

## Hexapod 6-Axis Systems / Parallel Kinematics Microrobotic Systems for Ultra-Precision Motion Control



# Selection Guide: Hexapods, Parallel Kinematics

## Parallel Kinematics (PKM) 3-Axis & 6-Axis Stages for Micro / Nanopositioning

PI parallel kinematics (PKM) precision positioning systems have many advantages over serial kinematics stages, such as lower inertia, improved dynamics, smaller package size and higher stiffness.

With two decades of Hexapod design and manufacturing experience, PI electro-mechanical Piezo Hexapods are the most advanced multiaxis precision positioning systems in the world, providing significantly

higher precision than hydraulically driven systems. They are available in many sizes, and configurations for loads from 2 kg to more than 1000 kg, and most are self locking.

Models	Description	Travel [mm]	Load Capacity [kg]	Page
M-810	Ultra-compact electro mechanical 6-axis Hexapod. Small, yet high forces	to 40 mm / 60°	5	4-14
M-824	Vacuum compatible compact 6-axis Hexapod	to 45 mm / 25°	10	4-10
M-840	HexaLight™ 6-axis Hexapod, fast, medium load capacity optional photometer, to 50 mm/s	to 100 mm / 60°	10	4-8
M-850	High-load 6-axis Hexapod, optional photometer	to 100 mm / 60°	200	4-6
F-206	HexAlign™ 6-axis micro alignment system. Very accurate, optional photometer	to 12 mm / 6°	2	4-12
M-850KWAH	Custom secondary mirror 6-axis Hexapod alignment system for astronomy, water resistant	to 16 mm	100	4-15
M-850KHLH	Ultra-high load 6-axis Hexapod	to 24 / 8°	1000	4-15
N-515KNPH	Piezo Hexapod with nonmagnetic PiezoWalk® high-force linear motors	to 10 mm / 6°	50	1-17
M-880.PD	Tripod 3-axis high-load XYθ <sub>z</sub> stage for LCD and semiconductor inspection	20 x 20 mm / 8°	150	4-16
M-833	Tripod: 3-axis stage: X, Z, and goniometer (θ <sub>y</sub> )	±25 mm (X, Z), ±30° (θ <sub>y</sub> )	4	4-16
M-850KLAH	High-load Hexapod w/ large free aperture, for inspection systems	to 50 mm / 10°	200	4-15
N-510	Tripod Z-Tip/Tilt nanopositioning platform	1.3 / 10 mrad	20	1-17



M-810 Miniature Hexapod

M-824 Vacuum compatible compact Hexapod

M-840 HexaLight™ Hexapod, fast, medium load capacity

M-850 High-load Hexapod, optional photometer

F-206 Photonics alignment system

M-850KWAH For astronomy system



M-850KHLH Ultra-high load Hexapod

M-850KLAH Custom, for inspection systems

N-515KNPH Non-magnetic piezo hexapod

 M-880 Tripod high-load XYθ<sub>z</sub> Stage

 M-833 Tripod: X, Z, goniometer (θ<sub>y</sub>)

N-510 Tripod Z-tip/tilt nanopositioning platform

Notes on specifications see p. 4-17 ff

# Parallel Kinematics Positioning Systems

## Controlling Motion in up to 6 Axes with Sub-Micron Precision

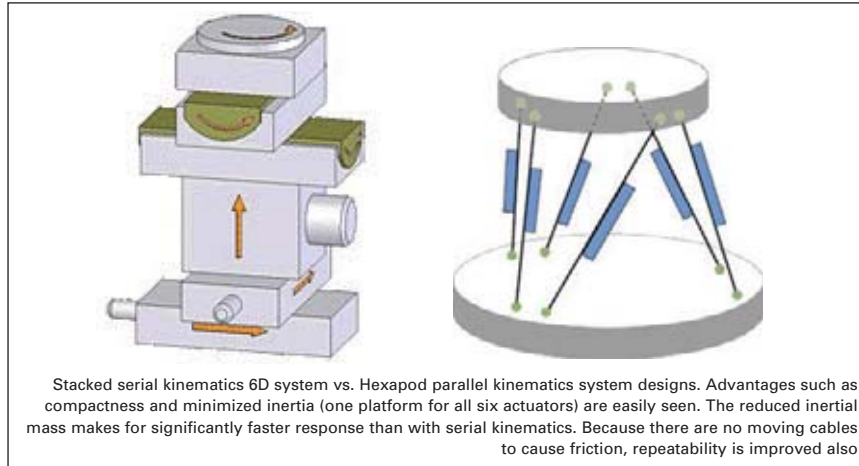


The ALMA project in the Atacama desert in Chile is to include up to 64 antennas interconnected to form an enormous radio telescope. PI Hexapod systems are used to position the secondary reflectors in the antennas. The M-850K systems, specially designed for outdoor operation in hostile conditions, can position loads of up to 75 kg (photo: Vertex Antennentechnik GmbH)

PI is the leading manufacturer of Hexapod high-performance micro- and nanopositioning systems. These parallel-kinematics devices, in a number of different forms, are suitable for diverse applications, ranging from handling systems in electronics fabrication and tool control in precision machining, through medical technology, to optical systems like those found in space telescopes and

### Advantages of PKM:

- Low moved mass, lower inertia
- Better dynamic behaviour, shorter settling times
- Smaller package size
- Higher stiffness
- No accumulation of position errors, increased accuracy
- Freely definable pivot point
- Reduced runout errors
- No moving cables: better repeatability



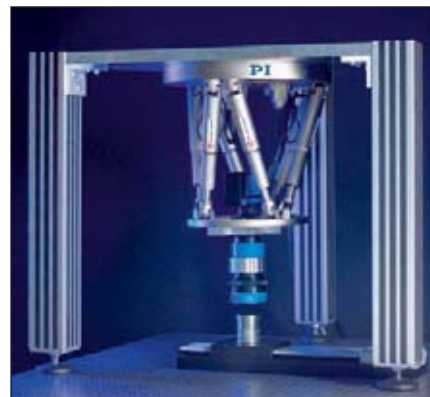
Stacked serial kinematics 6D system vs. Hexapod parallel kinematics system designs. Advantages such as compactness and minimized inertia (one platform for all six actuators) are easily seen. The reduced inertial mass makes for significantly faster response than with serial kinematics. Because there are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

satellite receiving antennas. Various models of the powerful parallel kinematic machines (PKM) can move masses of 50, 200 or even 1000 kilograms with micron accuracy as required in their respective applications.

These Hexapod systems are all built with six, high-resolution electro-mechanical or piezoelectric actuators all acting on a common platform. It is the familiar flight simulator design, but considerably more precise: in place of hydraulic cylinders, the Hexapods are driven by highly accurate, precision-controlled rotary or linear motors. Different drive principles are employed, depending on the application: Hexapods with NEXLINE® drives make for a positioning system which is not only vacuum compatible but also completely non-magnetic p. 1-3 ff.

