

Hexapods in Mechanical Engineering

What can be accomplished with parallel kinematics?



Mechanical and plant engineering has always benefitted from innovations, i.e., from creative ideas and their economical implementation. Today this is more true than ever, because in many areas of automation technology precision requirements are on the increase, and an end to this development is nowhere in sight. This is why whenever multi-axis systems are needed, it is worth having a closer look at parallel kinematics. One example of this are Hexapods. The travel ranges of Hexapods go normally from a few to several hundred millimeters. Even major loads can be positioned accurately to the micrometer using Hexapods. Due to their capacity acquired recently to communicate directly with PLC or CNC controls via fieldbus interfaces, they open up interesting possibilities in mechanical engineering.

Basically, there are two methods of constructing multi-axis positioning systems: Serial kinematics and parallel kinematics (Fig. 1).

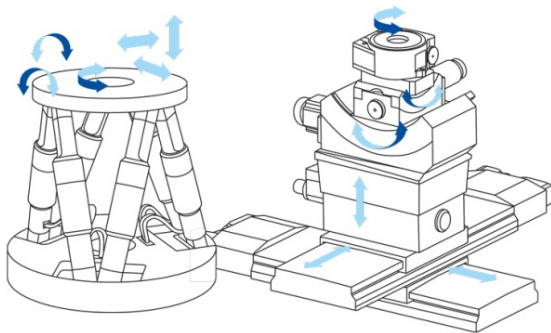


Fig. 1 A parallel-kinematic six-axis positioning system is much more compact and stiffer than a comparable serial-kinematic structure of stacked single-axis piezo stages

Serial kinematics has a simple design, and control of the single axes is not very complicated. However, it suffers from a series of drawbacks compared with the more powerful and more elegant parallel kinematic systems. The reason for this is that in a serial kinematic multi-axis system every actuator is assigned precisely to one degree of freedom in direction of motion.

When position sensors are integrated, they are also each assigned to one drive and only measure the motion in the corresponding positioning axis. Any undesirable motions in the other five degrees of freedom cannot be detected or compensated, resulting in an accumulation of guiding errors.

Parallel Kinematics and Parallel Metrology

In contrast, in a parallel-kinematic multi-axis system, all actuators act directly on the central moving platform. This is the only way of achieving identical resonance frequencies and identical dynamic behavior for the axes.

Flight simulators are probably the best-known application of six-axis parallel-kinematic systems; here six actuators act on the same platform, which can move and tilt in all directions. Industrial Hexapods, suitable for mechanical engineering, are, however, much more accurate. Depending on the requirements of the application, they are driven by high-precision drive screws and precisely controllable DC motors or directly by linear motors, e. g. based on piezo actuators, instead of using hydraulic drives.



Fig. 2 Hexapods are available in different sizes and with different drive principles

Independently of the drive principle, simple integration of parallel metrology is possible with parallel-kinematic systems. Here all controlled degrees of freedom can be monitored simultaneously, thus compensating guiding errors in real time (Active Trajectory Control). This results in numerous advantages of the system, such as much better path accuracy, repeatability and flatness. In addition, the moved mass is low enabling a better dynamic performance, which is the same for all motion axes. Moreover, cable management is no longer an issue, because cables are not moved, and, last but not least, the system features a substantially more compact design.

The latter simplifies in mechanical engineering, for example, the safety circuits, because the Hexapod can only move within the easily manageable work space. At the same time, thanks to their adaptability, Hexapods offer good integration possibilities in a wide range of different applications (Fig. 2).

Positioning with up to Six Degrees of Freedom

Over the last four decades, PI (Physik Instrumente) from Karlsruhe, Germany, has become known for high-capacity and high-precision positioning systems with up to six motion axes.

