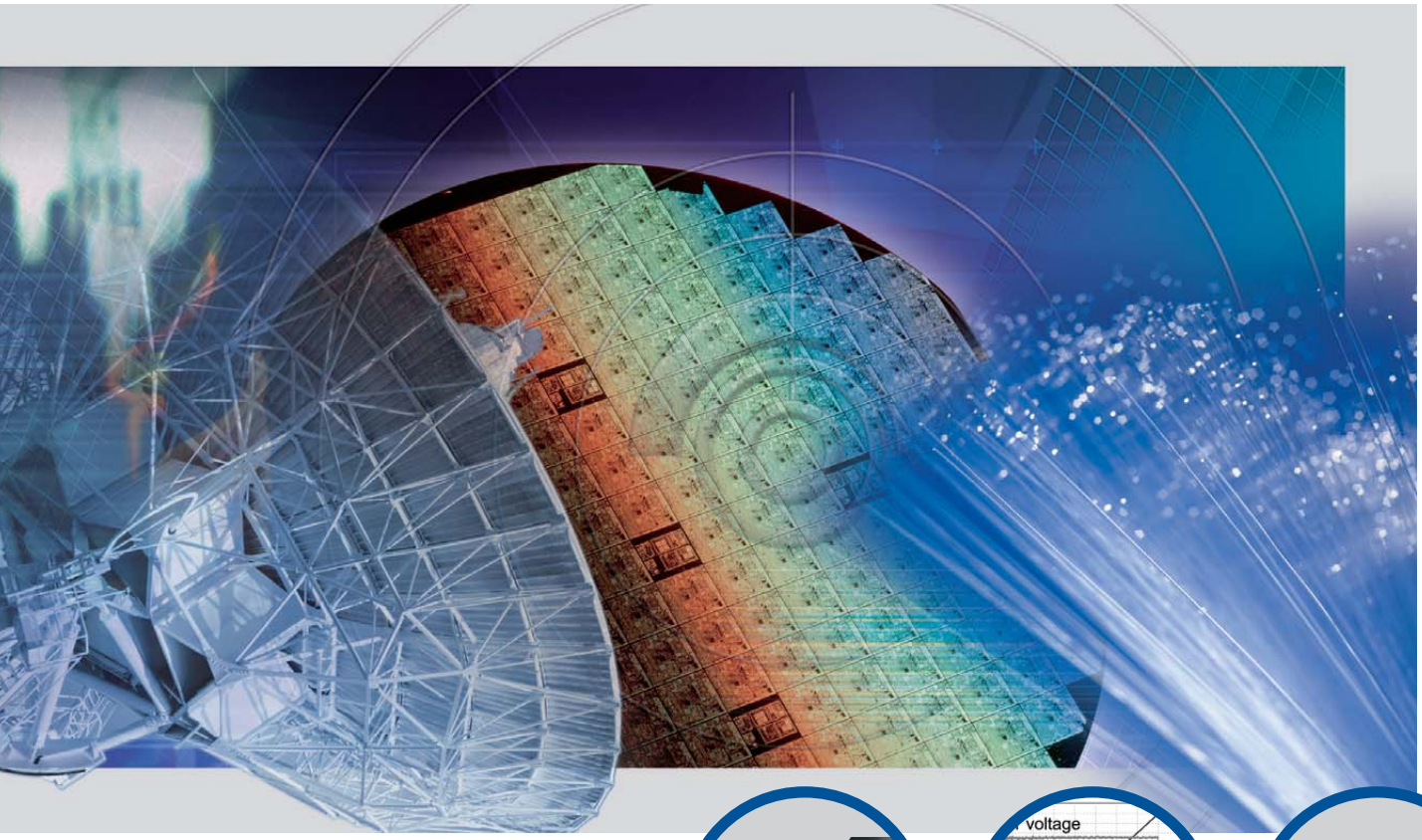
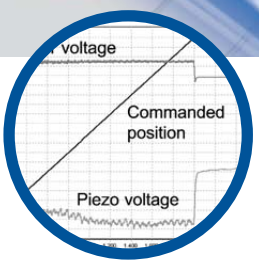
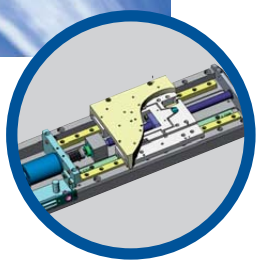
Piezo · Nano · Positioning