All PI Hexapod systems include a sophisticated, yet easy to use controller. The Hexapod con-

troller allows the user to set a pivot point anywhere inside or outside the Hexapod working space, by a simple software command. This freely definable pivot point stays with the platform, no matter how it moves—an invaluable feature for example in optics applications. Moves are specified in Cartesian coordinates and the PC-based controller transforms them into the required motion-vectors for the individual actuator drives. The latest controller generation features flexible interfaces: high-speed RS-232, or TCP/IP interface for remote / network / Internet addressing.



This automated interferometric inspection system allows optical mold inserts to be checked directly while still on the production line. The hexapod is mounted "upside down" on a 20-millimeter-thick aluminum plate with the interferometer positioned in the central core of the hexapod, where it does not interfere with the motion. Control is integrated into a MatLab program, which also handles the metrological image processing (photo: Physik Instrumente (PI) / Fraunhofer Institute for Production Technology IPT)



Linear Actuators & Motors

Nanopositioning / Piezoelectrics

Nanometrology

Micropositioning

Hexapod 6-Axis Systems / Parallel Kinematics

Linear Stages

Translation (X)

Vertical (Y)

Multi-Axis

Rotary & Tilt Stages

Accessories

Servo & Stepper Motor Controllers

Single-Channel

Hybrid

Multi-Channel

Micropositioning Fundamentals

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## M-850 Hexapod 6-Axis Positioning System High-Load Parallel-Kinematics Micropositioner with Controller, to 2000 N



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  $\pm 1 \mu\text{m}$
- Encoder Resolution to 0.005  $\mu\text{m}$
- Significantly Smaller and Stiffer than Serial-Kinematics Systems, Better Dynamics
- Vacuum-Compatible Versions Available
- Linear and Rotary Multi-Axis Scans
- Virtual Pivot Point
- Sophisticated Controller Using Vector Algorithms
- MTBF 20,000 h

### Application Examples

- Alignment of secondary mirrors
- Semiconductor technology
- Optics alignment
- Medical technology
- Micromachining
- Micromanipulation
- X-ray diffraction measurements
- Satellite testing equipment
- Tool control

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. The use of extremely stiff and accurate components for the M-850 Hexapod results in an unusually high natural frequency of 500 Hz with a 10 kg load. It can withstand loads of 200 kg vertically, and at least 50 kg in any direction. In addition to positioning all axes with resolutions in the submicron and arc-second 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 vs. Serial Kinematics Systems

The Hexapod is driven by six high-resolution actuators all connected directly to the same moving platform. This design provides a high system stiffness and a large clear aperture.

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, and the friction and inertia of moving cables all accumulate to limit accuracy and repeatability—problems which do not affect parallel kinematic systems like the Hexapod.

### Fixed Virtual 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 by software command. The pivot point remains fixed relative to the platform.

Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion.

### Open Architecture

Control of the hexapod is facilitated by the controller's open interface architecture, which

### Ordering Information

**M-850.11**  
Hexapod Microrobot with Controller, DC-Motor w/ Gearhead

**M-850.V11**  
Hexapod Microrobot with Controller, DC-Motor w/ Gearhead, Vacuum Compatible to  $10^{-6}$  hPa

**M-850.50**  
Hexapod Microrobot with Controller, Direct Drive

**M-850.V50**  
Hexapod Microrobot with Controller, Direct Drive, Vacuum Compatible to  $10^{-6}$  hPa

### Optional Photometers

**F-206.iiU**  
Photometer Card, IR Range, 2 Channels

**F-206.VVU**  
Photometer Card, Visual Range, 2 Channels



Custom Hexapod designed for neurosurgery Photo: IPA

provides a variety of high-level commands and includes a macro language for programming and storing command sequences.

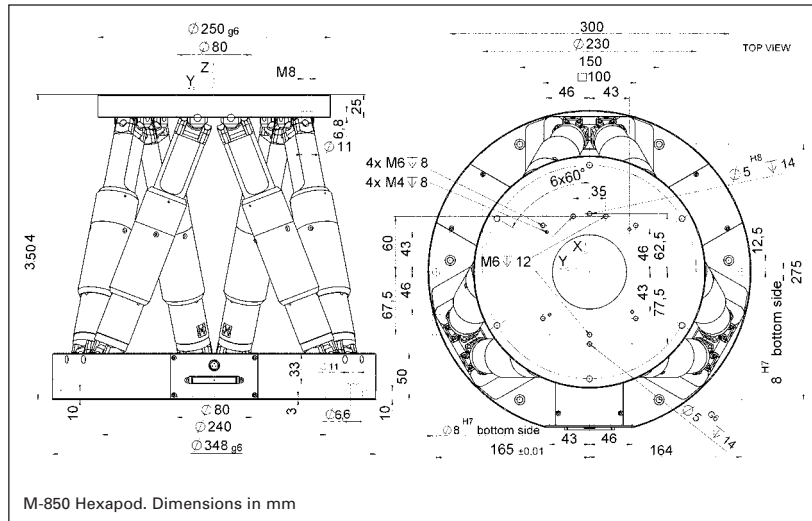
### Automatic Optical Alignment

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 [www.pi.ws](http://www.pi.ws).

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. 4-12).



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



M-850 Hexapod. Dimensions in mm

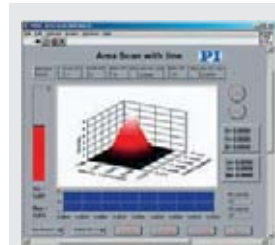
#### Technical Data

Model	M-850.11	M-850.50	Units
Active axes	X, Y, Z, $\theta_x$ , $\theta_y$ , $\theta_z$	X, Y, Z, $\theta_x$ , $\theta_y$ , $\theta_z$	
<b>Motion and positioning</b>			
*Travel range X, Y	$\pm 50$	$\pm 50$	mm
*Travel range Z	$\pm 25$	$\pm 25$	mm
*Travel range $\theta_x$ , $\theta_y$	$\pm 15$	$\pm 15$	°
*Travel range $\theta_z$	$\pm 30$	$\pm 30$	°
Actuator drive	DC-motor	DC-motor	
Actuator stroke	$\pm 25$	$\pm 25$	mm
Integrated sensor	Rotary encoder	Rotary encoder	
Sensor resolution	2048	2048	
Actuator design resolution	0.005	0.05	$\mu\text{m}$
**Min. incremental motion X, Y, Z	1 (XY), 0.5 (Z)	1 (XY), 0.5 (Z)	$\mu\text{m}$ (6-axis move!)
**Min. incremental motion $\theta_x$ , $\theta_y$ , $\theta_z$	5	5	$\mu\text{rad}$ (6-axis move!)
Repeatability X, Y	$\pm 2$	$\pm 2$	$\mu\text{m}$
Repeatability Z	$\pm 1$	$\pm 1$	$\mu\text{m}$
Repeatability $\theta_x$ , $\theta_y$ , $\theta_z$	$\pm 10$	$\pm 10$	$\mu\text{rad}$
Max. velocity X, Y, Z	0.5	8	mm/s
Max. velocity $\theta_x$ , $\theta_y$ , $\theta_z$	6	100	mrad/s
Typ. velocity X, Y, Z	0.3	5	mm/s
Typ. velocity $\theta_x$ , $\theta_y$ , $\theta_z$	3	50	mrad/s
<b>Mechanical properties</b>			
Stiffness ( $k_x$ , $k_y$ )	3	3	N/ $\mu\text{m}$
Stiffness ( $k_z$ )	100	100	N/ $\mu\text{m}$
Max. load (baseplate horizontal/any orientation)	200 / 50	200 / 50	kg
Max. holding force (baseplate horizontal/any orientation)	2000 / 500	250 / 85	N
Resonant frequency*** $F_x, F_y$	90	90	Hz
Resonant frequency*** $F_z$	500	500	Hz
<b>Miscellaneous</b>			
Operating temperature range	-10 to +50	-10 to +50	°C
Material	Aluminum	Aluminum	
Mass	17	17	kg
<b>Controller</b>			
Controller included	M-850.502	M-850.502	
Operating voltage	100–240 VAC, 50/60 Hz	100–240 VAC, 50/60 Hz	

Technical data are specified at 20  $\pm$  3 °C. Data for vacuum versions may differ.



