Piezo • Nano • Positioning

Hexapod Precision 6-Axis Parallel Kinematics

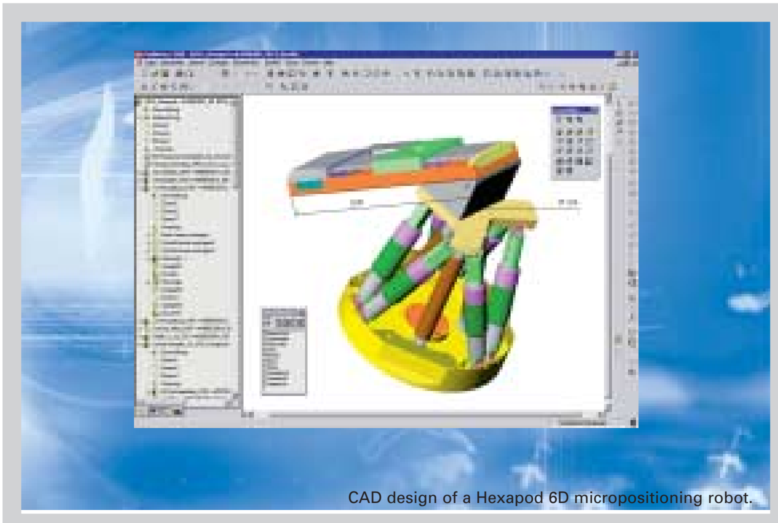
Positioners & Miniature Robots Featuring Sub-Micrometer Precision

updated 08/2007

Moving the NanoWorld www.pi.ws

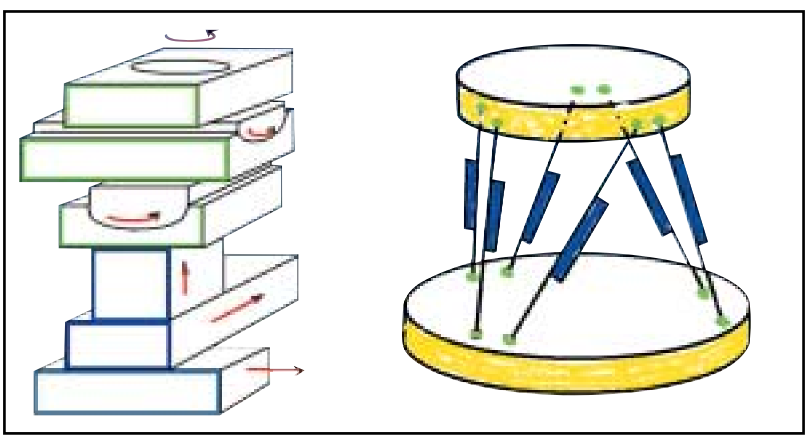
Hexapod **Micropositioning** Systems

Controlling Motion in 6 Degrees of Freedom



CAD design of a Hexapod 6D micropositioning robot.

PI is the leading manufacturer of Hexapod micro- and nanopositioning systems. In addition to these parallel kinematics devices, PI offers a wide selection of innovative precision positioning systems for science and industry. PI's products range from piezoceramic linear motors to actuators to translation and multi-axis stages and include systems with integrated controllers.



Stacked serial kinematics 6D system vs. Hexapod parallel kinematics system designs. Advantages such as compactness and minimized inertia (one platform for all sixactuators) are easily seen. The reduced inertial mass makes for significantly faster response than with serial kinematics. Because there are no moving cables to cause friction, repeatability is increased also.

Variety of Hexapod parallel kinematics micropositioning systems.

Large custom Hexapod with a positioning frame measuring some 1.0 x 1.5 meters.

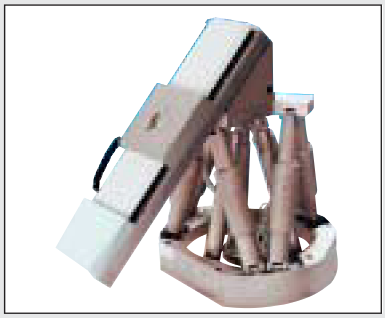
Hexapod Systems, Experience

PI offers a wide selection of innovative precision positioning systems for science and industry.

The following page shows but a few examples of hexapods which PI has developed in recent years.

These systems were designed for special customer applications and are not available off the shelf; many other custom systems are subject to non-disclosure agreements and cannot be shown at all.

Standard hexapods can be found on the following pages.



Custom "6+3" Hexapod with additional struts providing independent position feedback. Translation stage for extended Z-travel.

Custom, high-precision, non-magnetic Hexapod with the award-winning piezo-based NEXLINE® nano drives.

Custom Hexapod for alignment of secondary mirrors in astronomical telescopes.

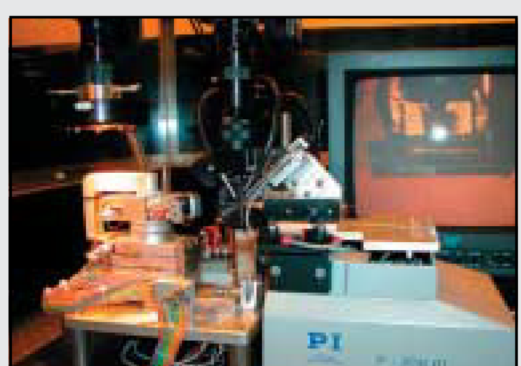
Custom Hexapod for automatic satellite antenna alignment.

Custom Hexapod with active tip/tilt mirror for the UKIRT infrared telescope on Mauna Kea, Hawaii

Custom Hexapod for brain surgery. Photo courtesy of IPA.

* Talk to your local PI office

Custom high-load, moisture-protected Hexapod



F-206 Hexapod alignment system at a workstation for automated pigtailing of fiber optic devices. Printed with permission from Aries Innovations.

F-206.S

HexAlign™ 6-Axis Precision Alignment System / Manipulator (Hexapod)


The F-206.S Hexapod comes with a digital 6D controller and comprehensive software

- **Parallel Kinematics with 6 Degrees of Freedom**
- **0.033 µm Actuator Resolution**
- **Repeatability 0.3 µm in Space**
- **No Moving Cables for Improved Reliability, Reduced Friction**
- **Better Dynamics, More Compact than Serial Kinematics Systems**
- **For Scanning and Alignment**
- **Cartesian Coordinate Control with Virtualized Pivot Point**
- **Powerful Digital Controller with Open Source LabView™ Drivers, DLL Libraries...**
- **Integrated Fiber Alignment Routines**

The F-206.S HexAlign™ Hexapod is a highly accurate micropositioning system for complex multi-axis alignment tasks. It is based on PI's long experience with ultra-high-resolution, parallel kinematics stages. Unlike hexapods with variable-length struts ("legs") the F-206 features constant-length struts and friction-free flexure guides. This gives the F-206 even higher precision than other hexapod designs.

Application Examples

- Micromachining
- Photonics packaging
- Fiber alignment
- Semiconductor handling / test systems
- Micromanipulation (life science)
- Optical device testing
- Collimator and fiber bundle alignment
- MEMS positioning/alignment

Compact, Plug & Play

The F-206.S Hexapod is considerably smaller and more accurate than comparable serial kinematics six-axis systems (stacks of single-axis units).

