TOPICS

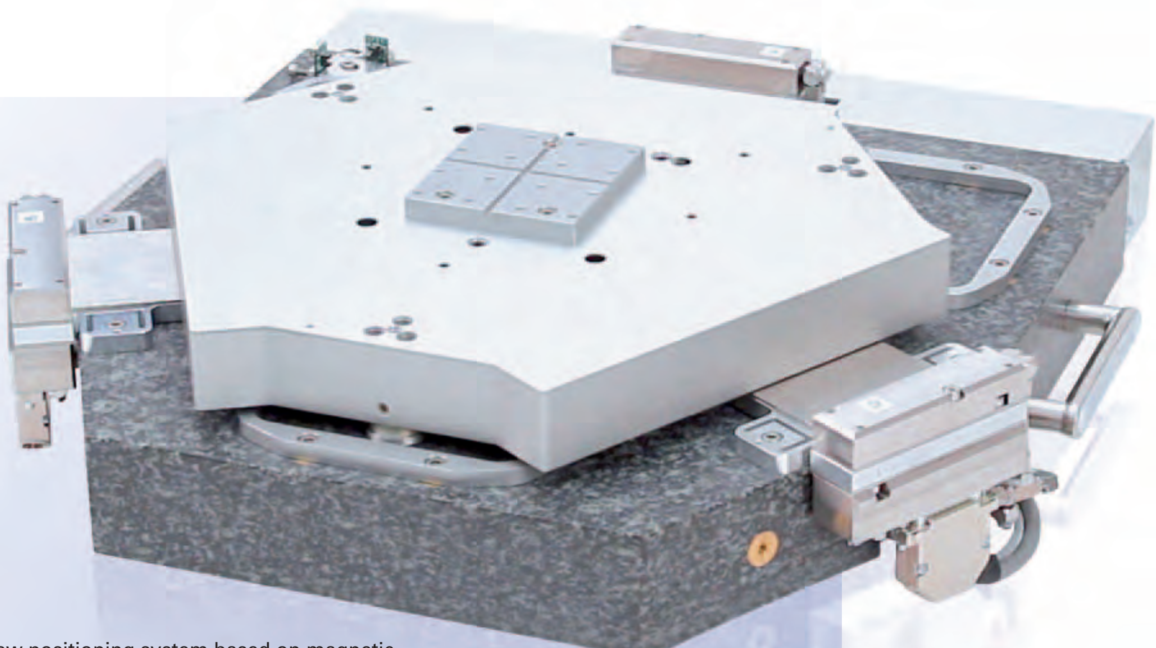
PIEZO NANO POSITIONING

ISSUE 48

PI

Actively Guided Magnetic Positioning System with Travel Accuracy in the Nanometer Range

Setting Trends in Nanopositioning Technology: Development Project PIMag™ 6D



New positioning system based on magnetic levitation: The passive platform levitates on a magnetic field, which actively positions and guides it. In this way, objects can be moved linearly or rotationally on a plane with a unprecedented guiding accuracy.

Achieving high positioning accuracy is not only possible with piezo actuators. Besides common motor-spindle drives, PI is increasingly using piezomotors for precision motion across longer travel ranges. With the PIMag™ 6D development study, however, PI adopts completely new approaches.

Thanks to this study, magnetic linear drives now allow for motion in 6 axes with positioning and guiding accuracy, never before achieved, in the range of a few nanometers. This is based on a high-resolution measurement system with controller, capable of detecting and compensating for deviations from the ideal path by variations of the magnetic field.

Friction-Free Active Guiding

Zero friction in the drivetrain and the guiding system as well as vacuum compatibility are often required, e.g. in semiconductor manufacturing, for adjusting a wafer in six degrees of freedom with nanometer precision during processing and inspection. Magnetic linear drives feature optimum properties to satisfy these demands.

The moving platform floats on a magnetic field generated by six coils and is controlled via a 6D sensor. The platform itself is passive, so it does not need any

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electrical supply lines. This provides more freedom of movement as there are no dragged cables to prevent the platform from moving quickly and accurately over an extensive surface area. The Halbach array of the magnets in the passive platform makes it possible to increase the load carrying capacity, minimize the energy required by the active coils in the stator for carrying the platform, and reduce thermal load at the same time.