Custom water-resistant Hexapod



HexControl™ software showing scan of a fiber optics component

\*The max. travel of the several coordinates (X, Y, Z,  $\theta_x$ ,  $\theta_y$ ,  $\theta_z$ ) 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.

Example: The following position is in the workspace:

X: +20 mm  $\theta_x$ : +10°

Y: +20 mm  $\theta_y$ : +10°

Z: +5 mm  $\theta_z$ : -2°

\*\*\*Baseplate mounted horizontally with 10 kg load

Linear Actuators & Motors

Nanopositioning / Piezoelectrics

Nanometrology

Micropositioning

Hexapod 6-Axis Systems / Parallel Kinematics

Linear Stages

Translation (X)

Vertical (Y)

Multi-Axis

Rotary & Tilt Stages

Accessories

Servo & Stepper Motor Controllers

Single-Channel

Hybrid

Multi-Channel

Micropositioning Fundamentals

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# M-840 HexaLight™ 6-Axis Positioning System

## High-Speed Parallel-Kinematics Micropositioner with Controller, to 50 mm/s



M-840 HexaLight™ 6D-Micropositioning System

- Six Degrees of Freedom, Travel Ranges to 100 mm/ 60° Rapid Response
- No Moving Cables for Improved Reliability and Precision
- Load Capacity 10 kg, Self-Locking Version M-840.DG
- Velocity up to 50 mm/s
- Repeatability up to  $\pm 2 \mu\text{m}$
- Encoder Resolution to 0.016  $\mu\text{m}$
- Significantly Smaller and Stiffer than Serial-Kinematics Systems, Better Dynamics
- Vacuum-Compatible Versions Available
- Virtual Pivot Point
- Sophisticated Controller Using Vector Algorithms
- MTBF 20,000 h

The M-840 is the ideal Micro-positioning System for all complex positioning tasks which

depend upon high speed and accuracy in six independent axes.

### Application Examples

- Biotechnology
- Semiconductor technology
- Micromachining
- Micromanipulation
- X-ray diffraction measurements
- Tool control

### Faster Positioning in All Six Axes

In comparison with the M-850 Hexapod (see p. 4-6 ff) 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. 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.

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 vs. Serial Kinematics Systems

The Hexapod is driven by six high-resolution actuators all connected directly to the same moving platform. This design provides a high system stiffness and a large clear aperture.

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, and the friction and inertia of moving cables all accumulate to limit accuracy and repeatability—problems which do not affect parallel kinematic systems like the Hexapod.

### Fixed Virtual 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 by software command. The pivot point remains fixed relative to the platform.

Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion.

### Open Architecture

Control of the hexapod is facilitated by the controller's open

### 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.iiU**  
Photometer Card, IR Range, 2 Channels

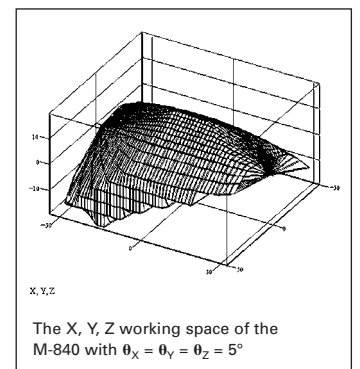
**F-206.VVU**  
Photometer Card, Visible Range, 2 Channels

**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  $\theta_x = \theta_y = \theta_z = 5^\circ$

interface architecture, which provides a variety of high-level commands and includes a macro language for programming and storing command sequences.

### Automatic Optical Alignment

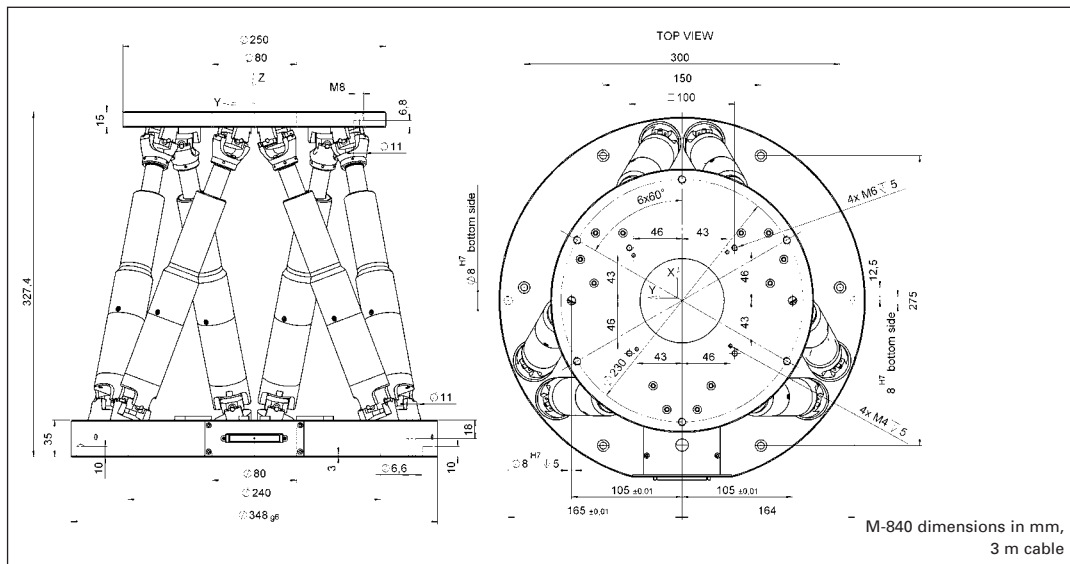
With the internal or external photometer option and the integrated scanning routines,

just a few commands are needed to perform an automated alignment of optical components. For more information on photometers / optical power meters, see [www.pi.ws](http://www.pi.ws).