The parallel kinematics of the F-206 is immune to the cumulative bending and guiding errors of the various axes which, together with the inertia and friction of the moving cables, can limit accuracy in stacked systems. In addition, rotations are not set in hardware, but about a pivot point freely definable in software. A high-performance controller does all necessary coordinate transformation for coordinating the six drives. Because all the actuators are attached directly to the same moving platform, there are none of the servo-tuning problems associated with the loading and inertia differences of the different axes, as are inherent in stacked systems.

Virtualized Pivot Point

It is important to have a fixed pivot point for alignment tasks, especially in photonics packaging. Because the parallel kinematics motion of the F-206 is calculated with complex algorithms in the digital controller, it was easy to allow programming any point in space as center of rotation. Furthermore, the cartesian coordinates of any position and any orientation can be entered directly and the specified target will be reached after travel along a smooth path.

Six Degrees of Freedom, No Moving Cables

In the F-206 Parallel kinematics design, all cable terminations are on the stationary base, eliminating unpredictable friction and inertia, increasing resolution and repeatability. Further advantages of the system are:

- No cable guides required
- Reduced Size and Inertia
- Improved Dynamic and Settling Behavior
- Identical Modular Actuators for Simplified Servicing

Open Command Set, Simplified Programming

Integration of the F-206 in complex applications is facilitated by the system's open command set and comprehensive tool libraries. The controller can be operated either through a host PC, or directly through a keyboard and monitor. It can also run programs stored in a user-friendly, fully documented macro language.

Automatic Optical Alignment

Optional internal and external photometers are available. Both types are fully integrated

Ordering Information

F-206.S0
Hexapod 6-Axis Precision Alignment System / Manipulator with 6 DOF Hexapod Controller

F-206.SD
Hexapod 6-Axis Precision Alignment System / Manipulator with 6 DOF Hexapod Controller, Built-in Display and Keypad

Options and Accessories

F-206.AC8
Upgrade for 2 Additional Servo-Motor Control Channels on F-206 Controller

F-206.i3E
GPIB/IEEE 488 Interface for F-206 Controller

F-206.MHU
Force-Limiting Mounting Platform, (included with F-206.SD)

F-206.MFU
Mounting Platform with Force Sensors

F-206.NCU
Upgrades: Rapid Nanopositioning Upgrade for F-206.S. Consists of P-611.3SF NanoCube® and E-760 Controller Card

F-206.MC6
6D Interactive Manual Control Pad

F-206.00U
2-Channel Photometer Card, (Visual Range)

F-206.iRU
2-Channel Photometer Card (IR Range)

F-361.10
Absolute-Measuring Optical Power Meter, 1000-1600 nm Wavelength (see complete PI catalog, p. 8-14)

Additional Accessories, see complete PI catalog, page 8-12 *ff.*

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Capacitive Position Sensors
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Hexapods / Micropositioning
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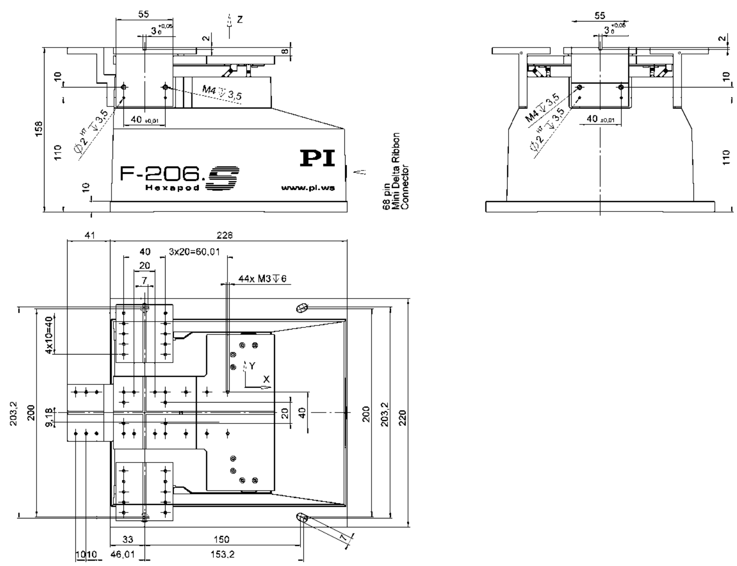
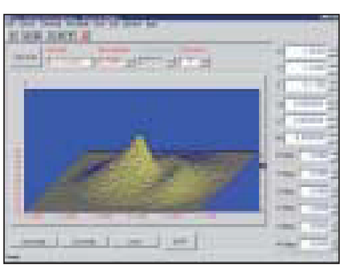
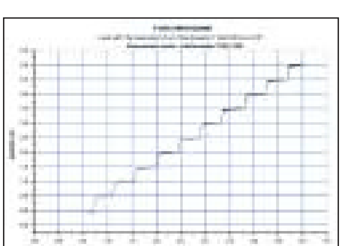
with the controller hardware and with routines designed for automatic alignment of collimators, optical fibers and arrays. For more information on the photometers see F-206.IRU and F-206.00U, p. 8-12 and F-361, p. 8-14, PI complete catalog.



F-206.S. Dimensions in mm



HexControl™ Software displaying scan of photonics component.



Interferometer test of an F-206.S system shows the excellent repeatability of small steps, here 0.5 µm spaced at 100 ms.

Technical Data

Models	F-206.S0 / F-206.SD
Travel range X*	-8 to +5.7 mm
Travel range Y*	±5.7 mm
Travel range Z*	±6.7 mm
Travel range θ_X *	±5.7°
Travel range θ_Y *	±6.6°
Travel range θ_Z *	±5.5°
Actuator resolution	33 nm
Minimum incremental motion X, Y, Z**	0.1 µm (6-axis move!)
Minimum incremental motion θ_X, θ_Y, θ_Z**	2 µrad (0.400115°) (6-axis move!)
Bidirectional repeatability X, Y, Z	0.3 µm
Bidirectional repeatability θ_X, θ_Y, θ_Z	3.6 µrad
Speed X, Y, Z	0.01 to 10 mm/s
Maximum load in Z	2 kg (centered on platform)
Weight	5.8 kg
Controller	Digital Hexapod controller with optional photometer card and integrated scan and align routines
Operating voltage	100-240 VAC, 50/60 Hz
Software	LabView™ drivers, software for alignment of arrays, DLL libraries, HexControl™, scan and align software, terminal software

* Travel ranges in the coordinate directions (X, Y, Z θ_X, θ_Y, θ_Z) are interdependent. The data given shows maximum travel range of the axis in question (i.e. its travel when all other axes are at their zero positions). If this is not the case, the available travel may be less.

** Six-axis move. No moving cables (unlike serial-kinematic stacked systems) to introduce bending forces, torque and friction which degrade positioning accuracy.

M-850

Hexapod 6-Axis-Parallel Kinematics Microrobot

M-850 Hexapod Microrobot.

- **Six Degrees of Freedom**
- **Works in Any Orientation**
- **No Moving Cables for Improved Reliability and Precision**
- **200 kg Load Capacity (Vertical)**
- **Heavy-Duty, Ultra-High-Resolution Bearings for 24/7 Applications**
- **Repeatability to ±1 µm**
- **Actuator Resolution to 0.005 µm**
- **Significantly Smaller and Stiffer Package than Conventional Multi-Axis Positioners**
- **Vacuum-Compatible Versions**
- **Linear and Rotary Multi-Axis Scans**
- **Virtualized Center of Rotation (Pivot Point)**
- **Sophisticated Controller Using Vector Algorithms**
- **20,000 h MTBF**

The M-850, M-824 and M-840 (see. p. 6 ff.) Hexapod systems are the results of PI's many years of experience with high-resolution parallel kinematics (PKM).

