Parallel-Kinematic 6D Alignment System with Sub-Micrometer Accuracy

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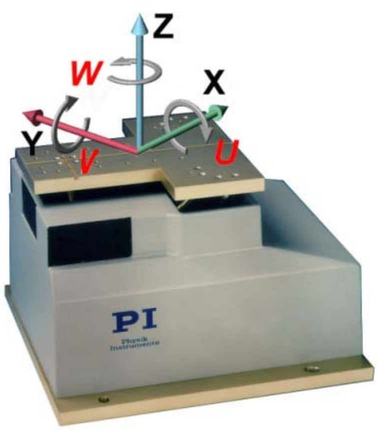
PI's hexapod parallel kinematic structures have been employed in ultra-precise positioning and alignment applications for a decade. Examples are precision alignment of satellite antennas, control of secondary mirrors (astronomical telescopes) and industrial handling and micromachining systems. Assembly and manufacture of micro optical devices (wave guides, laser chips) and micro mechanics such as MEMS (Micro Electro Mechanical Systems) require ultra-precise handling mechanisms with sub-micron resolution and motion in six degrees of freedom. For alignment purposes the motion should also be free of backlash.



Technical Data F-206:

Travel Range X,Y,Z:	12 mm
Tilting Angle U,V,W:	10 deg
Resolution:	0.1 µm
Dimensions:	230 x 220 x150 mm
Controller:	Special Multi-Axis Controller

Fig. 1. F-206 Six Axis Parallel Kinematics Micro-Alignment and -Positioning System

Two types of Hexapods designs are available today:

1 In the "classical" variable strut length design the distance between the top and bottom joint changes for each position change of the platform. This concept has been employed for many years, especially with hydraulic and pneumatic struts. The key to high accuracy are the joints which have to be stiff and free of backlash.

Fig. 2 a - 2 f. Different Variable Strut Length Hexapod 6-DoF Systems for Micro-Positioning and -Alignment

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2 The strut length is constant and the complete strut is moved for positioning.
This concept is relatively new and has a number of advantages over the "classical" variable strut length hexapod:

- The hexapod size can be minimized, because the strut/drive length does not determine the system height
- Small, lightweighted struts reduce the moved mass and improve the dynamic properties
- Separation of drives and struts simplifies exchange and reduces downtime during maintenance

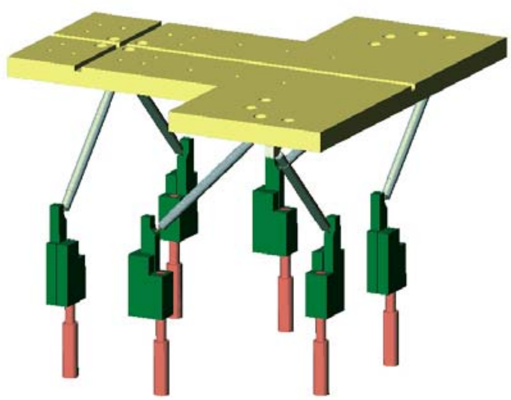

Fig. 3. Principle of a Constant Strut Length Six Axis MicroPositioning System

The system consists of six motors and linear drives (located in one plane) driving six struts attached to the top platform. The motor/drive units are folded for reduced height. Preloaded ultra-low friction nut/spindle assemblies provide high resolution and suppress backlash and hysteresis. The position of each drive is measured by a high resolution laser encoder attached to the spindle.

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Design of the Flexure Joints

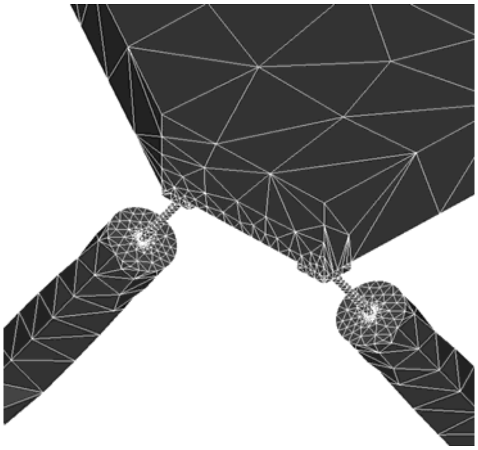


Fig. 4. FEM - Model of the strut/flexure design

As mentioned before, the constant length strut design minimizes system size and weight.