PI's product portfolio also includes a large variety of powerful six-axis parallel-kinematic systems. They are suitable for different loads, come with different types of drives and are designed for all kinds of ambient conditions. Numerous applications, ranging from handling systems in electronics production or tool control in precision machining, to medical technology and optical systems, like those found in space telescopes, can be covered (Fig. 3).

Positioning is in six degrees of freedom: three linear and three rotary motion axes. Depending on the geometry of the Hexapod, rotations from a few degrees up to 60° and translations from a few millimeters to several centimeters are possible. The repeatability and minimum incremental motion achieve values of below one micrometer.



Fig. 3 Hexapods have been tested and proven in many areas of application, including, for example, also telescopes (Image: ALMA (ESO / NAOJ / NRAO))

Mechanical engineering can benefit from this in many ways: Applications that require such high accuracy are, for example, high-precision electrical discharge machining processes. They are suitable for parts of complex contours that, for example in milling, cannot be clamped ideally. In this case, the electrode is moved by the Hexapod, while the workpiece remains fixed.

This applies analogously to wire bending work in the high-precision range. Wherever optical methods are used for quality assurance, plates or workpieces can be aligned precisely using Hexapods. Further areas of application are, for example, in laser beam control.

However, even if nano- or micrometer precision is not crucial, parallel-kinematic multi-axis systems provide the mechanical engineer with interesting options, for example in workpieces that are to be provided with several holes. If requirements such as offset or inclination must be taken into account, Hexapods with their six degrees of freedom of motion also simplify the production sequence. This applies analogously to mounting work, because even large and heavy parts can be aligned by Hexapods in such a way that they fit perfectly, for example in vehicle, aircraft and heavy machinery construction.

Synchronous Clock for the Entire Automation Line

Due to a direct connection to the master control, Hexapod systems can be integrated basically into every automated production line. A synchronized clock with other automated components can also easily be achieved, for example, for automated supply systems, etc. (Fig. 4).

In this case, the PLC can communicate with the Hexapod system over a standardized fieldbus interface. The PLC acts as master and defines the target position in Cartesian coordinates and the trajectories; in return, it gets the actual positions also over the fieldbus interface. All other calculations required to command the parallel-kinematic six-axis system are done by the Hexapod controller, i.e. transforming the target positions from Cartesian coordinates into drive commands for the individual drives. In this case, the controller acts just like an intelligent drive (Fig. 5). The cycle times for the input of new positions, signal evaluation and synchronization are between 1 and 3 ms. Fieldbus interfaces are currently available as exchangeable modules for EtherCAT and Profinet.

This makes Hexapod systems already compatible with a large number of fieldbus systems. More fieldbus interfaces such as Profibus, CANopen, SERCOS or others will be available if required.

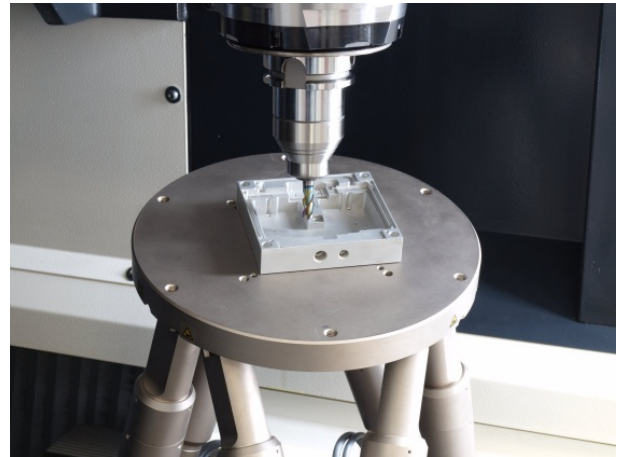


Fig. 4 Standardized fieldbus interfaces guarantee easy integration: Hexapod in automatic milling

Of course, the Hexapod controller can also act itself as master for position control. In this case, however, the PLC only issues a position command. During the run, the motion cannot be synchronized with other drive axes, measuring systems, etc.