The M-850 is the ideal micropositioning system for all complex positioning tasks which depend upon high load capacity and accuracy in six independent axes. In addition to positioning all axes with resolutions in the submicron and arcsecond ranges, it allows the user to define the center of rotation (pivot point) anywhere inside or outside the system envelope by one simple software command.

Two models are available: The M-850.50 featuring higher speed and direct-drive actuators, and the M-850.11 with a gear ratio that makes it self-locking even with large loads.

Hexapod Working Principle and Advantages

The M-850 Hexapod is driven by six high-resolution actuators (for the M-850.11, 0.005 µm resolution) all connected directly to the same moving platform. The principle is similar to that seen in flight simulators, but considerably more precise. In place of the hydraulic actuators used there, the M-850 uses custom high-load precision screws and servo-motors. It can withstand loads of 200 kg vertically, and at least 50 kg in any direction.

Laser metrology techniques and finite element method (FEM) simulations were used to design and optimize the system.

The low mass of the moving platform and the use of extremely stiff and accurate components results in an unusually high natural frequency of 500 Hz with a 10 kg load. This means that positioning operations can be performed with far lower settling times than with conventional, serial-kinematics multi-axis systems. In such systems, runout, guiding errors, friction and the inertia of moving cables all accumulate to limit accuracy and repeatability—problems which do not affect parallel kinematic systems like the Hexapod. Furthermore, the pivot point is freely definable, independent of the positions of the linear axes.

Virtualized Pivot Point

For optics and other alignment tasks, it is important to be able to define a fixed pivot point. The sophisticated Hexapod controller allows choosing any point in space as the pivot point for the rotation axes. Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion.

Open Architecture

Control of the M-850 is facilitated by the controller's open interface architecture, which provides a variety of high-level

Ordering Information

M-850.11
Hexapod 6-Axis Parallel Kinematics Microrobot with Controller, 0.5 mm/s

M-850.50
Hexapod 6-Axis Parallel Kinematics Microrobot with Controller, 8 mm/s

M-850.V50
Vacuum Version of the M-850.50

Optional Photometers

F-206.00U
Photometer Card (visible range)

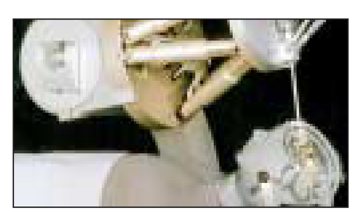
F-206.iRU
Photometer Card (IR range)

F-361.10
NIST Traceable Optical Power Meter, 1000 to 1600 nm

Ask about custom designs!

Application Examples

- Alignment and tracking of optics, electron beams, lasers, etc.
- Satellite testing equipment
- Surgical robots
- Micromachining
- Micromanipulation (life sciences)
- X-ray diffraction measurements
- Semiconductor handling systems
- Tool control for precision machining & manufacturing
- Fine positioning of active secondary mirror platforms in astronomical telescopes

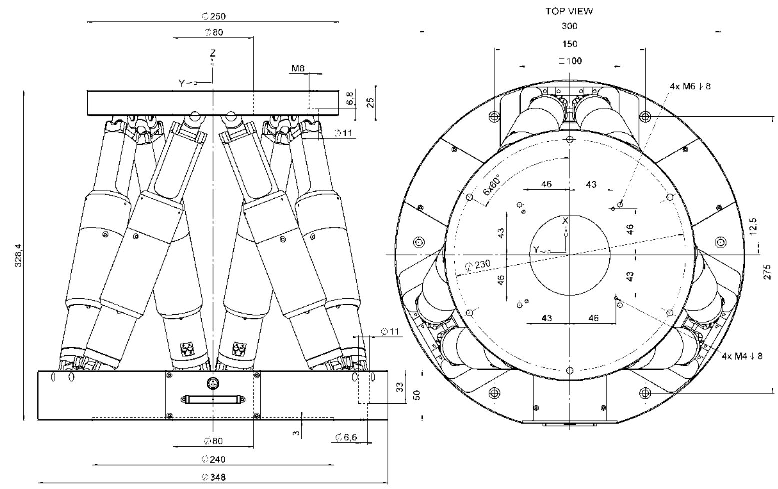


Custom Hexapod designed for neurosurgery Photo: IPA commands and includes a macro language for programming and storing command sequences.

Automatic Optics Alignment

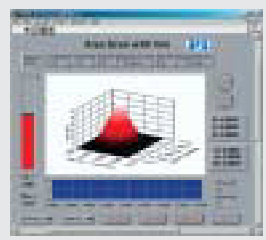
With the internal or external photometer option and the integrated scanning routines, just a few commands are needed to perform an automated alignment of optical components. For more information on photometers / optical power meters, see the F-206.IRU and F-206.00U, p. 8-12 and the F-361, p. 8-14, PI complete catalog.

A smaller, even-more-precise hexapod, specially developed for alignment of collimators, fiber bundles and I/O chips, is available as the F-206 (see p. 7-18 and p. 8-8, PI complete catalog).



M-850 Hexapod. Dimensions in mm.


Custom water-resistant Hexapod


HexControl™ software showing scan of a fiber optics component.


Custom "6+3" Hexapod with additional struts providing independent position feedback.

Technical Data

Models	M-850.11	M-850.50	Units
* Travel range X, Y	±50	±50	mm
* Travel range Z	±25	±25	mm
* Travel range θ_X, θ_Y	±15	±15	°
* Travel range θ_Z	±30	±30	°
Actuator stroke	±25	±25	mm
Actuator design resolution	0.005	0.049	µm
** Minimum incremental motion, X, Y, Z	1 (XY), 0.5 (Z)	1 (XY), 0.5 (Z)	µm
** Minimum incremental motion θ_X, θ_Y, θ_Z	5	5	µrad
Repeatability X, Y	±2	±2	µm
Repeatability Z	±1	±1	µm
Repeatability θ_X, θ_Y, θ_Z	±10	±10	µrad
Speed X, Y, Z (typical)	0.3	5	mm/s
Speed X, Y, Z (max.)	0.5	8	mm/s
Speed θ_X, θ_Y, θ_Z (typical)	3	50	mrad/s
Speed θ_X, θ_Y, θ_Z (max.)	6	100	mrad/s
Stiffness (k_X), (k_Y)	3	3	N/µm
Stiffness (k_Z)	100	100	N/µm
Weight	17	17	kg
Load capacity (vertical / random)	200 / 50	200 / 50	kg
In Z with power off (holding force)	200	25	kg
Resonant frequency	90	90	Hz
Resonant frequency F_Z ***	500	500	Hz

* The maximum travel ranges in the different coordinate directions (X, Y, Z, θ_X, θ_Y, θ_Z) are interdependent. The data for each axis in this table shows its maximum travel, where all other axes are at their zero positions. If the other linear or rotational coordinates are not zero, the available travel may be less.

Example: The following position is in the workspace:
X: +20 mm θ_X : +10°
Y: +20 mm θ_Y : +10°
Z: +5 mm θ_Z : -2°

** Six-axis move. No moving cables (unlike serial-kinematic stacked systems) to introduce bending forces, torque and friction which degrade positioning accuracy.