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. 4-12 *ff.*

For a compact, vacuum-compatible Hexapod see M-824 see p. 4-10 *ff.*



Hexapodcontroller with optional display and keyboard



High-Speed Photometer F-361

#### Technical Data

Model	M-840.5PD	M-840.5DG	Units
Active axes	X, Y, Z, $\theta_x$ , $\theta_y$ , $\theta_z$	X, Y, Z, $\theta_x$ , $\theta_y$ , $\theta_z$	
<b>Motion and positioning</b>			
*Travel range X, Y,	$\pm 50$	$\pm 50$	mm
*Travel range Z	$\pm 25$	$\pm 25$	mm
*Travel range $\theta_x$ , $\theta_y$ ,	$\pm 15$	$\pm 15$	°
*Travel range $\theta_z$	$\pm 30$	$\pm 30$	°
Actuator drive	DC-motor	DC-motor	
Actuator stroke	$\pm 25$	$\pm 25$	mm
Integrated sensor	Rotary encoder	Rotary encoder	
Sensor resolution	2048	2048	
Actuator design resolution	0.5	0.017	$\mu\text{m}$
**Min. incremental motion X, Y	3	1	$\mu\text{m}$
**Min. incremental motion Z	1	0.5	$\mu\text{m}$
**Min. incremental motion $\theta_x$ , $\theta_y$ , $\theta_z$	5	5	$\mu\text{rad}$
Repeatability X, Y	$\pm 2$	$\pm 2$	$\mu\text{m}$
Repeatability Z	$\pm 1$	$\pm 1$	$\mu\text{m}$
Repeatability $\theta_x$ , $\theta_y$ , $\theta_z$	$\pm 20$	$\pm 20$	$\mu\text{rad}$
Max. velocity X, Y, Z	50	2.5	mm/s
Max. velocity $\theta_x$ , $\theta_y$ , $\theta_z$	600	30	mrad/s
Typ. velocity X, Y, Z	30	2	mm/s
Typ. velocity $\theta_x$ , $\theta_y$ , $\theta_z$	300	20	mrad/s
<b>Mechanical properties</b>			
Max. load	10 / 3	10 / 3	kg
(baseplate horizontal/any orientation)			
Max. holding force	15 / 5	100 / 25	N
(baseplate horizontal/any orientation)			
Resonant frequency*** $F_x$ , $F_y$	100	100	Hz
Resonant frequency*** $F_z$	300	300	Hz
<b>Miscellaneous</b>			
Operating temperature range	-10 to +50	-10 to +50	°C
Material	Aluminum	Aluminum	
Mass	12	12	kg
<b>Controller</b>			
Delivered controller	M-850.502	M-850.502	
Operating voltage	100-240 VAC, 50/60 Hz	100-240 VAC, 50/60 Hz	

Technical data are specified at 20  $\pm$  3 °C. Data for vacuum versions may differ.

\*The max. travel of the several coordinates (X, Y, Z,  $\theta_x$ ,  $\theta_y$ ,  $\theta_z$ ) 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.

\*\*\*Baseplate mounted horizontally without load

Linear Actuators & Motors

Nanopositioning / Piezoelectrics

Nanometrology

Micropositioning

Hexapod 6-Axis Systems / Parallel Kinematics

Linear Stages

Translation (X)

Vertical (Y)

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Hybrid

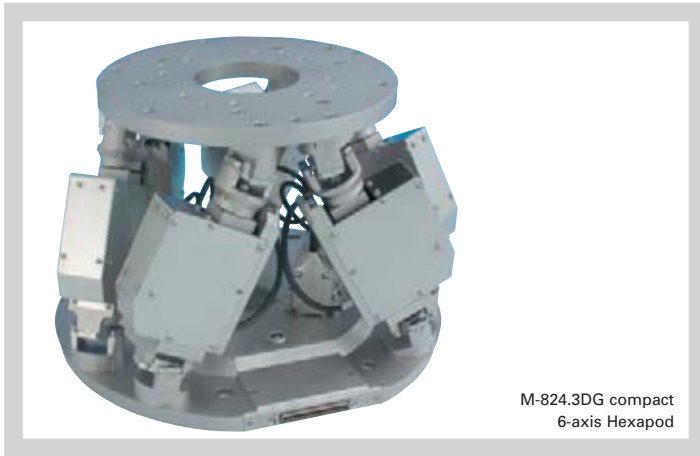
Multi-Channel

Micropositioning Fundamentals

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# M-824 Compact 6-Axis-Positioning System

## Precision Parallel-Kinematics Micropositioner with Controller, Vacuum Versions



M-824.3DG compact  
6-axis Hexapod

- **Extremely Compact**
- **Travel Ranges to 45 mm (linear), 25° (rotation)**
- **Load Capacity to 10 kg, Self Locking Version**
- **Resolution to 7 nm**
- **Min. Incremental Motion to 300 nm**
- **Repeatability  $\pm 0.5 \mu\text{m}$**
- **Velocity to 25 mm/sec**
- **Vacuum-Compatible Versions Available**

The M-824 is the ideal micro-positioning system for all complex positioning tasks which depend on high speed and accuracy in six independent axes. In addition to positioning all axes, it allows the user to define a center of rotation (pivot point) anywhere inside or outside the system envelope by one simple software command.

### Application Examples

- **Biotechnology**
- **Semiconductor technology**
- **Micromachining**
- **Micromanipulation**
- **X-ray diffraction measurements**
- **Tool control**

### Extremely Compact, Two Motor Versions

The M-824 uses a very compact drive with motor and spindle mounted side-by-side and, with a height of 188 mm, has a considerably lower profile than either the M-850, page 4-6, or M-840, page 4-8 Hexapods. Two versions featuring different drives are offered: the self-locking M-824.3DG with DC motor and gearhead can position loads of up to 5 kg in any orientation (10 kg with baseplate horizontal) with sub-micron precision. The M-824.3PD with integrated ActiveDrive™ system provides a significantly higher velocity of up to 25 mm/sec with loads up to 5 kg.

### Hexapod vs. Serial Kinematics Systems

The Hexapod is driven by six high-resolution actuators all

connected directly to the same moving platform. This design provides a high system stiffness and a large clear aperture.

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, and the friction and inertia of moving cables all accumulate to limit accuracy and repeatability—problems which do not affect parallel kinematic systems like the Hexapod.

### Fixed Virtual 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 by

### Ordering Information

**M-824.3PD**  
Compact Hexapod Microrobot with Controller, Direct Drive

**M-824.3DG**  
Compact Hexapod Microrobot with Controller, DC Motor Gearhead

**M-824.3VP**  
Compact Hexapod Microrobot with Controller, Direct Drive, Vacuum Compatible to  $10^{-6}$  hPa

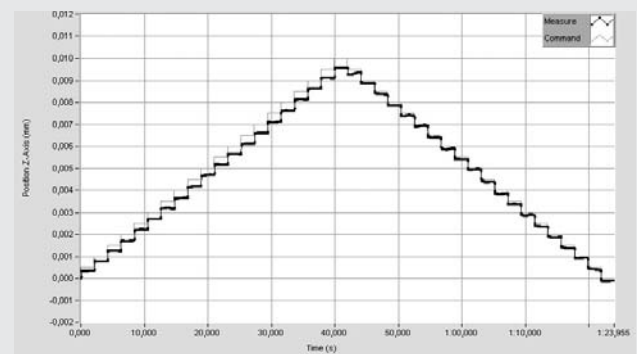
**M-824.3VG**  
Compact Hexapod Microrobot with Controller, DC Motor Gearhead, Vacuum Compatible to  $10^{-6}$  hPa

software command. The pivot point remains fixed relative to the platform.