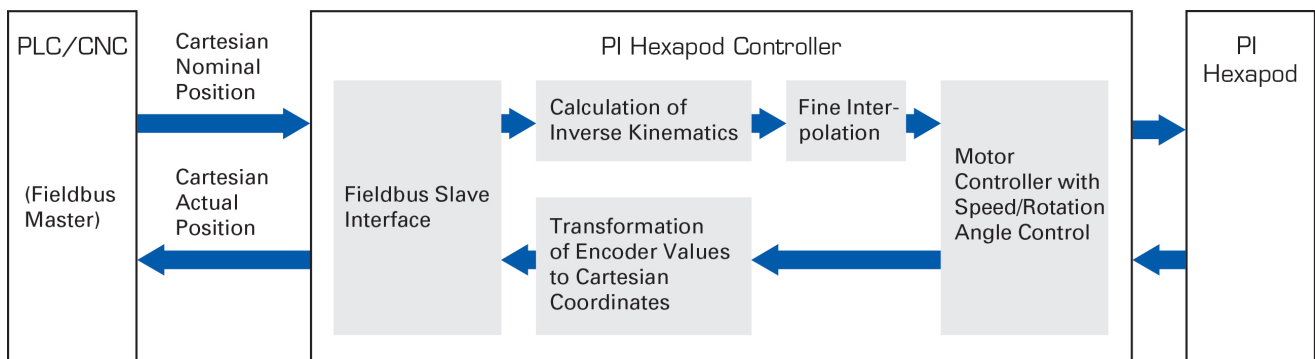


Fig. 5 Block diagram: In this case, the controller acts just like an intelligent drive. The fieldbus interface can be exchanged to allow communication with numerous types of PLC or CNC controls

Precise Trajectory Control and User-Defined Coordinate Systems

If there is no parent PLC or if synchronizing with other system components is not required, the Hexapod controller can now also control the trajectory based on G-code according to DIN 66025/ISO 6983.

The advantage of G-code is that it can be easily generated by trajectory generation software tools and has become very well established in production technology and mechanical engineering. The G-code interpreter now implemented in the Hexapod controller allows the Hexapod system to move the workpiece or tool smoothly and with high precision during machining so that the mechanical system does not start to vibrate.

To adapt the trajectory perfectly to the requirements of the application, it is possible to define various coordinate systems by means of the controller, for example for workpiece and tool, which refer to the position of the workpiece or tool.

Modular Design for Maximum Flexibility

Hexapods can come with many different structures. A modular concept allows them to be customized within a short time. The Hexapod struts are designed so that their length can be easily scaled. They include the required electronics for reference point switch, limit switch, position sensor and – depending on the motor – electronic commutation. Their standardized joints allow to combine them with almost any base plate and top, whatever type of geometry. To find a suitable solution for a certain task will be much easier, in particular because Hexapods can readily position and move even major loads of up to several tons with the high precision that is typical of them.

Automation control and mechanical engineering will benefit from these advantages in many areas. Look forward to it.

About the PI Group

Over the last four decades, PI (Physik Instrumente) with headquarters in Karlsruhe, Germany, has developed into the leading manufacturer of positioning systems with accuracies in the range of only a few nanometers.

With four company sites in Germany and ten sales and service offices abroad, the privately managed company operates globally. More than 700 highly qualified employees all over the world enable the PI Group to fulfill almost any requirement from the area of innovative precision positioning technology.

All key technologies are developed in-house. This allows the company to control every step of the process, from design right down to shipment: precision mechanics and electronics as well as position sensors. The required piezoceramic elements are manufactured by our subsidiary PI Ceramic in Lederhose, Germany, one of the global leaders for piezo actuator and sensor products.

The PI miCos GmbH in Eschbach near Freiburg, Germany, is a specialist for positioning systems for ultrahigh vacuum applications and parallel-kinematic positioning systems with six degrees of freedom and custom-made designs.

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