*** Mounted vertically with 10 kg load

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M-840

HexaLight™ 6-Axis-Parallel Kinematics Microrobot

M-840 HexaLight™ 6-axis micropositioning system

- **Six Degrees of Freedom**
- **Rapid Response**
- **No Moving Cables for Improved Reliability and Precision**
- **10 kg Load Capacity**
- **Repeatability to ±2 µm**
- **Actuator Resolution to 0.016 µm**
- **Significantly Smaller and Stiffer than Serial-Kinematics Systems, Better Dynamics**
- **Vacuum-Compatible Versions**
- **Virtualized Pivot Point**
- **Sophisticated Controller Using Vector Algorithms**
- **20,000 h MTBF**

The M-840, M-824 and M-850 (see. p. 6 ff.) Hexapod systems are the results of PI's many years of experience with high-resolution parallel kinematics (PKM).

The M-840 is the ideal micropositioning system for all complex positioning tasks which depend upon high speed and accuracy in six independent axes. In addition to positioning all axes, it allows the user to define the center of rotation (pivot point) anywhere inside or outside the system envelope by one simple software command.

Application Examples

- Micromachining
- Micromanipulation
- Life sciences
- X-ray diffraction measurements
- Semiconductor handling systems
- Tool Control for precision machining & manufacturing

Two models are available: The M-840.5PD featuring higher speed and direct-drive actuators, and the M-840.5DG with a gear ratio that makes it self-locking.

Hexapod Working Principle and Advantages

The M-840 HexaLight™ is driven by six high-resolution actuators (for the M-840.5DG, 0.016 µm resolution) all connected directly to the same moving platform. The principle is similar to that seen in flight simulators, but considerably more precise. In place of the hydraulic actuators used there, the M-840 uses highly accurate micrometer screws and servo-motors.

Laser metrology techniques and finite element method (FEM) simulations were used to design and optimize the system.

Because of the low mass of the moving platform, positioning operations can be performed with far lower settling times than with conventional, stacked multi-axis systems.

In such systems, runout, guiding errors, friction and the inertia of moving cables all accumulate to limit accuracy and repeatability—problems which do not affect parallel kinematic systems like the Hexapod. Furthermore, the pivot point is freely definable, independent of the positions of the linear axes.

Faster Positioning in All Six Axes

In comparison with the M-850 Hexapod (p. 6) the M-840 is designed for higher speeds and lighter loads. Loads of up to 10 kg can be positioned at up to 50 mm/s and 600 mrad/s with micron accuracy.

Virtualized Pivot Point

For optics and other alignment tasks, it is important to be able to define a fixed pivot point. The sophisticated Hexapod controller allows choosing any point in space as the pivot point for the rotation axes. Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion.

Ordering Information

M-840.5PD
Hexapod 6-Axis Parallel Kinematics Microrobot with Controller, Direct Drive

M-840.5DG
Hexapod 6-Axis Parallel Kinematics Microrobot with Controller, Gearhead Drive

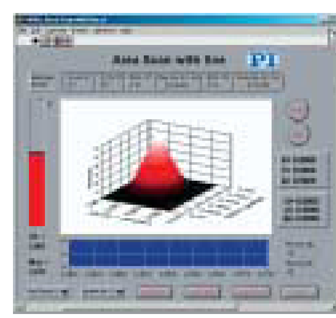
Optional Photometer

F-206.00U
Photometer Card (Visible Range)

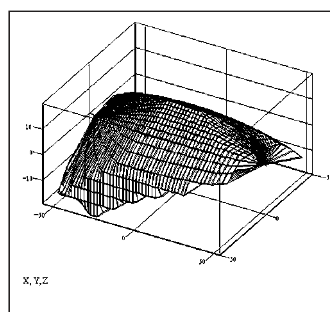
F-206.iRU
Photometer Card (IR Range)

F-361.10
NIST Traceable Optical Power Meter, 1000 to 1600 nm

Ask about custom designs!



HexControl™ software showing scan of a fiber optics component.



The X, Y, Z working space of the M-840 with $\theta_X = \theta_Y = \theta_Z = 5°$.

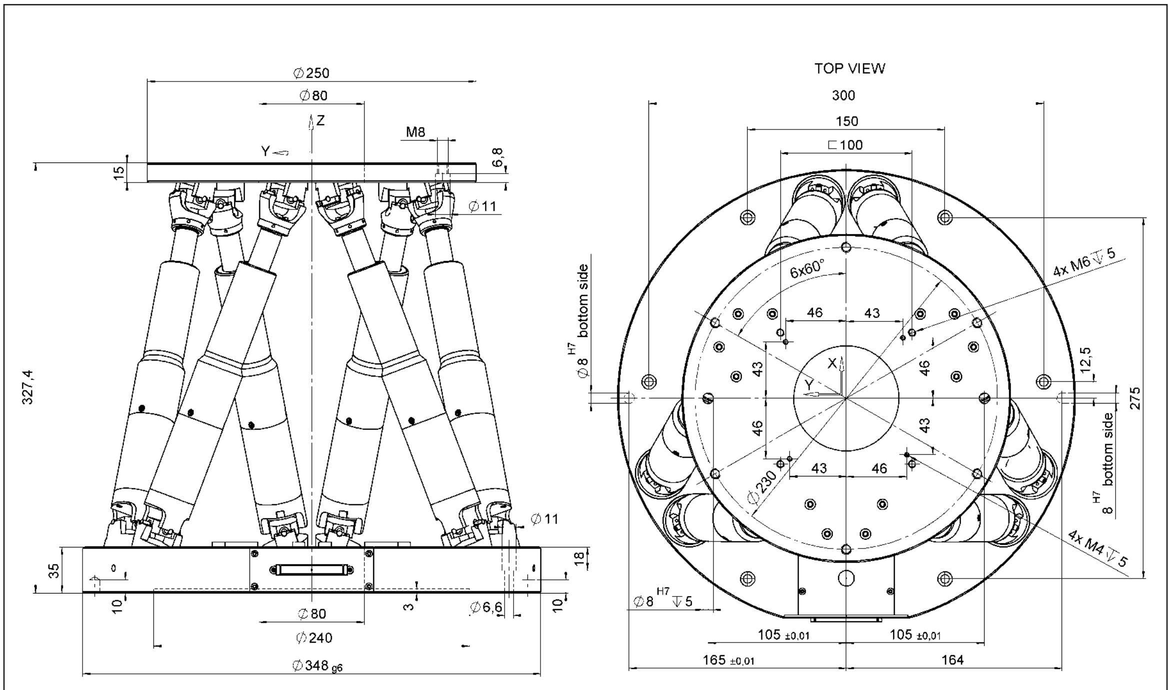
Open Architecture

Control of the M-840 is facilitated by the controller's open interface architecture, which provides a variety of high-level commands and includes a macro language for programming and storing command sequences.

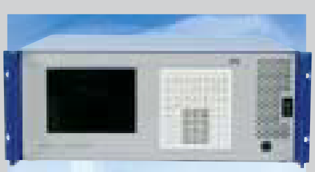
Automatic Optics Alignment

With the internal or external photometer option and the integrated scanning routines, just a few commands are needed to perform an automated alignment of optical components. For more information on photometers / optical power meters, see the F-206.IRU and F-206.00U, p.8-12 and the F-361, p.8-14, PI complete catalog.

A smaller, even-more-precise hexapod, specially developed for alignment of collimators, fiber bundles and I/O chips, is available as the F-206 (p. 4).



M-840 dimensions in mm



Hexapod Controller with optional built-in display and keyboard.