Six Degrees of Freedom at Nanometer Precision

A high-resolution measurement system is integrated in the stator. This system consists of optical and capacitive sensor elements, detecting the platform position in all six degrees of freedom. The incremental optical 2D sensor has a resolution of 10 nm and is able to detect rotations about the vertical axis by up to ± 0.25°.

This allows objects to be moved in-plane by linear or rotary motion with unprecedented guiding accuracy, while out-of-plane and tilting errors in the Z axis can be measured and controlled directly.

The prototype currently has a motion range of 100 x 100 x 0.15 mm^3. Trajectory motions can be carried out with nanometer precision at an acceleration of up to 2 m/s^2 and a velocity of currently up to 100 mm/s. At present, PIMag™ 6D allows for positioning at a resolution of 10 nm. If the system moves on a circular path with a diameter of 100 nm, for example, the maximum deviation from the ideal line is only a few nanometers.

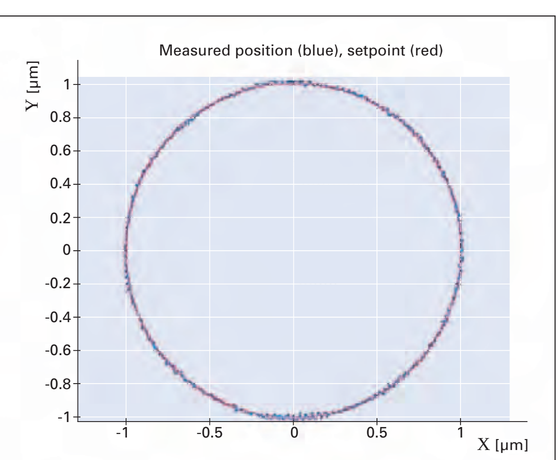
The 6-axis motion is controlled by a 6D sensor. The sensor's reference surface is located in the center below the magnetically levitated platform, a passive component with no need for electrical power or external connection.

The digital motion controller of the electromagnetic drive, based on a modular system from PI, is capable of processing different geometry files and coordinate transformations, thus providing an optimal basis for scaling.

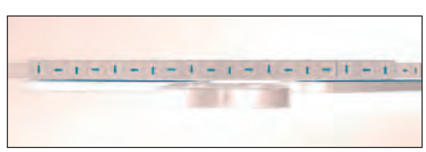
Potential for the Future

PI shares its profound knowledge and extensive experience in nanopositioning, sensor technology, electronics and software: In collaboration with the IMMS (Institute for microelectronics and mechatronic systems in Illmenau, Germany), PI developed a magnetic levitation positioning system that is simpler in its structure, faster and more precise than any existing system.

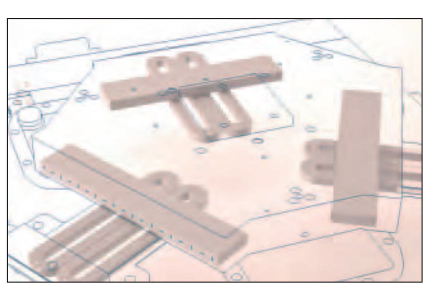
For the next develpoment steps, precise user requirements will be taken into account for further extending the positioning performance.



