are that they have much better path accuracy, repeatability and flatness.

In addition, the moved mass is lower, enabling better dynamic performance, which is the same for all motion axes. Moreover, cable management is no longer an issue, because cables are not moved, and, last but not least, the system features a much more compact design. Positioning takes place with up to six degrees of freedom: Three linear and three rotational motion axes. Depending on the geometry of the Hexapod, rotations from a few degrees up to 60° and translations of a few millimeters to several centimeters are possible.

The repeatability and minimum incremental motion achieves values of below one micrometer. Due to the low mass of the moving platform, Hexapods have considerably shorter settling times than conventional, stacked multi-axis systems. These characteristics can be used in a wide range of applications. Applications range from mechanical engineering and robotics to medical technology, and, in particular, materials research with PETRA-III X-ray radiation which is more powerful and more tightly collimated than the radiation of any other storage-ring-based system in the world. With 14 beamlines and 30 experimental stations, the system therefore provides optimum research capabilities.



Fig. 2 Basic design: In parallel-kinematic systems, all actuators act directly on the same platform (image: PI)

Short-Wave X-Ray Radiation for Materials Research

The X-rays generated are up to 5000 times finer than human hair, enabling very tiny samples to be examined, e.g. minute crystals from proteins or nano-crystals for the storage media of the future. Furthermore, PETRA III also provides very 'hard', i.e., short-wave X-ray radiation that penetrates very deeply into the material and thus is also capable of passing through material of greater thickness.

This enables welded seams to be inspected and fatigue symptoms in workpieces to be measured as an aid to quantifying the anticipated durability and service lives, or to analyze new metal alloys. Here effects can be proven down to the level of domain or crystal structures.

The opportunities that proceed from this in respect of materials research are leveraged by Helmholtz-Zentrum Geesthacht (HZG), for example when conducting in-situ measurements of the material properties that occur during reshaping processes such as welding, pressing, rolling or stamping.

The application of a mechanical load causes tensile and elongation stresses to occur inside the material. The investigation involving X-ray radiation then indicates the chronological sequence of effects occurring within a material at a crystalline level in micrometer-sized domain areas (Fig. 3 and Fig. 4).

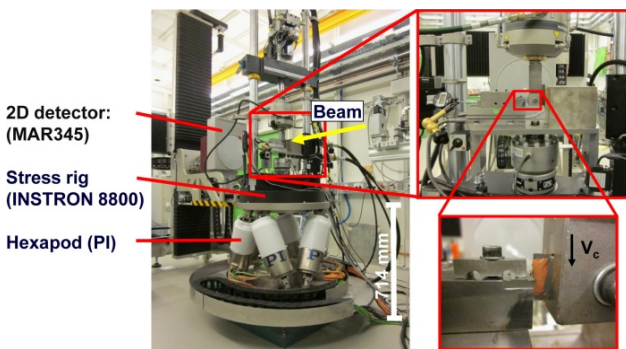


Fig. 3 The microstructure of C45E steel were investigated during machining (chip-cutting) operations. For this, a cutting edge was pressed against the workpiece with a 100 kN press (Instron 8800) mounted on the Hexapod (image: PI/HZG)

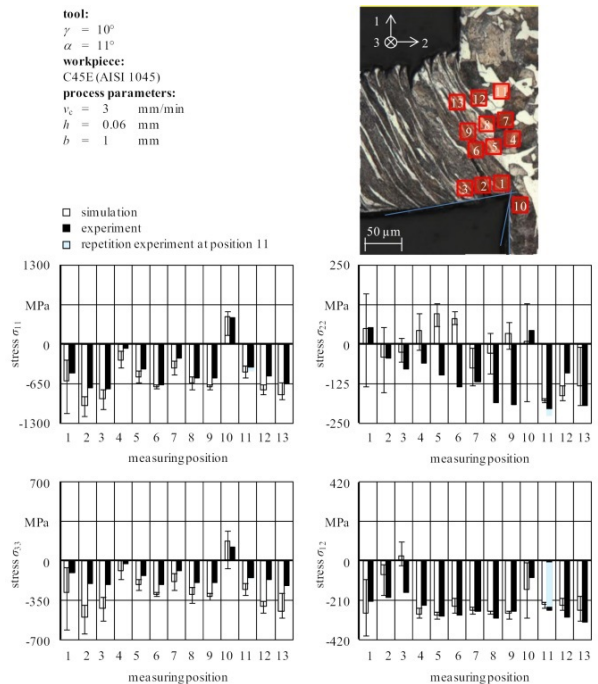


Fig. 4 The stress values are measured comparatively at the corresponding location of the metal chip against the process parameters employed and applied in a simulated manner. Details of the microstructural characterization itself, and of the modeling improvements required, can be obtained from the original publications: [1] K. Brömmelhoff et al., Space resolved microstructural characteristics in the chip formation zone of orthogonally cut C45E steel samples characterized by diffraction experiments, *Journal of Materials Processing Technology* 213 (2013) 2211-2216 und [2] E. Uhlmann et al., An extended shear angle model derived from in-situ strain measurements during orthogonal cutting, *Production Engineering: Research and Development* 7 (2013) 401-408

Powerful Positioning System for the Experimentation Chamber

At the heart of the described experimentation chamber is an Hexapod, developed by Physik Instrumente (PI) (Fig. 5).