High-speed F-361 optical power meter

Technical Data

Models	M-840.5PD	M-840.5DG	Units
* Travel range X, Y	±50	±50	mm
* Travel range Z	±25	±25	mm
* Travel range θ_X, θ_Y	±15	±15	°
* Travel range θ_Z	±30	±30	°
Actuator stroke	±25	±25	mm
Actuator design resolution	0.5	0.016	µm
** Minimum incremental motion, X, Y	3	1	µm
** Minimum incremental motion, Z	1	0.5	µm
** Minimum incremental motion θ_X, θ_Y, θ_Z	5	5	µrad
Repeatability X, Y	±2	±2	µm
Repeatability Z	±1	±1	µm
Repeatability θ_X, θ_Y, θ_Z	±20	±20	µrad
Typical Speed X, Y, Z	30	2	mm/s
Max. Speed X, Y, Z	50	2.5	mm/s
Typical Speed θ_X, θ_Y, θ_Z	300	20	mrad/s
Max. Speed θ_X, θ_Y, θ_Z	600	30	mrad/s
Load capacity (mounted vertically)	10	10***	kg
Weight	12	12	kg

* The maximum travel ranges in the different coordinate directions (X, Y, Z, θ_X, θ_Y, θ_Z) are interdependent. The data for each axis in this table shows its maximum travel, where all other axes are at their zero positions. If the other linear or rotational coordinates are not zero, the available travel may be less.

** Six-axis move. No moving cables (unlike serial-kinematic stacked systems) to introduce bending forces, torque and friction which degrade positioning accuracy

*** self-locking

M-824

Compact 6-Axis Parallel Kinematics Microrobot

M-824.3DG compact 6-axis Hexapod

- **Six Degrees of Freedom**
- **Vacuum Compatible Versions**
- **Load Capacity 10 kg**
- **Travel Ranges to 45 mm (linear), 25° (rotation)**
- **7 nm Resolution**
- **300 nm Min. Incremental Motion**
- **Repeatability ±0.5 µm**
- **Very Compact Design**
- **Self Locking to 10 kg**

The new M-824 is based on PI´s experience of more than a decade with parallel kinematics Hexapods like the M-850 / M-840 and F-206 (see p. 4 ff.). The M-824 is the ideal micropositioning system for all complex positioning tasks which depend upon high accuracy and resolution in six independent axes. In addition to positioning all axes it allows the user to define the center of rotation (pivot point) anywhere inside or outside the system envelope by one simple software command.The vacuum version, the M-824.3VG, enables use in applications such as X-ray diffraction microscopy with ambient pressures down to 10^{-6} hPa.

Application Examples

- Micromachining
- Micromanipulation
- Life sciences
- X-ray diffraction measurements
- Semiconductor handling systems
- Tool control for precision machining & manufacturing

Extremely Compact

The M-824 uses a very compact drive and, with a height of 188 mm, has a considerably lower profile than either the M-850 or M-840 Hexapods. The unit can be mounted in any orientation, and can position loads of up to 10 kg.

Hexapod vs. Serial Kinematics Systems

The M-824 is based on 6 actuators with a high resolution of 0.007 µm, all connected directly to the same moving platform. The principle is similar to that seen in flight simulators, but considerably more precise. In place of the hydraulic actuators used there, the M-824 uses highly accurate micrometer screws and servo-motors.

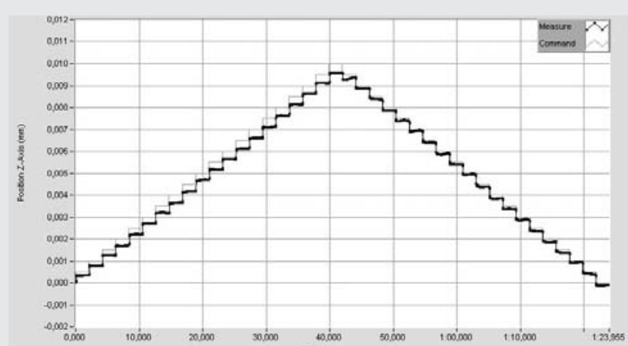
The low mass of the moving platform permits positioning with significantly shorter settling times compared to those obtainable in conventional, stacked, multi-axis systems (serial kinematics).

In serial kinematics systems wobble and guiding errors in the bearings of each axis accumulate. Friction and torque caused by moving cables further limit accuracy and repeatability. The parallel kinematics Hexapods are not affected by these ills because all actuators operate directly on the same platform. A further advantage is that the rotation axes do not have their centers of rotation determined by the hardware.

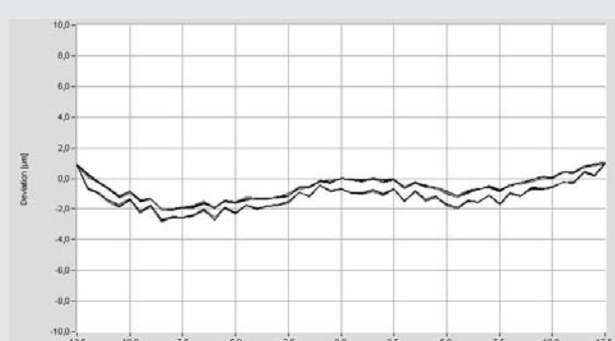
Ordering Information

M-824.3DG
Hexapod 6-Axis Parallel Kinematics Robot with Controller.

M-824.3VG
Hexapod 6-Axis Parallel Kinematics Robot with Controller, Vacuum Version down to 10^{-6} hPa.



The interferometer test shows the highly repeatable minimum incremental motion of 500 nm.



The interferometer test shows the Z axis accuracy over the entire travel range of 25 mm and the extremely high repeatability of ± 0.046 µm.

Piezo Actuators
Nanopositioning & Scanning Systems
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Tutorial: Piezo-electrics in Positioning
Capacitive Position Sensors
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Hexapods / Micropositioning
Photonics Alignment Solutions
Motion Controllers
Ceramic Linear Motors & Stages
Index

Plug-and-Play

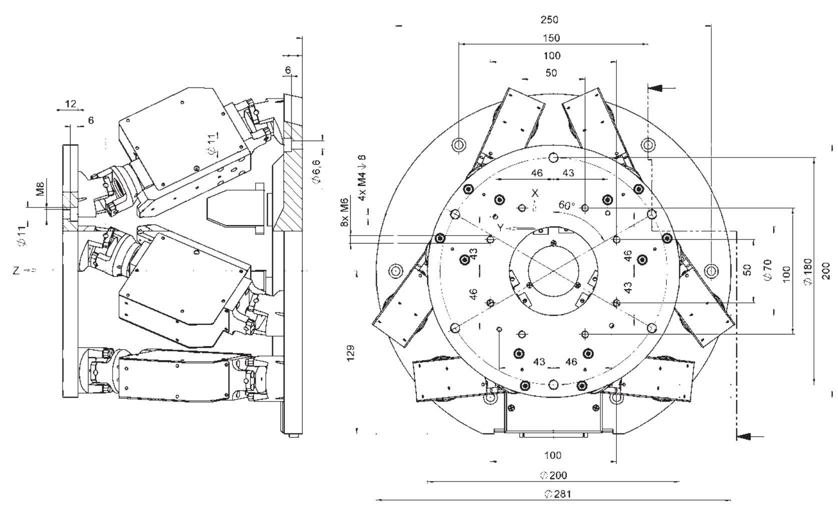
The M-824 is a true plug-and-play system and comes with a powerful 6D controller. Its sophisticated, user-friendly positioning and alignment software can save hundreds of hours of the programming time required to achieve similar functionality with a conventional, stacked, 6-axis system.