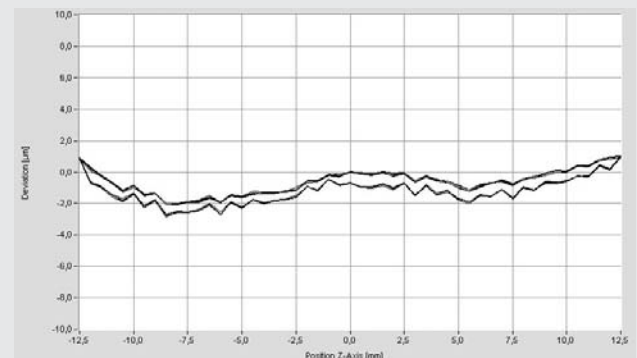
Target positions in 6-space are entered in user-friendly coordinates and reached by smooth vectorized motion.

### Open Architecture

Control of the hexapod is facilitated by the controller's open



Interferometer tests show the high repeatability, here with 500 nm steps



The interferometer test shows the Z axis accuracy over the entire travel range of 25 mm and the extremely high repeatability of  $\pm 0.046 \mu\text{m}$

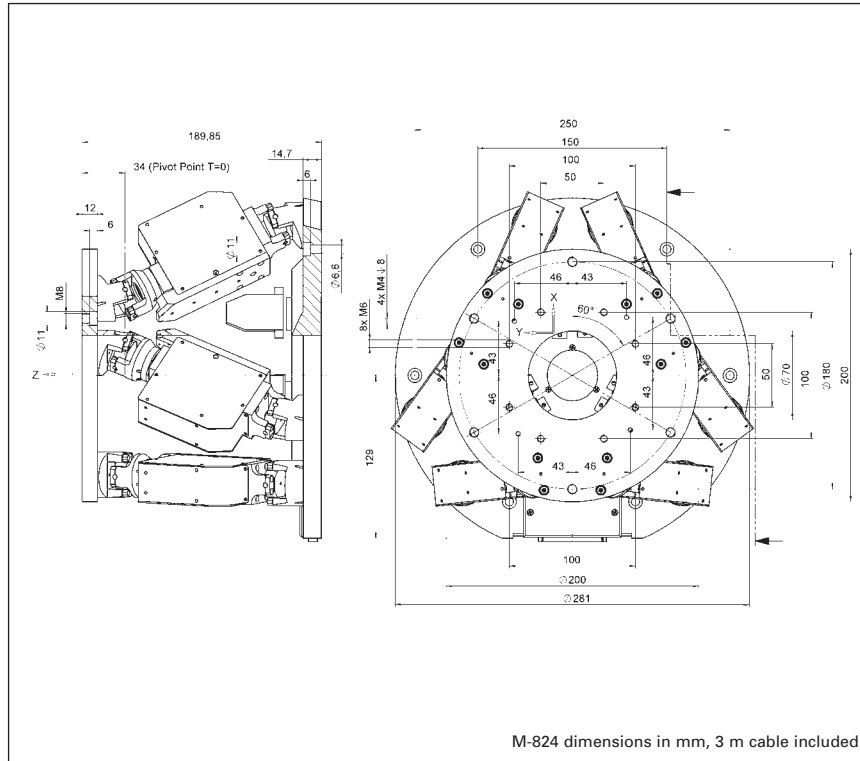
interface architecture, which provides a variety of high-level commands and includes a macro language for programming and storing command sequences.

### Vacuum Versions

Both models are available as vacuum versions that enable use in applications such as X-ray diffraction microscopy with ambient pressures down to  $10^{-6}$  hPa.



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



M-824 dimensions in mm, 3 m cable included

### Technical Data

Model	M-824.3DG	M-824.3PD	Units
Active axes	X, Y, Z, $\theta_x$ , $\theta_y$ , $\theta_z$	X, Y, Z, $\theta_x$ , $\theta_y$ , $\theta_z$	
<b>Motion and positioning</b>			
*Travel range X, Y	$\pm 22.5$	$\pm 22.5$	mm
*Travel range Z	$\pm 12.5$	$\pm 12.5$	mm
*Travel range $\theta_x$ , $\theta_y$	$\pm 7.5$	$\pm 7.5$	°
*Travel range $\theta_z$	$\pm 12.5$	$\pm 12.5$	°
Single-actuator drive	DC-motor, gearhead	ActiveDrive™ DC Motor	
Actuator stroke	$\pm 12.5$	$\pm 12.5$	mm
Single-actuator design resolution	0.007	0.5	$\mu\text{m}$
Integrated sensor	Rotary encoder	Rotary encoder	
Sensor resolution	2048	2048	cts./rev.
**Min. incremental motion X, Y, Z	0.3	1	$\mu\text{m}$
**Min. incremental motion $\theta_x$ , $\theta_y$ , $\theta_z$	3.5	12	$\mu\text{rad}$
Repeatability X, Y, Z	$\pm 0.5$	$\pm 0.5$	$\mu\text{m}$
Repeatability $\theta_x$ , $\theta_y$ , $\theta_z$	$\pm 6$	$\pm 6$	$\mu\text{rad}$
Max. velocity X, Y, Z	1	25	mm/s
Max. velocity $\theta_x$ , $\theta_y$ , $\theta_z$	11	270	mrad/s
Typ. velocity X, Y, Z	0.5	10	mm/s
Typ. velocity $\theta_x$ , $\theta_y$ , $\theta_z$	5.5	55	mrad/s
<b>Mechanical properties</b>			
*Stiffness X, Y	1.7	1.7	N/ $\mu\text{m}$
Stiffness Z	7	7	N/ $\mu\text{m}$
Load capacity (baseplate horizontal/any orientation)	10/5***	5/2.5	kg
<b>Miscellaneous</b>			
Operating temperature range	-10 to +50	-10 to +50	°C
Material	Aluminum	Aluminum	
Mass	8	8	kg
<b>Controller</b>			
Controller included	M-850.502	M-850.502	
Operating voltage	100–240 VAC, 50/60 Hz	100–240 VAC, 50/60 Hz	

\*The travel ranges of the individual coordinates (X, Y, Z,  $\theta_x$ ,  $\theta_y$ ,  $\theta_z$ ) 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

\*\*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

\*\*\*Self Locking

Technical data are specified at  $20 \pm 3$  °C. Data for vacuum versions may differ.

Linear Actuators & Motors

Nanopositioning / Piezoelectrics

Nanometrology

Micropositioning

Hexapod 6-Axis Systems / Parallel Kinematics

Linear Stages

Translation (X)

Vertical (Y)

Multi-Axis

Rotary & Tilt Stages

Accessories

Servo & Stepper Motor Controllers

Single-Channel

Hybrid

Multi-Channel

Micropositioning Fundamentals

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# F-206.S HexAlign™ 6 Axis-Hexapod

## Parallel-Kinematics Precision Alignment System / Manipulator, with Controller



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

- **Parallel Kinematics with 6 Degrees of Freedom**
- **0.033  $\mu\text{m}$  Actuator Resolution**
- **Repeatability 0.3  $\mu\text{m}$  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 micro-positioning system for complex multi-axis alignment tasks. It is based on PI's long experience with ultra-high-res-

olution, 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, improving 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 com-

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

**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.VVU**  
2-Channel Photometer Card, (Visual Range)

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

**F-361.10**  
Absolute-Measuring Optical Power Meter, 1000-1600 nm Wavelength

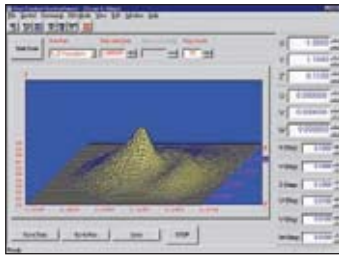
**Additional Accessories, see [www.pi.ws](http://www.pi.ws).**

mand 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.