One of the key components is the zero stiction/friction flexure joint. These joints are made from wires of a high strength alloy providing extremely high stiffness and insensitivity to torsion and stress.

Working Space

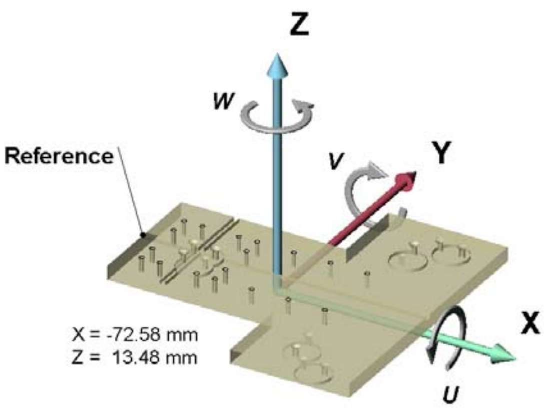
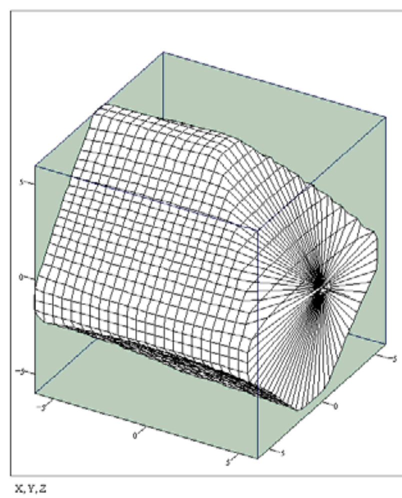
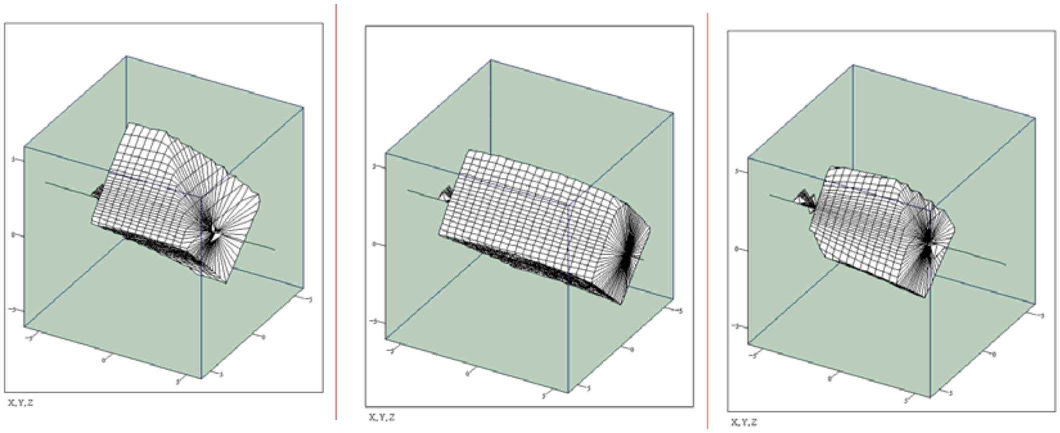