Freely Definable Pivot Point

For optics and other alignment tasks, it is important to be able to define a fixed pivot point. The sophisticated Hexapod controller allows choosing any point in space as the pivot point for the rotation axes.
Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion.

Open Interface Architecture

Control of the M-824 is facilitated by the controller's open interface architecture, which provides a variety of high-level commands and includes a macro language for programming and storing command sequences.



M-824 dimensions in mm.

Vacuum Version

The M-824.3VG is available in a vacuum-compatible model suitable for operation down to to 10^{-6} hPa.

Technical Data

Models	M-824.3DG	Unit
** Travel X, Y	±22.5	mm
** Travel Z	±12.5	mm
** Travel θ_X, θ_Y	±7.5	°
** Travel θ_Z	±12.5	°
Actuator stroke	±12.5	mm
Actuator design resolution	0.007	µm
* Min. incremental motion X, Y	0.3	µm
* Min. incremental motion Z	0.3	µm
* Min. incremental motion θ_X, θ_Y, θ_Z	3.5	µrad*
Repeatability X, Y	±0.5	µm*
Repeatability Z	±0.5	µm
Repeatability θ_X, θ_Y, θ_Z	±6	µrad
Typ. velocity X, Y, Z	0.5	mm/s
Typ. velocity θ_X, θ_Y, θ_Z	0.35	°/s
Max. velocity X, Y, Z	1	mm/s
Max. velocity θ_X, θ_Y, θ_Z	0.7	°/s
Stiffness (k_X, k_Y)	1.7	N/µm
Stiffness (k_Z)	7	N/µm
Load capacity (horizontal mounting)	10***	kg
Weight	7.8	kg

The M-824 comes with a powerful 6D controller and sophisticated, user-friendly positioning and alignment sofware. Keypad and display are optional.

* Simultaneous motion of all 6 actuators! No moving cables (as in serial-kinematics stacked systems) to introduce bending sources, torque and friction, which degrade positioning accuracy.
** The travel ranges of the individual coordinates (X, Y, Z, θ_X, θ_Y, θ_Z) are interdependent. The data for each axis in this table shows its maximum travel, where all other axes are at their zero positions. If the other linear or rotational coordinates are not zero, the available travel may be less.
*** Self locking

PI Wins Substantial Hexapod Contract for ALMA Millimeter Radio Telescope


Six-axis weatherproof secondary Hexapod for the ALMA telescopes


Model of the ALMA telescope

General Dynamics subsidiary Vertex Antennentechnik has ordered 25 high-precision micropositioners for large array radio telescope

The ALMA (Atacama Large Millimeter Array) international partnership is constructing and will operate a radio telescope comprising an array of up to 64 antennas. The partnership is made up of North America (USA and Canada), Europe and Japan, in cooperation with Chile. PI will deliver a total of 25 Hexapod systems for the extremely precise alignment of the telescope's secondary reflectors to Vertex Antennentechnik in Duisburg, Germany by 2011. Hexapods are the first choice of positioning system for astronomical multi-axis alignment tasks. They can provide very high stiffness, a very large aperture, and are devoid of cable management issues.

The PI Hexapod combines a load capacity of 200 kg with sub-micron linear resolution and microrad-level angular resolution. A highly sophisticated digital controller provides advanced features such as a user-programmable virtual pivot point, extremely important in complex alignment applications. Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion which saves valuable programming time when integrating the system. Similar six-axis micropositioning systems from PI have already proven reliable in operation at the ALMA VertexRSI test antenna and the Atacama Pathfinder Experiment (APEX) radio telescopes. Millimeter and sub-millimeter astronomy investigates the universe in the spectral range which traditionally stretches from radio waves to the infrared.

ALMA will be used in this spectral range to investigate the structure of the early universe as well as galaxies, stars and planets in their formative stages. ALMA is being built in the Chilean Atacama desert at an altitude of over 5000 m, one of the driest places on earth. These are favorable conditions for the best possible observations, since millimeter radiation is absorbed by water vapor in the atmosphere.

Each individual ALMA antenna has a primary reflector 12 m in diameter, higher than a four-story house. The mobile antennas will be used together in various arrangements as a single


The APEX radio telescope in Chile also uses a PI Hexapod system


The ALMA VertexRSI test antenna with PI Hexapod system

telescope. The spread of the antenna array will be between 150 m and a maximum of 12 km. On completion in 2011, ALMA will be the largest and most powerful radio telescope in the world, with a resolution ten times better than that of the Hubble space telescope.

In supplying the six-axis Hexapods and their high-performance controllers, Physik Instrumente is contributing its many years of experience in extremely high-precision positioning to the ALMA project. PI was able to demonstrate the reliability and accuracy of its systems in the ALMA VertexRSI test antenna in New Mexico, USA. ALMA's technological forerunner project, the APEX radio telescope in Chile, is already successfully using the same PI micropositioning system.

PI has been supplying hexapods, micropositioning actuators and active optics for astronomical telescopes, including several infrared telescopes on Mauna Kea in Hawaii as well as telescopes in Chile, South Africa and the Canary Islands, for over 15 years.

http://www.alma.nrao.edu
http://www.eso.org/projects/alma
http://www.apex-telescope.org
http://pi.ws

Ultra-Precise 6D-Measuring System for Optical Surfaces

Inserts for precision optical molds make high demands on the testing process. Today, such testing can easily be automated with the help of interferometric measuring devices. Parallel-kinematics Hexapod 6-axis alignment systems even make it possible to integrate testing directly in the manufacturing process.

Fig. 1: The tighter the tolerances required for a product, the higher the precision required of the testing equipment. The optical mold inserts for production of plastic or glass lenses have especially high precision requirements.
(Illustration: Fraunhofer Institute for Production Technology, IPT)

The integration of testing equipment for optical mold inserts (Fig. 1) directly into the manufacturing cell avoids complex and time-consuming setup steps and completely eliminates rechucking errors. The new testing unit developed by the Fraunhofer Institute for Production Technology (IPT) in Aachen, Germany tests the optical mold inserts directly in-line, on the production machine. Discrepancies are calculated and the error is fed back into the process where it can, if necessary, trigger automatic reworking of the optical surface. Automated interferometric surface testing is the key to the system.

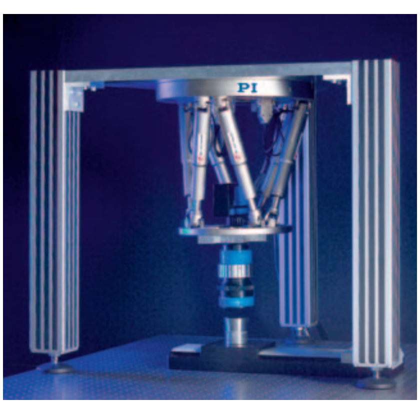


Fig. 2: The Hexapod is mounted on a 20 mm thick aluminum plate. The parallel-kinematic design and large aperture allow for the interferometer to be integrated into the Hexapod. Images are captured by a CCD camera and evaluated in real time. A MATLAB program, controls the position of the Hexapod.
(Photo: Physik Instrumente, PI / Fraunhofer Institute for Production Technology, IPT)

Interferometric testing: non-contact, fast and extremely precise

Interferometric optical mold testing uses the interference pattern (fringe pattern) which gives information about the topography of the test sample. Image processing algorithms automatically recognize and evaluate shape deviations with nanometer accuracy. The interferometer must, of course, be positioned very precisely relative to the optical surface.