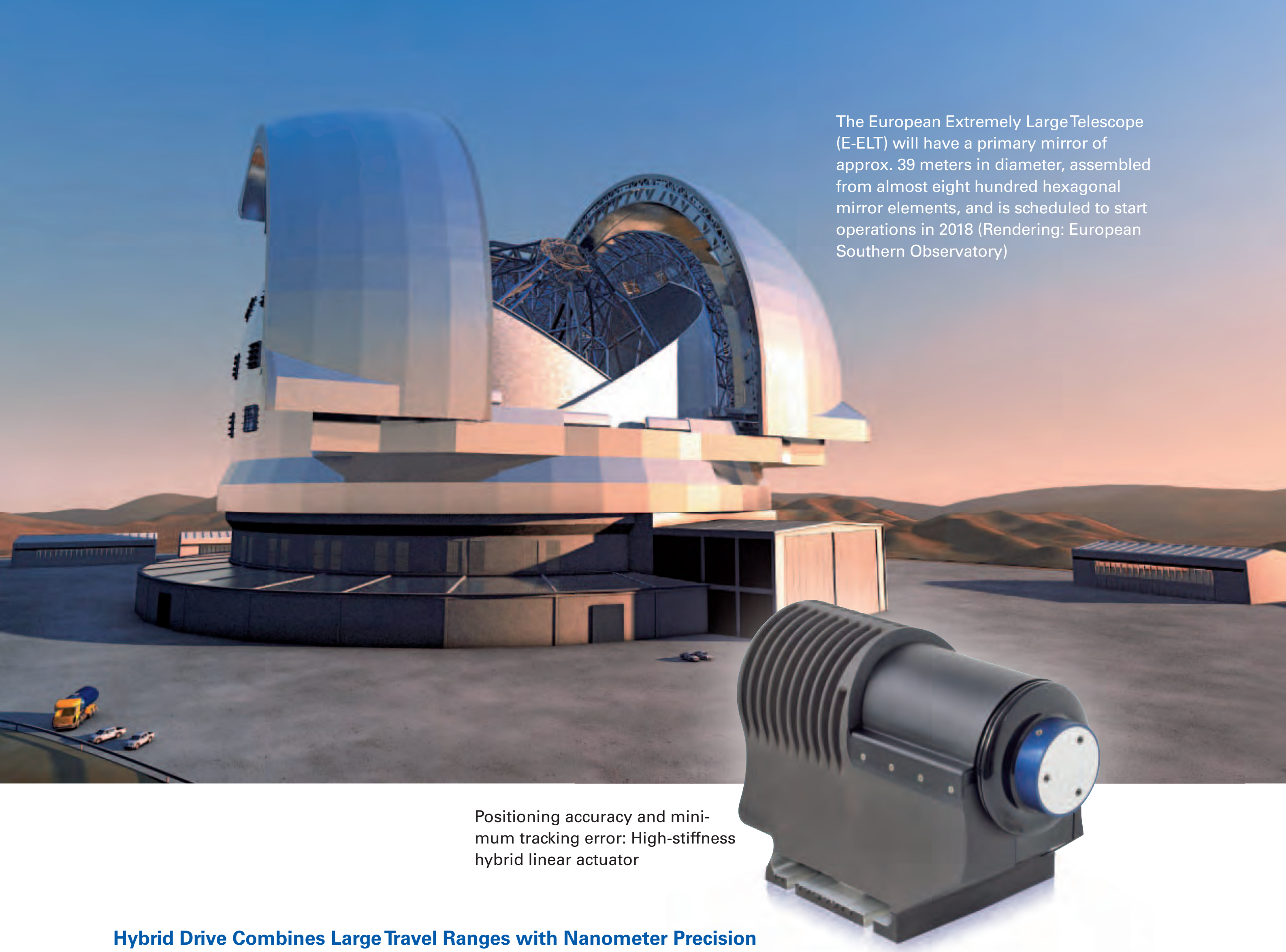
Extremely precise circular motion with a diameter of 1 µm: The maximum deviation from the ideal path is only a few nanometers.



Halbach array of the magnets.



The platform levitates on a magnetic field generated by only six planar coils in the stator.



The European Extremely Large Telescope (E-ELT) will have a primary mirror of approx. 39 meters in diameter, assembled from almost eight hundred hexagonal mirror elements, and is scheduled to start operations in 2018 (Rendering: European Southern Observatory)

Positioning accuracy and minimum tracking error: High-stiffness hybrid linear actuator

Hybrid Drive Combines Large Travel Ranges with Nanometer Precision

Active Optics for the Largest Telescope in the World

Highly stiff hybrid linear actuators position segments of the primary mirror under extreme stress.