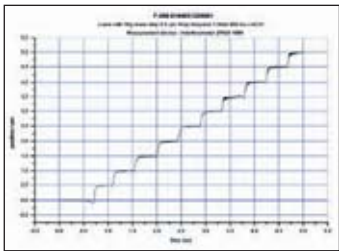
### Automatic Optical Alignment

Optional internal and external photometers are available.

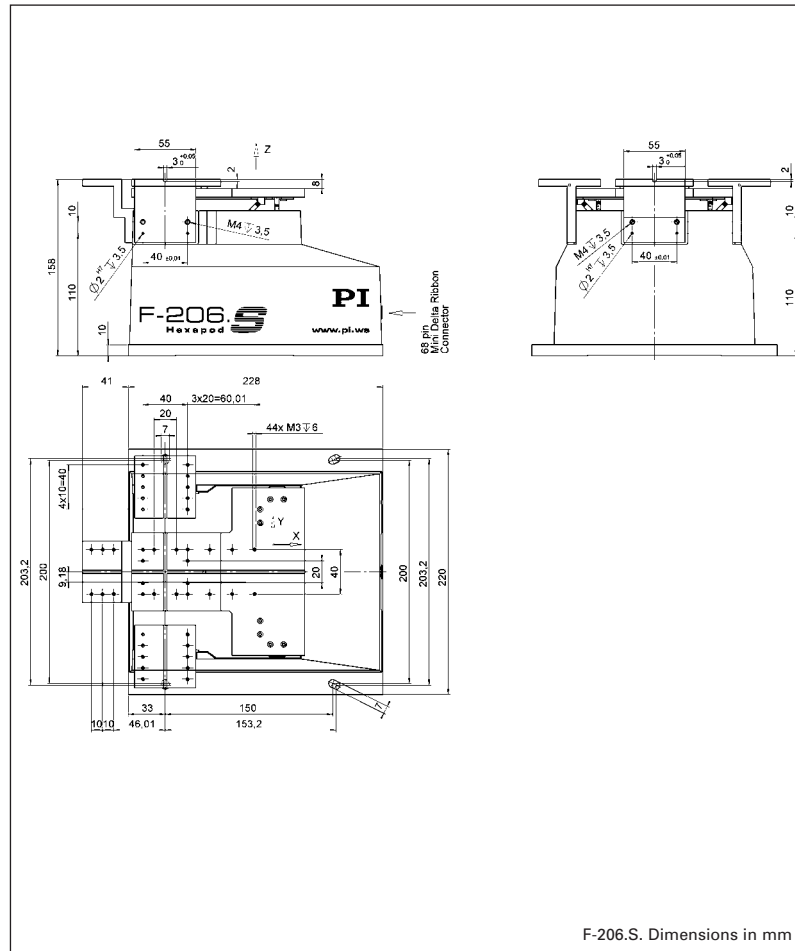
Both types are fully integrated with the controller hardware and with routines designed for automatic alignment of collimators, optical fibers and arrays. For more information on the photometers see [www.pi.ws](http://www.pi.ws).



HexControl™ Software displaying scan of photonic component



Interferometer test of an F-206.S system shows the excellent repeatability of small steps, here 0.5  $\mu\text{m}$  spaced at 100 ms



Linear Actuators & Motors

Nanopositioning / Piezoelectrics

Nanometrology

**Micropositioning**

**Hexapod 6-Axis Systems / Parallel Kinematics**

Linear Stages

Translation (X)

Vertical (Y)

Multi-Axis

Rotary & Tilt Stages

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## Technical Data

Model	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 $\theta_x$ *	±5.7°
Travel range $\theta_y$ *	±6.6°
Travel range $\theta_z$ *	±5.5°
Actuator resolution	33 nm
Minimum incremental motion X, Y, Z**	0.1 $\mu\text{m}$ (6-axis move!)
Minimum incremental motion $\theta_x$ , $\theta_y$ , $\theta_z$ **	2 $\mu\text{rad}$ (0.400115°) (6-axis move!)
Bidirectional repeatability X, Y, Z	0.3 $\mu\text{m}$
Bidirectional repeatability $\theta_x$ , $\theta_y$ , $\theta_z$	3.6 $\mu\text{rad}$
Speed X, Y, Z	0.01 to 10 mm/s
Maximum load in Z	2 kg (centered on platform)
Mass	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  $\theta_x$ ,  $\theta_y$ ,  $\theta_z$ ) 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-850K Vacuum Hexapod 6-Axis Positioner

### Parallel-Kinematics System for Wide Temperature Ranges

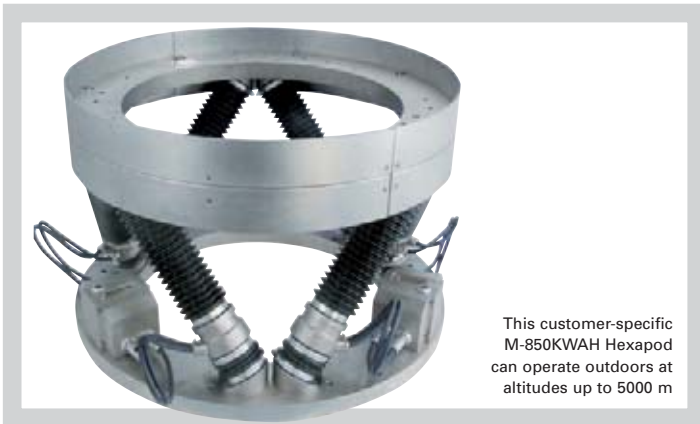


- 6 Degrees of Freedom, Works in Any Orientation
- Vacuum Compatible up to  $10^{-6}$  hPa
- 200 kg Load Capacity (Vertical)
- Repeatability to  $\pm 1 \mu\text{m}$
- Encoder Resolution to 5 nm

Model	Operating temperature range	Storage temperature	Travel ranges	Dimensions
M-850KTVH Vacuum Hexapod	-10 bis +25 °C	-20 bis +40 °C	$\pm 50$ mm (X,Y), $\pm 25$ mm (Z), $\pm 15^\circ$ ( $\theta_x, \theta_y$ ), $\pm 30^\circ$ ( $\theta_z$ )	$\varnothing$ 350 mm 330 mm height

## M-850K Weatherproof Hexapod

### Ultra-High-Precision Hexapod for Outdoor Operation



- Load Capacity to 750 N
- Unidirectional Repeatability to  $5 \mu\text{m}$
- Clear Aperture  $\varnothing$  420 mm
- Long Lifetime: 2 Million Cycles
- Drive: Brushless Motors
- Correspond to protection class IP 64
- Corrosion Protection