First, coarse adjustment aligns the beam reflected off the test surface with the CCD sensor. Then, with the fine adjustment, a well-defined interference pattern is created. The automated fine-adjustment algorithm uses the Fast Fourier Transformation (FFT) technique to analyze the fringe pattern. The adjustment strategy is based on an evaluation system newly developed at the Fraunhofer IPT, which determines the topology from a single interference pattern.

In order to test both spherical and aspherical elements, motion in six degrees of freedom is required (Fig.3). For this purpose, a PI parallel-kinematics positioning system is used. In addition to very high accuracy, it offers further advantages such as low inertia, uniformly high dynamic performance for all motion axes, and a compact design with a large aperture.

Hexapod: Six Degrees of Freedom and Freely Definable Pivot Point

The PI M-840 Hexapod chosen also provides rapid settling after a move, a linear travel range of up to 100 mm and a rotational travel range up to 60°. The large working space makes it possible to measure spherical surfaces with a radius of up to 100 mm. Also important for both the coarse and fine alignment process is the freely definable pivot point, which is not affected by motion. The optical mold testing interferometer system achieves impressive values: 3 µm accuracy in X and Y, 1 µm in Z – with repeatabilities also of 3 µm and 1 µm, respectively. The rotational minimum incremental motion of only 0.017 arc minutes (5 µrad) is over an order of magnitude better than the required 1 arc minute.

Simple Integration

It was surprisingly easy to integrate the Hexapod into the application's automation environment. Control is simplified by the Hexapod controller's open interface architecture, which facilitates programming with high-level commands using any of a variety of included drivers (COM Object or DLL). The Hexapod controller can thus be operated by external programs, such as the MATLAB programs employed for image processing and analysis in the testing interferometer. The flexibility of the Hexapod system played an important part in making possible the first fully integrated automated testing device for optical components with complex geometries. The new interferometer will significantly simplify quality control while providing higher precision than otherwise possible.

Karl Vielhaber, MSc, scientific assistant at the Fraunhofer Institute for Production Technology (IPT) in Aachen, Germany and Ellen-Christine Reiff, M.A., Editorial Service Stutensee

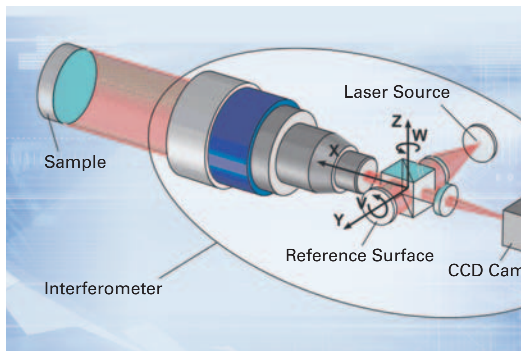


Fig. 3: Degrees of freedom for positioning the interferomet (Illustration: Fraunhofer Institute for Production Technology IPT)

M-850 Hexapod Advances Research in Dental Biomechanics

From Christoph Bourauel and Ludger Keilig–Department for Orthodontics at the Rheinischen Friedrich-Wilhelms-Universität, Bonn.

Dental biomechanics deals with the interactions between dental materials, treatment instruments or dentures and the reaction of teeth, biological tissues, etc. to mechanical stresses. A wide spectrum of force systems occur here with masticatory forces exerting loads to 380 N and torques to several Nm.

At the same time, movements of several orders of magnitude are involved: orthodontic equipment can change the position of teeth by up to several mm, whereas—during mastication—teeth are deflected by less than 100 µm and implants by as little as a few microns or less. These combinations of small forces with large deflections, on the one hand, and large forces and extremely small deflections on the other, represent a challenge with respect to the biomechanical metrology.

To deal with this challenge, the Dental Clinic of the University of Bonn designed the HexMeS (Hexapod Measuring System) based on the M-850.50 Hexapod. The ability to move in 6 degrees of freedom and the combination of small dimensions, very high stiffness and resolution of less than 1 µm (1 arcsec) were the key reasons for choosing the M-850 system.

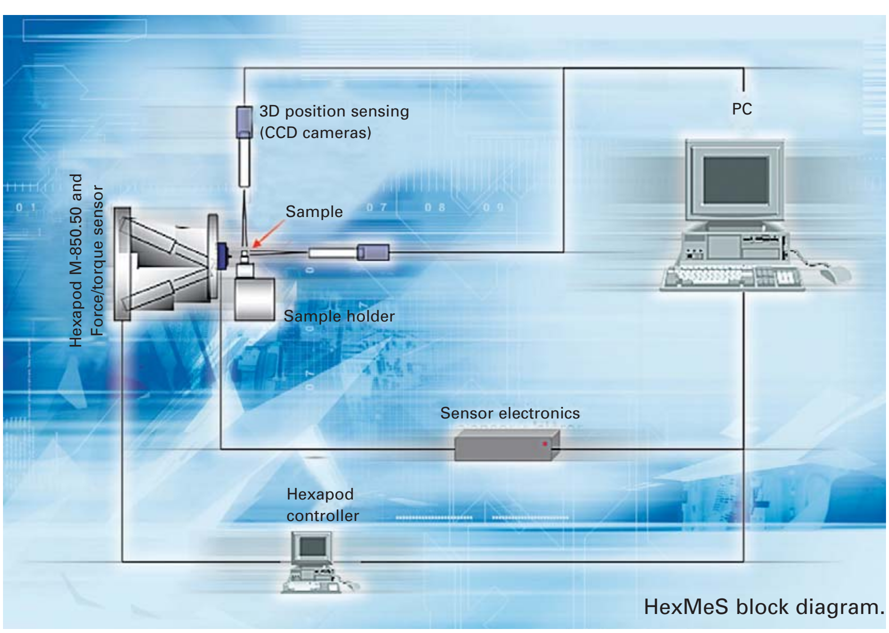
HexMeS also features two 6-component force/torque sensors for the Hexapod with measuring ranges of 12 N (120 Nmm) and 130 N (10 Nm) respectively and an optical detection system equipped with 3 CCD cameras.

Because of its high stiffness (100 N/µm), sample deflections can usually be calculated directly from the Hexapod motion.

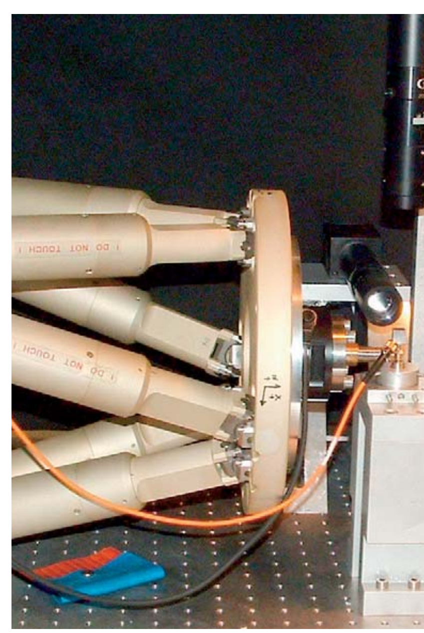
For high-load testing—simulations of mastication in the 100 N range—the optical portion of the HexMeS is used. It resolves sample deflections to 0.7 µm / 0.2 arcsec.

The M-850-based HexMeS currently represents one of the most flexible measuring systems in the field of dental biomechanics. Its efficiency and the broad spectrum of its application have been demonstrated in a whole series of experimental investigations into dental implants, telescope crowns and orthodontic prostheses.