Millimeters of Travel / Nanometer Resolution

Hybrid Nanopositioning Linear Slides by PI

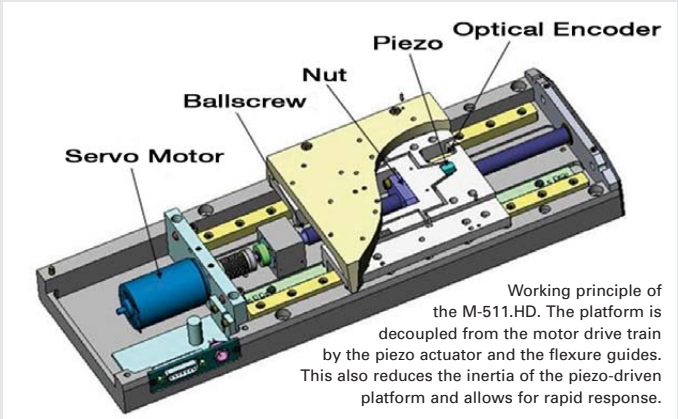






Hybrid Nanopositioning Technology by PI

Long Travel Ranges with Nanometer Precision



Working principle of the M-511.HD. The platform is decoupled from the motor drive train by the piezo actuator and the flexure guides. This also reduces the inertia of the piezo-driven platform and allows for rapid response.

- **Active Compensation of Stick/Slip During Startup and Settling**
- **Active Backlash Compensation**
- **Excellent Velocity Control**
- **Millisecond Settling to Nanometer Accuracy**
- **Reliable Execution of Minimal Increments**
- **High Drive and Holding Forces with Minimal Power**

The direct integration of piezo actuators in micropositioning stages allows combining travel ranges of hundreds of millimeters with resolutions in the nanometer range. Servo-control of the system employs a single high-resolution position feedback sensor (parallel metrology) which means that the high resolution can be used over the entire travel range. This makes hybrid systems ideal for applications where the position of an incident needs to be read and refound precisely, or where an externally specified target position needs to be hit within few a nanometers, such as in surface inspection or metrology. The challenge of implementing hybrid technology is not only the mechanical design of the positioning stage, but also the use of high-resolution sensors over large travel ranges, the processing of the resulting high-frequency signals and the design of special control algorithms to take full advantage of the hybrid design.

Integrated Servo-Control Spans Both Drives

The basic idea of combining classical motorized micropositioners with high-resolution piezo actuators is not new. For example, PI offers a fiber-scanning and coupling system comprising a 6-DoF micropositioner (F-206) mounted beside a multi-axis piezo system (P-611 Nanocube®) with high position resolution.

The servo-control algorithms with stacked systems like these generally operate independently, with the piezo system only becoming activated after the motorized positioner has come to a complete stop. Because separate position sensors are used the absolute accuracy (not the resolution) is limited by the precision of the motorized long-range positioner.

The new PI hybrid systems use a single high-resolution encoder and a controller that can actuate both drives at the same time. Thus every move benefits from the specific advantages of both the motorized actuator and the piezo actuator from startup to settling.

On the mechanical side, this is accomplished by decoupling the motion platform of the hybrid positioning stage from the micropositioner's motor-ballscrew-drive by frictionless flexures and stiff, fast response piezo actuators.

The controller continuously compares the actual platform position (by reading the integrated linear encoder) with a calculated, smooth trajectory. The piezo actuators actively compensate out the irregularities in the motion of the platform caused by the motorized drive train.

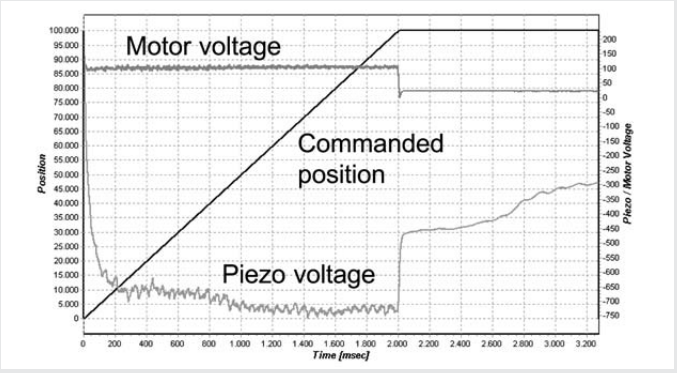
Absolute Accuracy

The servo-control loops for both the motorized and the piezo drive use the same position sensor. The result is a motion system with hundreds of millimeters travel but with the precision of a piezo-based nanopositioner. The resolution and the positioning accuracy depend on the choice of the feedback sensor. PI hybrid systems currently use optical linear encoders with a resolution of 2 nm. Depending on the stage, a minimum incremental motion or a repeatability of 4 nm can be achieved over the entire travel range.

One Controller for One Motion System

In PI hybrid systems, the motor-leadscrew and piezo actuator are fully integrated to form one motion system. The motor and piezo act together at all times. The result is far more than a coarse-adjust/fine-adjust system: effects like startup stick/slip and backlash can be completely compensated and a motion profile with high constancy of velocity can be followed. Because of the high piezo stiffness, setting to a few nanometers only takes a few milliseconds, significantly faster than with conventional, higher-inertia, linear-motor-driven stages. Furthermore minimal increments in the range of the sensor resolution can be reliably executed.