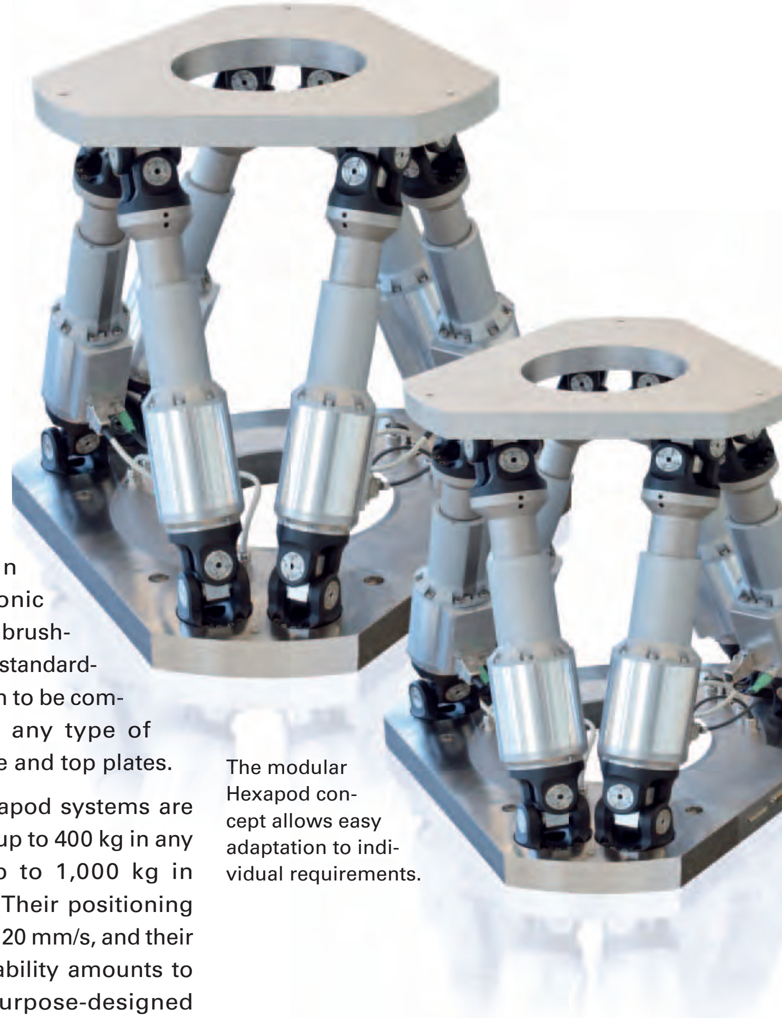
The light collection and resolution power of earth-bound telescopes can be increased by enlarging the primary mirror. The current concept of the European Southern Observatory for the European Extremely Large Telescope (E-ELT) describes a telescope with a primary mirror of approx. 39 m in diameter assembled from nearly eight hundred hexagonal mirror elements. This makes it the worldwide largest telescope for observation in the visible and infrared light regions.

To compensate for optical aberrations caused by deviations of the large primary mirror from the required shape of the paraboloid, the mirror segments must be aligned precisely, relative to one another. The two main challenges are the travel range of 15 mm and – at the same time – a tracking error of less than 2 nm RMS. This requires dynamic drives that allow nanometer-precision positioning.

To achieve this objective, PI has developed a hybrid linear actuator drive with a controller comprising a servo-motor-driven precision ballscrew combined with a piezoelectric actuator. These highly stiff hybrid actuators achieve travel ranges of several ten millimeters while providing sub-nanometer resolution. Mounted under each mirror segment are three drives, which compensate for the height difference of adjacent segments. If the telescope is tracked or aligned to a different object, alignment speeds of up to 250 µm/s are obtained. This involves moving considerable weights and requires forces up to 900 N.

Any deviations of the motor-spindle drive can be measured by a high-resolution sensor and corrected by means of the highly dynamic frictionless piezo actuator. This guarantees extremely high positioning accuracy of the hybrid drives during the compensating motion.

The piezo actuator used is encapsulated in a hermetically sealed metal container filled with inert gas. This protects the actuator from moisture, allowing it to reach its required lifetime of 30 years even under adverse ambient conditions. The high-resolution sensor is an incremental optical encoder, placed as closely as possible to the tip of the actuator. It provides a resolution of 250 picometers and is insensitive to changing environmental conditions.



Modular, Scalable High-Load Hexapod Concept

Quick & Economical for 6-Axis Positioning Tasks

Complex positioning tasks are rarely alike and individual solutions are often required. This is also true of the Hexapod parallel-kinematic systems employed to precisely position heavy loads in six degrees of freedom. A modular concept now ensures that individual requirements can be implemented within a very short period of time and easily integrated into the application.