Load testing of a double crown.



HexMeS block diagram.



PI News / Press Releases

Date: 05/2006

M-850K102 Ultra-High Load Hexapod

PI has designed a unique Hexapod high-load 6-axis positioner for astronomy applications and other alignment tasks. The M-850K102 custom Hexapod combines extremely high precision with a load capacity of up to 1000 kg. It provides minimum incremental motion to 0.8 µm and 1 µrad, respectively. The six individual actuators have a design resolution of 0.08 µm and a stiffness of 40 N/µm.

- Six Degrees of Freedom
- Works in Any Orientation
- No Moving Cables for Improved Reliability and Precision
- 1000 kg Load Capacity (Vertical)
- Heavy-Duty, Ultra-High-Resolution Bearings for 24/7 Applications
- Repeatability to 0.5 µm
- Actuator Resolution 0.008 µm
- Significantly Smaller and Stiffer Package than Conventional Multi-Axis Positioners
- Vacuum-Compatible Versions
- Linear and Rotary Multi-Axis Scans
- Virtualized Center of Rotation (Pivot Point)
- Sophisticated Controller Using Vector Algorithms

M-850K102, 1000 kg Hexapod shown with M-840 Hexalight.

Hexapod Working Principle and Advantages
The M-850 Hexapod is driven by six high-resolution actuators all connected directly to the same moving platform. The principle is similar to that seen in flight simulators, but considerably more precise. In place of the hydraulic actuators used there, the M-850 uses custom high-load precision screws and servo-motors. It can withstand loads of 1000 kg vertically, and at least 180 kg in any direction.

Technical Specifications:

Number of Axes:	6
Linear travel range XYZ:	24 mm
Rotation range:	8 deg. (rot z) 6 deg. (rot x, y)
Actuator design resolution:	< 0.08 µm
Minimum incremental motion XYZ:	0.8 µm
Minimum incremental motion Rot xyz:	1 µrad
Repeatability X, Y:	1 µm
Repeatability Z:	0.5 µm
Max Linear Velocity XYZ:	0.5 mm/s
Max Rotary Velocity:	6 mrad/s
Actuator Stiffness:	40 N / µm
Load capacity:	up to 1000 kg (depends on orientation)
Weight:	450 kg

Typical Applications
Alignment and tracking of optics, electron beams; fine positioning of active secondary mirror platforms in astronomical telescopes

PI News / Press Releases

Date: 04/2005

NEXLINE® Piezo Hexapod - Non Magnetic 6-Axis Precision Positioning System

PI has developed a custom, non-magnetic piezoelectric hexapod based on the N-215 NEXLINE® ultra-precision piezo motor drives. This Hexapod 6-axis positioning stage can be used in applications with very strong magnetic fields.

Preliminary Specifications:

- 8” Aperture
- Load 50kg
- Low Profile: 140mm
- Translation XYZ: 10mm
- Rotation all axes: 6 °

For further information on the piezo Hexapod, please contact PI.

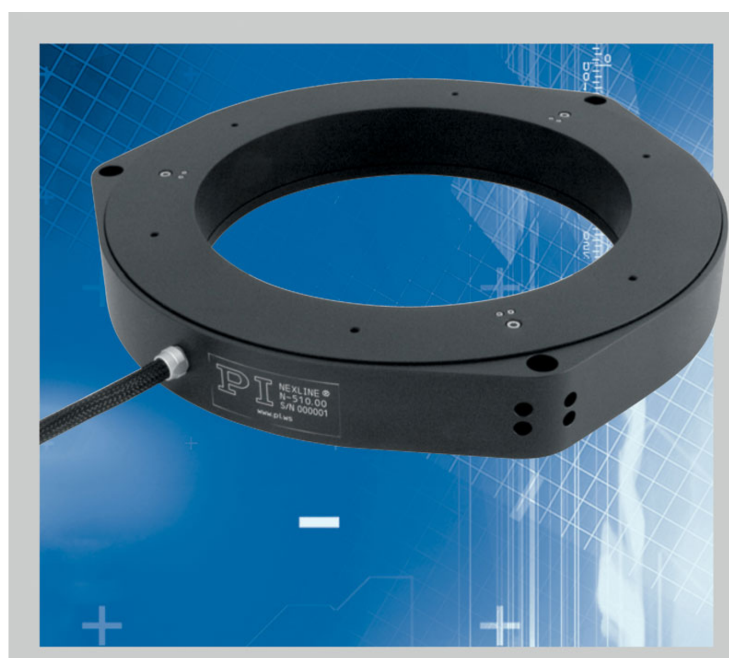
Custom Non-Magnetic Piezoelectric Hexapod.

A large Z-Tip/Tilt Nanopositioning Platform was also developed:

Preliminary Specifications:

- Z, Tip, Tilt platform with closed-loop NEXLINE® drives and position sensors:
- Diameter: 300 mm (12“)
- Load capacity: 200 N
- Travel range: 1.3 mm
- Tilting angle: 10 mrad
- Sensor: High-resolution incremental sensor.

For further information on the large Z-Tip/Tilt Nanopositioning Platform, please contact PI.



Z-Tip/Tilt Nanopositioning Platform.

Micropositioning, Nanopositioning, NanoAutomation®

Cutting-Edge Solutions for Industry and Research

PI headquarters

Positioning Technology - 30 Years Ahead of its Time

PI has been a world market leader in nanopositioning technology and ultra-high-precision motion-control systems for many years. The first nanopositioning systems served research centers working in interferometry and laser technology. Today, entire branches of industry – such as the semiconductor industry, biotechnology and, increasingly, the machine-tool industry – are dependent on progress in nanopositioning.

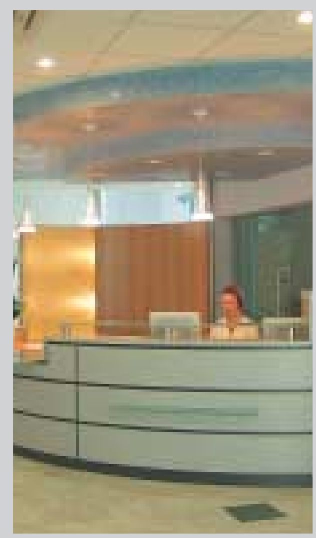
Key Technologies Under One Roof: A Plus for Our Customers

PI has a strategy of vertical integration with all key technologies developed and maintained in one company. This permits direct control over every step from conception to shipment, optimizing quality and cost. As a customer, you, too, can profit from our over 30 years experience in micro- and nanopositioning.
PI can react quickly to development and production needs of OEM customers – even for highly complex custom products and assemblies.

Applications

Today PI delivers Micro- & NanoPositioning solutions for all important high-tech markets:

- Semiconductors
- Data Storage
- Photonics, Fiber Optics, Telecom
- Life Sciences
- Lasers, Optics, Microscopy
- Aerospace Engineering
- Precision Machining
- Astronomy



Request the hardbound PI Catalog

Call or go to: http://www.pi.ws

Program Overview

- Piezoelectric Actuators
- Piezo Nanopositioning Systems and Scanners
- Active Optics / Tip-Tilt Platforms
- Capacitive Sensors
- Piezo Electronics: Amplifiers and Controllers
- Hexapods
- Micropositioners
- Positioning Systems for Fiber Optics, Photonics and Telecommunications
- Motor Controllers
- PILine® High-Speed Ceramic Linear Motors

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