To allow high velocities beyond 100 mm/sec and nanometer-range incremental resolution, position information must be transmitted and processed very rapidly and a complex control algorithm is required. PI's C-702 is a controller providing PWM signal generators, piezo amplifiers and control algorithms specially tailored for hybrid systems.



PI hybrid servo-controller output during a positioning command. The controller reads the system position off a high-resolution encoder and actuates both the motor and piezoelectric actuator at the same time giving a system with the advantages of both drives.

M-511.HD, M-714, C-702

Nanopositioning Systems with Hybrid Drive, Hybrid Controller

M-511.HD hybrid stage (left), M-714.00 (right front) and the C-702 controller (rear).

- **Long Travel Ranges with Nanometer Resolution**
- **Travel Range: to 100 mm Translation/7 mm Elevation**
- **Resolution to 2 nm**
- **Velocity to 125 mm/s**
- **Linear Encoder for Highest Precision**
- **Backlash-Free Precision Ballscrew under Frictionless Piezo Drive**

C-702 Controller—Key to Hybrid Technology

The optimized interaction between the piezoelectric and motorized drive components to make them a single motion unit requires a high-speed sensor as well as powerful control algorithms. The digital, 2-channel, C-702 controller, based on modern CPU technology with a real time operating system, has been designed for this task. It is able to read the position signals with virtually no delay and process the data immediately. The integrated piezo amplifiers use a high-resolution 24-bit DAC to fully support the high position resolution of the piezo actuators. The new ultra-fast broadband SSI interface for the optical linear encoder supports stage velocities of 600 mm/s at a resolution of 1 nm. With custom firmware, one of the sensor interfaces can be reprogrammed for use as a high-speed command interface capable of processing commands at the servo rate.

Application Examples

- Surface inspection
- Microscopy
- Laser technology
- Interferometry
- Metrology

M-714 Heavy-Duty Nanopositioning System

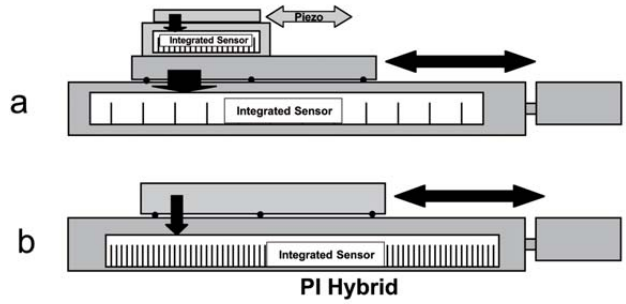
The M-714 was designed from the ground up to use the hybrid drive technology. A high gear reduction ratio enables the M-714 to position loads up to 10 kg with nanometer precision, even in the vertical direction. Compared to high-resolution magnetic linear drives, the hybrid principle allows high holding forces with minimum power consumption, without counterbalancing the load. The angular deviation is less than ±10 µrad over the entire travel range of 7 mm. The high-performance drive components, including ballscrew, bearings, motor and gearhead are chosen for minimum mechanical play and friction.

M-511.HD Long-Travel, High-Speed Nanopositioning Systems

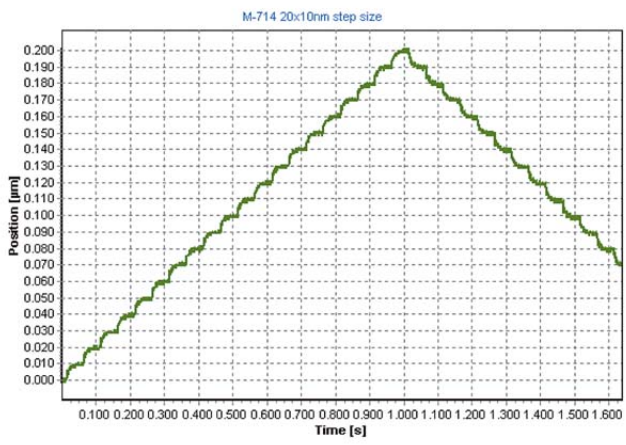
The M-511.HD is based on the proven design of the M-5x1 precision micropositioning stage series, with an integrated, flexure-guided, piezo actuator added. The M-511.HD allows velocities to 125 mm/s with an encoder resolution of 4 nm and load capacity of 50 kg for horizontal operation.

C-702 Highlights!