Hexapods have six actuators, which simultaneously move a common platform, enabling a combination of high precision, stiffness and dynamics not achieved with serial kinematic designs. PI has now developed a modular concept that allows application-specific adjustments within a short period of time.

PI's modular Hexapod struts are designed such that their length can be scaled easily. They include the required electronics for reference point switches, limit switches, position sensors and electronic commutation for the brushless DC motors. Their standardized joints allow them to be combined with almost any type of geometry of the base and top plates.

These modular Hexapod systems are suitable for loads of up to 400 kg in any orientation and up to 1,000 kg in horizontal position. Their positioning velocities reach up to 20 mm/s, and their bidirectional repeatability amounts to about 5 µm. The purpose-designed digital controller handles all coordinate transformations, features vector control, a stable freely programmable pivot point and comes with a solid package of software tools and drivers. In addition to the Hexapod, the controller can handle two more independent motor axes as well.

The modular Hexapod concept allows easy adaptation to individual requirements.

Dynamic, Precise and Powerful:

The New E-709.CHG Digital Piezo Controller

The E-709.CHG digital single-channel piezo controller provides high output power for dynamic applications.

Thanks to its high output power, the E-709.CHG digital servo controller provides highly dynamic and nanometer-precise operation of piezo-based stages with high stiffness and electrical capacitance.

The E-709.CHG is based on the successful E-709 compact single-axis controller line. It adds significantly more output power for applications that require high throughput, e.g. in microscopy.

Compared to analog controllers, digital servos feature the following benefits: They allow optimizing the settling and positioning behavior by use of complex control algorithms. Control parameters can easily by modified on-the-fly with simple software commands.

The piezo controller is commanded via digital SPI, USB and RS-232 interfaces. In addition, the E-709.CHG is equipped with a high-bandwidth analog interface for target values or sensor signals. The analog output can be configured for the control of additional external amplifiers or for the output of position values.

The software package comprises the powerful user software PIMikroMove and NanoCapture for quick start-up, as well as LabVIEW drivers and shared libraries for Windows and Linux.

The systems can also be controlled with the software platforms µManager, MetaMorph and MATLAB.

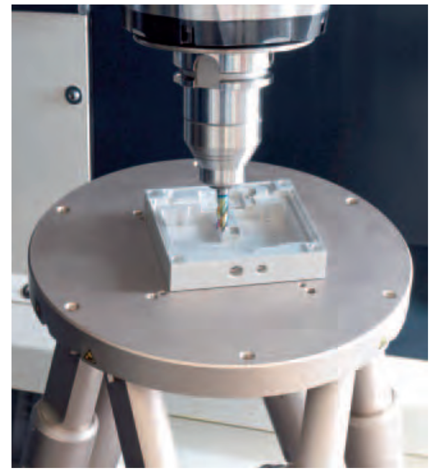
Clock Synchronization for the Entire Automation Line:

Hexapods Communicate via Fieldbus Interfaces

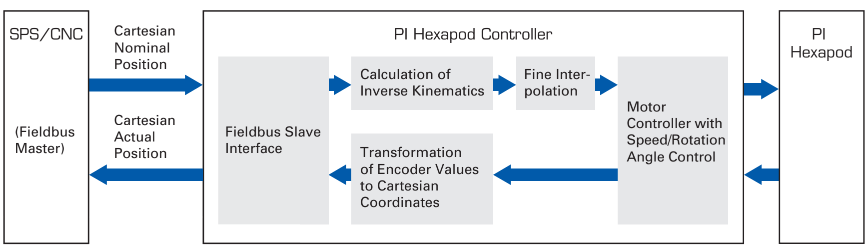
The benefits of parallel-kinematic precision positioning systems can now also be used in automation technology. PI's high performance Hexapods can communicate directly via fieldbus interfaces with a PLC controller.

Fieldbus interfaces are currently available as plug-in modules for Profibus, EtherCAT, Profinet, CANopen and SERCOS. Due to this direct connection, Hexapod systems can be integrated in virtually any automated production line; a clock synchronization with other automated components can easily be achieved, for example, for automated supply systems, machining or other complex adjusting processes.