Fig. 5. Axis definition



U= V= W= 0



U = 4 deg V = 4deg W = 4deg

Fig. 6. Working Space for different platform angles

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Measurement results

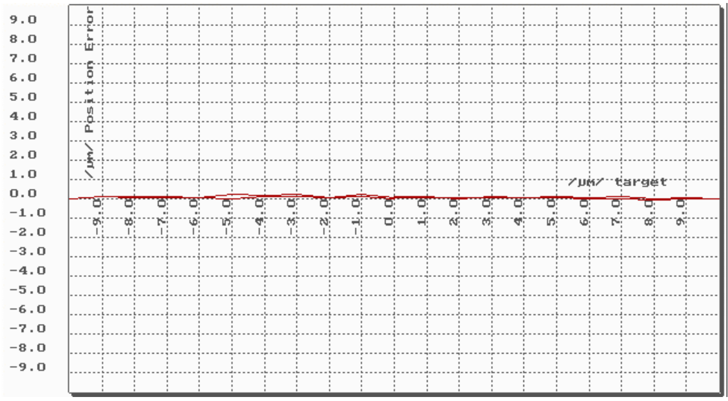

Fig. 5. F-206 Parallel Kinematics Micro-Manipulator: Measured linear positioning accuracy of the y- axis. The graph shows deviation from the target position for a forward/backward motion.
The absolute accuracy is better than 0.3µm.

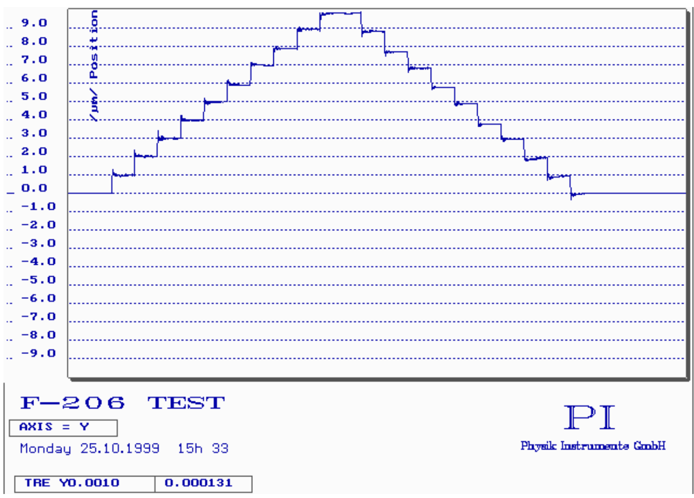

Fig. 7. F-206 Parallel Kinematics Micro-Manipulator: Forward/backward step accuracy for 20 consecutive 1 µm steps (y- axis)

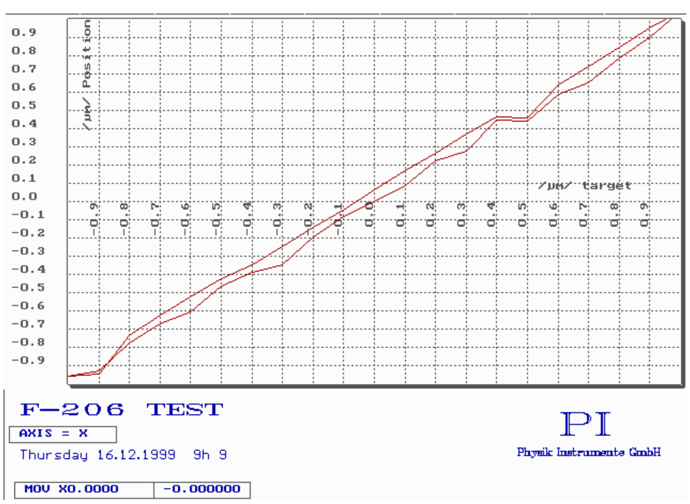

Fig. 8. F-206 Parallel Kinematics Micro-Manipulator: Resolution/repeatability for 0.1 µm steps (X-axis)

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Conclusion

Hexapod structures provide motion in six degrees of freedom with high stiffness, fast response and high resolution. The constant length strut design incorporating preloaded ultra-low friction, spindle/nut assemblies and zero stiction/friction flexure joints (instead of roller joints) is state-of-the-art for compact systems. It provides resolution of 0.1 µm and step response on the order of 10 ms and below.

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