Fig. 5 The parallel-kinematic custom model, the M-850K, delivers positioning down to the micrometer for loads of up to one ton in every orientation (image: PI)

Dr. Norbert Schell (Fig. 6), the scientist in charge of the HEMS Beamline, illustrates the context: "For an increasingly large range of in-situ investigations of 'real' processes, that is processes that actually occur in industry (but of course not only there) – associated with the cutting of workpieces, the coating of surfaces for the hardening or improvement of tribological properties, reshaping, welding, heat treatment as well as combinations of these techniques – it is our ultra-rigid Hexapod with its tremendous load-bearing capability and micrometer precision positioning that makes it possible for the first time for us to conduct scientifically rigorous examinations of the structural changes that occur at an atomic level.

This is highly interesting, and is also important in helping us to understand the processes that are occurring and that, ultimately, enable customized materials to be optimized."



Fig. 6 Dr. Norbert Schell, the scientist responsible for the HEMS beamline: "Only the in-situ investigations enabled the discovery of 'transient' phases, i.e. of states that only occur within the process for a transitory period. Simply investigating the starting and finished products leaves far too much to the imagination to facilitate any true understanding." (image: PI / HZG)

The parallel-kinematic custom model, the M-850K (Fig. 7), delivers micrometer-precision positioning for loads of up to one ton in every orientation. It stands approx. 700 mm high and has a diameter of 800 mm (top platform with large aperture) and/or 900 mm (bottom). The lower platform is installed on a 360° rotation table and the cabling was designed to be dragchain compatible.



Fig. 7 Hexapod in the experimentation station EH3 on the P07 beam guidance unit on PETRA III: With its high load capacity, it can carry the entire measuring setup including the structure where mechanical forces are applied – in this figure a chamber for the laser-welding of titanium aluminides (image: PI / HZG)

With its high load capacity of up to one ton, the Hexapod can carry the entire measurement setup including the equipment where mechanical forces are applied.

The Hexapod positions even these large masses over distances of 400 mm to a precision of ± 1 micron, and performs rotational motions of $\pm 20^\circ$ with a resolution to $0.5 \mu\text{rad}$.

Inside the experimental hutch, this enables complete engine blocks, turbine components, sinter furnaces and cryogenic chambers as well as welding fixtures or other machining units to be aligned precisely for the planned investigations and to be moved accordingly during the analysis. Despite the high forces, the position reached is held in a stable manner; the brushless DC motors integrated in the Hexapod struts are equipped with brakes.

Comfortable Motion Control

For adequate motion control of the Hexapod system, the Hexapod controller communicates with the primary controller used in the experimental setup. Positions are commanded in Cartesian coordinates, while all kinematic transformations to the single drives are effected by the controller. Virtually any desired point in space can be set as center of rotation via software commands. This freely definable pivot point is maintained independently of the motion, thus allowing the motion of the Hexapod platform to be tuned precisely to each positioning task.

Similar properties are applicable to many other areas of application. There are in fact many different variants of the Hexapod design, and they can be equipped with different drive concepts. Depending on the application requirements, they are driven by high-precision drive screws and precisely controlled DC motors or directly by linear motors, e.g. based on piezo-ceramic actuators. They have now proven their capabilities in a diverse range of sectors, starting with mechanical engineering and tool machining, extending to semi-conductor production, astronomy, biotechnology or life sciences.

About P07 / HEMS

P07 or HEMS (High Energy Materials Science Beamline) is one of the first operational lines on the PETRA III light source. Since 2010, P07 facilitates diffraction and imaging experiments such as tomography in the high-energy X-ray range of 30 to 200 keV. In-house and development activities are shared by DESY and Helmholtz-Zentrum Geesthacht (HZG).

HZG has specialized here in materials research associated with engineering science, with two experimentation stations (EH3 and EH4), while DESY has been in charge of one experimentation station (EH2) that deals with the 'more general' field of high-energy scattering experiments.

All of this scientific work comprises basic research into metallurgy, physics, chemistry and biology, disciplines that are converging to an ever greater extent.

Previous research work tackled the interaction of the macroscopic and microstructural properties of polycrystalline materials, grain-grain reciprocal interactions, the development of new and 'intelligent' materials or process technologies and in-situ catalysis. The experimental equipment makes it possible to investigate all types of materials to high standards of precision and stability and low substrate, including surfaces, buried layers, single-crystals, powders or amorphous solids as well as fluids.

The applied research into the optimization of manufacturing and reshaping processes on P07 benefits in particular from the high level of photon flux in combination with the high-speed 2D detectors that enable complex and dynamic in-situ studies to be conducted into the transformation changes to microstructure that occur during processes such as welding, cutting or heat treatment.

The infrastructure enables large and heavy sample environments to be created, as well as process chambers, also for external users. The heavy-duty Hexapod has a major role to play here.

About Helmholtz-Zentrum Geesthacht – Center for Materials and Coastal Research

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.

Author



Dipl.-Phys. Birgit Schulze, Market & Products at PI (Physik Instrumente)

About PI

In the past four decades, PI (Physik Instrumente) with headquarters in Karlsruhe, Germany has become the leading manufacturer of nanopositioning systems with accuracies in the nanometer range. With four company sites in Germany and fifteen sales and service offices abroad, the privately managed company operates globally. Over 850 highly qualified employees around the world enable the PI Group to meet almost any requirement in the field 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 its subsidiary PI Ceramic in Lederhose, Germany, one of the global leaders for piezo actuator and sensor products.

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