Here, the PLC defines the target position and trajectories in Cartesian coordinates; in return, it gets the actual positions over the fieldbus interface. All other calculations are handled by the Hexapod controller, i.e. transforming the nominal positions from Cartesian coordinates into the drive commands for the individual drives. The controller acts like an intelligent drive. The cycle times for determining new positions, evaluating signals and synchronizing are between 1 and 3 milliseconds.



Clock synchronization for the entire automation line: Hexapods communicate via fieldbus interfaces.



The Hexapod controller acts like an intelligent drive. Due to the exchangeability of the fieldbus interface, communication with numerous types of PLC or CNC controllers is possible.

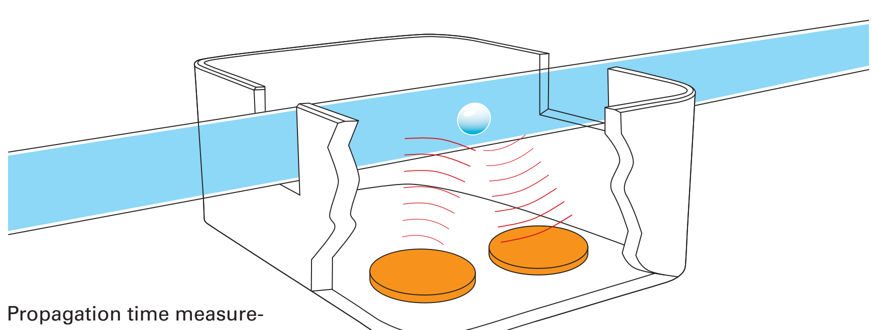
New Solutions for Medical Technology

Bubble Detection with Piezoceramic Disks

In medical device engineering, an undisturbed liquid flow with no air or gas pockets (bubbles) is very important. A method for bubble detection is measuring the propagation time via ultrasonic technology. The measurement of the propagation time is based on alternate transmission and receiving of ultrasonic pulses.

Two piezoceramics discs work as transmitter and receiver. The oscillating piezoceramic rings operate at frequencies of up to 100 kHz. The propagation time of the ultrasound signal is evaluated to measure flow velocities, or to detect bubbles or impurities in the liquid by means of irregularities in the reflected signal - for dialysis and transfusion pumps, for example. The sensors are mounted on the outside of flexible tubes.

Since there is no contact with the transported medium, they do not interfere with the flow rate, nor is there any danger of contamination.



Propagation time measurement for a bubble-free flow

Cost-Efficient High-Performance Motion Controller

New Four Axis Motion Controller for DC Motors

Many positioning applications require only one or two motion axes. These are easily satisfied with PI's successful networkable single-axis Mercury controller. When three and more axes are involved, the new C-884 is a cost-efficient solution. It includes all the performance of the popular Mercury and adds more functions and features into one four-axis system.

The C-884 is commanded by PI's universal GCS software commands making it fully compatible with other PI controllers including the Mercury product family – no need to rewrite existing codes.

The C-884 is based on a dual-core architecture in which position control of all four synchronized axes takes place on a common DSP (digital signal processor). This allows for vectorized motion of the individual axes, which start and stop simultaneously. Commands are given via a USB or TCP/IP interface, while the encoder bandwidth is 50 MHz.

The command interpreter runs on a separate ARM processor core as an independent thread under a Linux operating system, separately from the DSP, providing great flexibility to adapt the system to the needs of OEM customers.

This allows flexible programming of the system in terms of application-specific sequences, without the need for computer-intensive translation into the PI language GCS2.

Useful extended functions of the C-884

- Macro program language: Execution of nested stack commands in response to a command or external trigger (e.g., via a digital input) even without connection to the host PC
- Autostart Macro: Execution of a macro upon power-on
- Data recorder: Recording of operating parameters such as motor voltage, velocity, position or position error
- PIMikroMove: Graphical user program for start-up and operation of PI products; for example, a settling process can be recorded by the data recorder and displayed in PIMikroMove. The user can then adjust the PID servo-control parameters in PIMikroMove until an optimum settling behavior is achieved.
- Programming tools: LabVIEW driver, shared libraries for Windows and Linux are included in the scope of delivery of the device.