Model	Travel Range X / Y / Z	Max. load capacity	Mass	Dimensions
M-850KWAH Weatherproof Hexapod	$\pm 10 / \pm 11 / \pm 16$ mm	750 N	46 kg	Outer $\varnothing$ 580 mm height 357 mm

## M-810 Miniature Hexapod

### High Precision in a Small Package

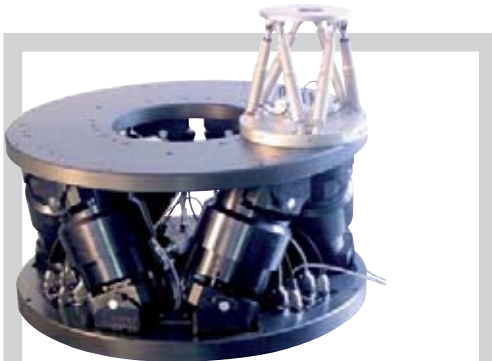


- Most-Compact Hexapod in the PI Portfolio
- Travel Range  $40 \times 40 \times 13$  mm
- Resolution of a Single Strut  $< 100$  nm
- Integrated Driver Electronics

Model	Load capacity	Travel range X / Y / Z	Travel range $\theta_x / \theta_y / \theta_z$	Max. velocity	Dimensions
M-810.00	5 kg	$\pm 20$ mm $\pm 20$ mm $\pm 6,5$ mm	$\pm 11^\circ$ $\pm 11^\circ$ $\pm 30^\circ$	10 mm/s	Outer $\varnothing$ 100 mm height 118 mm

## M-850K Ultra-High-Load Hexapod

### Precise Hexapod for Ultra-High Loads up to 1 Ton



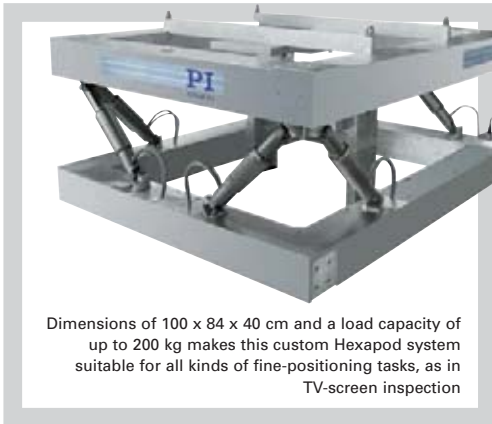
The vacuum compatible Hexapod M-850KHLH provides six degrees of freedom for loads up to 1 t, here with a standard M-840 hexapod for size comparison

- Six Degrees of Freedom
- Max. Load Capacity to 1000 kg
- Repeatability to 2  $\mu\text{m}$
- Drive: Brushless Motors with Brake
- Vacuum Compatible up to  $10^{-6}$  hPa

Model	Travel range X / Y / Z	Rotation range $\Theta_x, \Theta_y, \Theta_z$	Max. velocity X/Y/Z	Dimensions
M-850KHLH	$\pm 12$ mm	$\pm 3^\circ / \pm 3^\circ / \pm 4^\circ$	0.5 mm/s	$\varnothing$ outside 1 m height 0.5 m

## M-850K Large-Aperture High-Load Hexapod

### 6-Axis Precision Positioning & Alignment System for Inspection Systems



Dimensions of 100 x 84 x 40 cm and a load capacity of up to 200 kg makes this custom Hexapod system suitable for all kinds of fine-positioning tasks, as in TV-screen inspection

- 200 kg Load Capacity (Vertical)
- Very Large Aperture (640 x 820 mm)
- Six Degrees of Freedom
- No Moving Cables for Improved Reliability and Precision
- Parallel-Kinematics Design—Significantly Smaller and Stiffer than Serial-Kinematics Systems, Better Dynamics
- Virtual Pivot Point
- Sophisticated Controller Using Vector Algorithms Included

Model	Max. load base-plate horizontal optional)	Travel range X / Z / Z	Travel range $\Theta_x, \Theta_y, \Theta_z$	Typ. velocity	Dimensions
M-850KLAH Large Hexapod	200 / 50 kg	$\pm 25$ mm	$\pm 5^\circ$	2 mm/s lin. 25 mrad/s rot.	100 x 84 x 40 cm

## M-850K Ultra-High Load Hexapod

### 6-Axes, Long Travel, Micron Precision, 1 Ton in Any Orientation



This custom parallel-kinematics system positions loads up to one ton in any orientation with micron accuracy

- Load Capacity to 1000 kg in Any Orientation
- Six Degrees of Freedom
- Travel Ranges to  $\pm 200$  mm, to  $\pm 20^\circ$
- Resolution to 0.8  $\mu\text{m}$ , to 0.5  $\mu\text{rad}$
- Drive: Brushless Motors with Brake
- Sophisticated Controller Using Vector Algorithms

Model	Travel ranges	Push/pull force	Max. velocity	Unidirectional Repeatability	Dimensions
M-850KHTH High-Load Hexapod with Long Travel Range	$\pm 200$ mm (X, Y), $\pm 100$ mm (Z) $\pm 20^\circ$ ( $\Theta_x, \Theta_y$ ), $\pm 5^\circ$ ( $\Theta_z$ )	10,000 N	1 mm/s	$\pm 1$ $\mu\text{m}$ ; $\pm 3$ $\mu\text{rad}$	Baseplate: 900 mm $\varnothing$ Upper platform: 800 mm $\varnothing$ height 714 mm aperture: $\varnothing$ 500 mm

Linear Actuators &amp; Motors

Nanopositioning / Piezoelectrics

Nanometrology

Micropositioning

Hexapod 6-Axis Systems / Parallel Kinematics

Linear Stages

Translation (X)

Vertical (Y)

Multi-Axis

Rotary &amp; Tilt Stages

Accessories

Servo &amp; Stepper Motor Controllers

Single-Channel

Hybrid

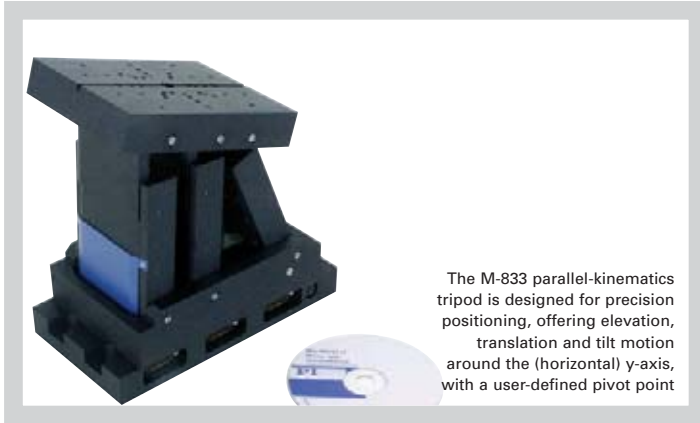
Multi-Channel

Micropositioning Fundamentals

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# M-833 Parallel Kinematic Tripod / Goniometer