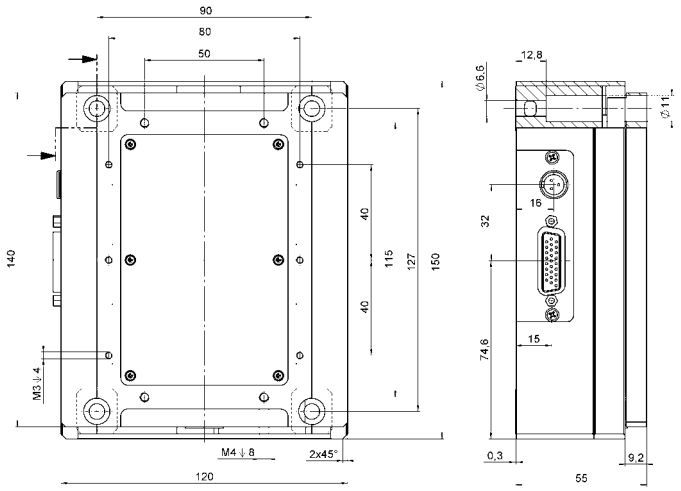
- Two channels
- 10 kHz Sampling Rate
- 24-Bit Piezo Motion Resolution (<1 picometer)
- High-Resolution Incremental Sensor with Serial Interface
- Real-Time Operating System
- Interfaces: VGA, Keyboard, Mouse, RS-232, TCP/IP Ethernet



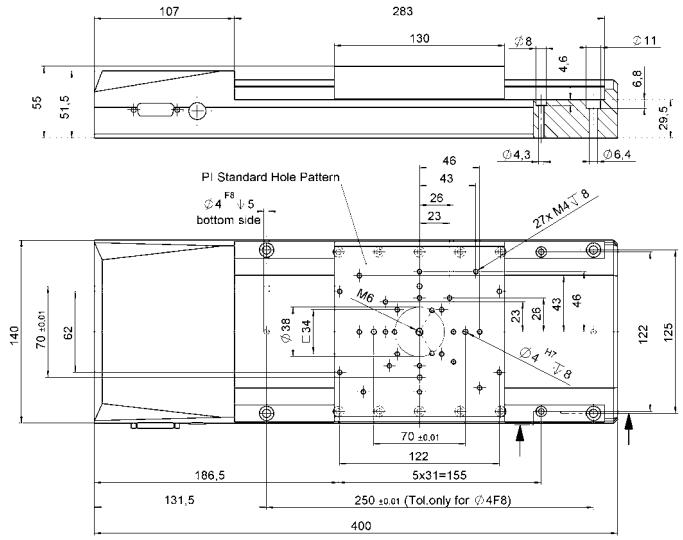
Different types of combined motorized and piezo positioning systems:
a) Serially stacked drives with individual integrated position sensors
b) PI Hybrid drive with integrated, internal, high-resolution sensor, for use with highly specialized controller.



10 nm steps of an M-714 stage, as measured by an interferometer.



Dimensions of the M-714 in mm.



Dimensions of the M-511.HD in mm.

Technical Data

Models	M-714.00	M-511.HD	Unit	Tolerance
Active Axes	X	X		
Motion and positioning				
Travel range	7	100	mm	
Integrated sensor	Linear encoder	Linear encoder		
Encoder resolution	0.002	0.004	µm	
Min. incremental motion	0.004	0.008	µm	typ.
Backlash	0.03	0.05	µm	typ.
Unidirectional repeatability	0.03	0.05	µm	typ.
Pitch	±10	±25	µrad	typ. over the entire travel range
Yaw	±10	±25	µrad	typ. over the entire travel range
Max. velocity	0.2	125	mm/s	
Mechanical properties				
Spindle pitch	1	2	mm/U	
Gear ratio	80:1	-		
Belt drive transmission ratio	3:1	-		
Load	200	200	N	max.
Push/Pull force	100/100	80/80	N	max.
Self inhibitance	100	50	N	min.
Lateral force	100	200	N	max.
Drive Properties				
Drive type	DC motor/gearbox ballscrew/piezo	DC motor/ ballscrew/piezo		
Operating voltage (motor/piezo)	24/45	24/45	V	
Electric power	4.5	30	W	nominal
Miscellaneous				
Material	Al	Al		
Mass	2.1	5.1	kg	±5 %
Cable length	3	3	m	±10 mm
Connector	D-Sub 26 (m)	D- Sub 26 (m)		
Recommended controller/driver	C-702	C-702		

Resolution does not equal to positioning accuracy

Resolution of a servo-system is the precision with which it can detect its motion. This is different from the precision with which a commanded motion can be executed. Closed-loop systems tend to be instable if they have high sensor resolution without being able to execute correspondingly small increments due to mechanical properties such as excessive play, friction, or elasticity. Because they are equipped with a highly stiff, frictionless piezo actuator, PI hybrid systems provide full move capability down to the sensor range. There is an excellent match between minimum incremental motion and sensor resolution.