The C-884 four-axis motion controller from PI combines performance, robustness and economy.

Microscopy: Fast Autofocus and Tracking

Autofocus Applications in Microscopy

Solid results in high-resolution microscopy largely depend on the velocity, precision and stability of the focusing mechanism. Vibrations and drift in the direction of the optical axis (Z direction) can be detrimental.

If high output rates are targeted, short response times are even more critical. Moreover, the irradiation of fluorescent tracers can have toxic effects on the cells, which is why the time factor is so crucial in focusing.

Focusing drives based on piezo-ceramic elements offer many advantages. Depending on the application, it may be best to move the objective lens, the objective nosepiece or the sample along the optical axis. PI can provide solutions for each case. PIFOC® Z drives for the objective lens are very compact, stiff and employ frictionless flexure guides. This allows them to react with the shortest response times and position very precisely due to good guiding, even over relatively long travel ranges to 0.5 mm. For two-photon microscopy, a new standard system with 2 mm travel is now available and custom designs to move the entire revolving nosepiece are also offered.

In some cases, it is more suitable to move the sample instead of the optics. In this case, scanning piezo positioning stages are recommended. They come in different designs, and can accommodate slides, sample holders and microtiter plates.

Drift Tracking During Long-Term Imaging

Long-term imaging applications often suffer from thermal effects that cause instability in the focus. For meaningful results, drift processes must always be compensated by constantly readjusting the focal plane according to the deviation from the target value. Depending on the application, here too a precision positioning system moves the objective, the objective revolving nosepiece or the sample for tracking the drift.

When selecting the appropriate positioning solution, a major requirement is the ease of integration into the microscope's autofocus control system. In addition to drift stabilization, a stiff, high-resolution piezo drive can also be used for fast 3D imaging and Z-stack acquisition, providing high position resolution and response times of only a few milliseconds.

PI's digital piezo controllers can be quickly switched between focus tracking and closed-loop positioning, and also accommodate fast focus and freeze applications.

Imaging under Special Ambient Conditions

For long-term, live-cell imaging applications, the cells are analyzed under regulated ambient conditions, here it is crucial that the drives used "tolerate" the necessary humidity and temperature conditions. This is where the all-ceramic insulation gives PI's PICMA® piezo actuators an edge, protecting them against ambient humidity and significantly improving their lifetime compared to conventional piezo actuators.

Studies have proven the PICMA® actuators' high reliability: PICMA® actuators were tested for up to 100 billion cycles by NASA's Jet Propulsion Lab and passed with no failures.

The combination of robust drives, high precision mechanics and sensors with PI's flexible digital servo technology not only guarantees high-quality microscopy results during long-term examinations but also long system life, easy serviceability and adaptability to new requirements.

The MCS XY stage from PI miCos offers high guiding and positioning accuracy for industrial applications.

Precision XY Measuring Stage with Nanometer Resolution

For satisfying the demands of industrial surface inspection PI miCos extends its product range with the new MCS XY stage.

Highly dynamic and precise motion control is crucial for achieving sound, high-resolution measurement results in surface inspection, and consequently for a reliable quality assurance in industrial production. PI miCos now satisfies these demands with the new MCS stage. This XY positioning system combines high guiding and positioning accuracy with high dynamics. Its areas of applications include industrial surface measurement technologies, such as topology measurements of workpieces and optics, or structural measurements of semiconductor wafers. Its high load capacity of 20 kg allows additional motion axes, e.g., rotary stages, vertical positioners and tilting stages to be mounted on the platform.

The outstanding characteristics of the MCS positioning system are attained by PI miCos' extensive know-how in precision-machining and assembly as well as sensor and control technologies. An available interferometric linear encoder gives the MCS a resolution of 5 nanometers, repeatability of 0.2 µm and absolute positioning accuracy of 3 µm over the entire travel range of 102 mm per axis. Furthermore, the MCS stage excels with its straightness and minimum out-of-plane motion of less than 2 µm.

The MCS can be equipped with different drive options, ranging from cost-effective open-loop stepper motors to closed-loop non-contact magnetic linear motors. Driven by the company's compact SMC Hydra Controller, the MCS attains velocities of up to 200 mm/s, but is also capable of constant velocities down to 1 µm/s.

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