## Precision Positioning in X, Z, $\theta_y$



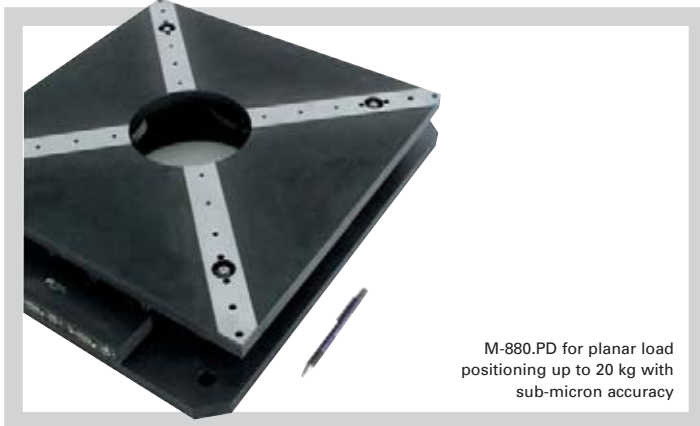
The M-833 parallel-kinematics tripod is designed for precision positioning, offering elevation, translation and tilt motion around the (horizontal) y-axis, with a user-defined pivot point

- Goniometer Z Stage with Freely Selectable Pivot Point
- Travel Ranges  $\pm 25$  mm /  $\pm 25$  mm /  $\pm 30^\circ$
- Load Capacity to 4 kg
- Min. Incremental Motion to 0.1  $\mu\text{m}$
- ActiveDrive™ Servo Motors
- Compact Design with Parallel Kinematics

Model	Travel ranges	Max. velocity	Stiffness	Dimensions
M-833.00 Tripod	$\pm 25$ mm (X, Z),	10 mm/s	50 N/ $\mu\text{m}$	223,2 x 110 x 192 mm
Goniometer-Stage	$\pm 30^\circ$ ( $\theta_y$ )	(linear)		

# M-880 3-Axis Planar Precision Positioning System

## XY-Rot-Z Parallel Kinematics System with Very High Holding Force



M-880.PD for planar load positioning up to 20 kg with sub-micron accuracy

- Travel Ranges 20 x 20 mm / 8°
- Static Load Capacity to 150 kg
- ActiveDrive™ Servo Motors
- Low Profile through Parallel Kinematics
- Min. Incremental Motion to 0.75  $\mu\text{m}$
- Large Clear Aperture
- Sophisticated Controller Included

Model	Active Axes	Travel range	Max. velocity	Stiffness (linear axes)	Dynamic load capacity	Static load capacity
M-880.PD	X, Y, $\theta_z$	$\pm 10$ mm, $\pm 4^\circ$	20 mm/s	5 N/ $\mu\text{m}$	200 N	1500 N

# Notes on Specifications for Micropositioning Stages

## Active axes

Specifications given in the data sheet are measured in relation to the defined motion axis. A different motor orientation may result in modified data.

## Motion and positioning

### Travel range

The maximum allowed travel is limited by the length of the drive screw in a spindle/motor combination. Given in the data sheet is the distance between the two limit switches, if present.

### Integrated sensor

Rotary or linear encoder

### Encoder resolution

*Rotary encoder:* counts per drive-screw revolution

*Linear encoder:* interpolated minimum increment that can be distinguished

### Design resolution

The theoretical minimum movement that can be made, based on the selection of the mechanical drive components (drive screw pitch, gear ratio, angular motor resolution etc.). Design resolution is usually better than the practical position resolution (minimum incremental motion). For linear encoders, the design describes the resolution of the of the position feedback sensor system.

### Minimum incremental motion

The minimum motion that can be repeatably executed for a given input, which is sometimes referred to as practical or operational resolution. Design resolution and practical resolu-

tion have to be distinguished. Design resolutions of 1 nm or better can be achieved with many motor, gearbox and lead-screw combinations. In practical applications, however, stiction/friction, windup, and elastic deformation limit operating resolution. Several PI motorized micropositioners are available with additional piezo fine positioners for applications where repeatable nanometer scale resolution and / or fast response are required. The data table states typical measured values.

For repeatable nanometer or sub-nanometer resolution see the "Piezo Flexure Stages / High-Speed Scanning Systems" (p. 2-3 ff) and "Piezo Actuators & Components" (p. 1-61 ff) sections.

### Backlash

Position error that appears upon reversing direction due to error in the drivetrain. See page 4-128 ff for details. The data table states typical measured values.

### Rotation / linear input, tangent-arm length

Angular displacement of tangent-arm rotation stages is determined by the arm length and the linear motion input pushing the arm (see p. 4-82) for information on how to calculate angular displacement from linear input).

### Unidirectional / bidirectional repeatability

Values are typical results (RMS, 1 sigma), see also Glossary

### Pitch / yaw

The maximum angular deviation around Y- (pitch) and Z-axis (yaw) over the whole travel range, with X being the direction of motion. Pitch and yaw are usually given as  $\pm$  values. The data table states typical measured values. See "Definition of Axes and Angles" (see p-128 ff).

### Max. velocity

This is the short-term peak value for horizontal mounting, with no load, and not intended for continuous operation. The average velocity and continuous velocity are lower than the peak value and depend on the load conditions and other environmental parameters.

### Origin repeatability

Repeatability of the reference switch (if present)

Linear Actuators & Motors

Nanopositioning / Piezoelectrics

Nanometrology

Micropositioning

Hexapod 6-Axis Systems / Parallel Kinematics

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## Mechanical properties Drive properties

### Motor resolution

Resolution with micro-stepping specified for PI's stepper motor controllers.

### Stiffness in motion direction

Typical tolerance:  $\pm 20\%$

### Max. normal load capacity

Centered, vertical load (horizontal installation).

### Max. push / pull force

Active and passive force limit in operating direction, at center of stage. Some stages may be able to generate higher forces at the cost of reduced lifetime.

### Drive type / Operating voltage

*ActiveDrive™*: The operating voltage (usually 24 VDC) for the ActiveDrive™ motors is provided by an external power supply (included in the delivery).

*DC motors*: DC servo motors require a supply voltage of up to 12 VDC. The operating voltage is usually given as differential value where the magnitude determines the velocity, and the sign determines the motion direction.

*Stepper motors*: PI stepper motors are usually driven in chopper mode.

### Electrical power

Motor manufacturer's information.

### Torque

Motor manufacturer's information.

## Miscellaneous

### Operating temperature range

Safe operation, no damage to the mechanics. All technical data specified in the data sheet refer to room temperature ( $22\text{ °C} \pm 3\text{ °C}$ ).

### Material

Micropositioning stages are typically made of anodized aluminum or stainless steel. Small amounts of other materials may be used (for bearings, preload, coupling, mounting, etc.). For special applications other materials are possible like Invar.

Al: Aluminum

N-S: Nonmagnetic stainless steel

St: Steel

I: Invar

### Mass

Typical tolerance:  $\pm 5\%$

### Cable length

Typical tolerance:  $\pm 10\text{ mm}$

### Recommended motor controller

Compatible motor controllers are described in the "Servo & Stepper Motor Controllers" (p. 4-109 ff) section

For further information read "Micropositioning Fundamentals" section (p. 4-127 ff).

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