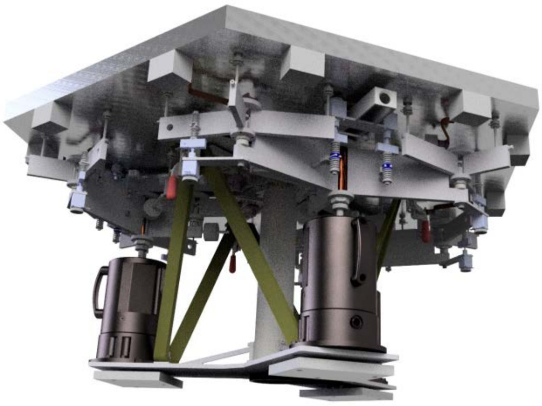
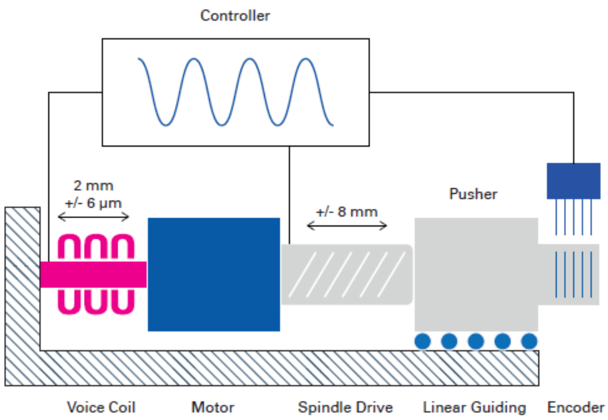
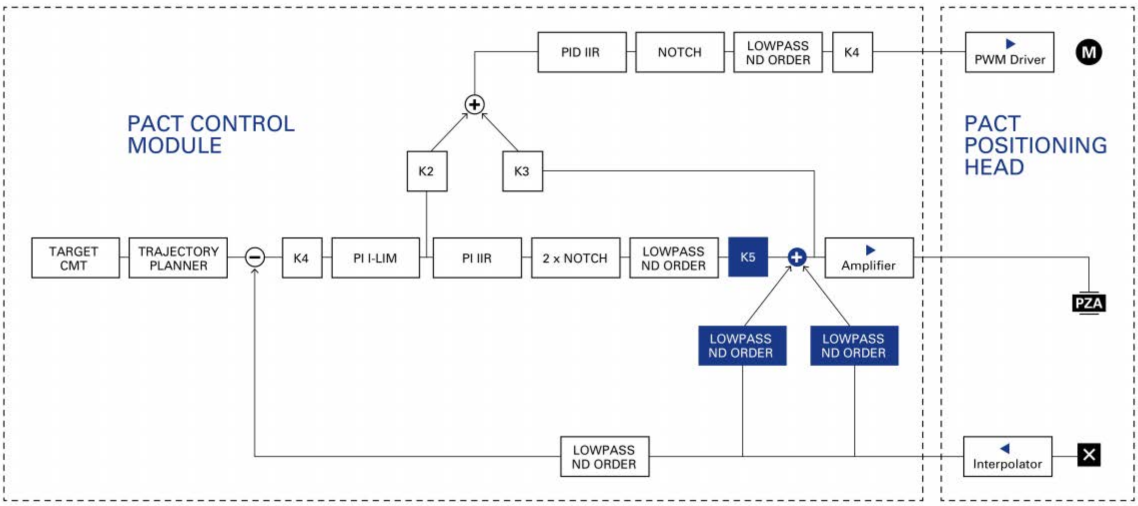
Smart, Hybrid Actuators Combine Nanometer Precision, Large Forces and Long Travel Ranges with High Dynamics







1 Introduction

Hybrid drives combine two different drive concepts into a high-performance and precision positioning system. They take advantage of both drives. These types of solutions are always in demand when one drive alone is not in a position to meet all of the requirements of applications. An example of this is nanometer-precision positioning of heavy loads over long travel ranges. Nanopositioning systems that combine piezo drives with classical drive screws therefore offer a practical solution, but also other drive concepts are possible.

The examples of applications for hybrid drives range from semiconductor manufacturing through quality assurance and optical inspection to biomedical engineering.

2 Hybrid Concept with Electric Motor and Voice Coil

Various concepts have already been developed and implemented for hybrid positioning systems. One solution for example, is a combination of linear motors and voice coil actuators (see Fig. 1).

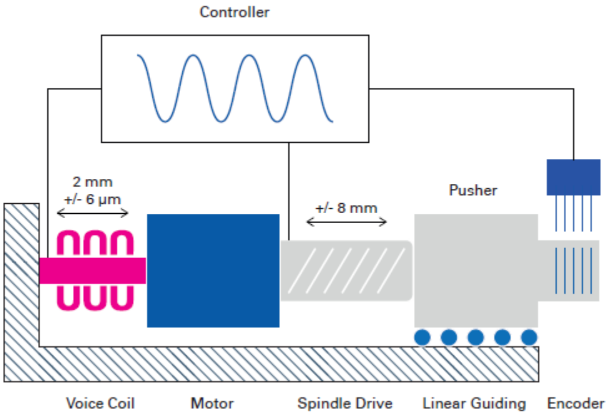


Fig. 1 Hybrid concept with electric motor and voice coil actuator (image: PI)

Linear motors offer long travel ranges with high positioning accuracy and repeatability, but do have the disadvantage of high friction in the linear guides used for taking up the load.

Nevertheless, voice coil actuators do provide precision positioning as well as good force control and smooth motion. However, their travel range is limited to 100 mm and they can only hold loads at rest when they are powered on.

3 Hybrid Concept with Piezo Walking Drive and Piezo Actuator

PI has already successfully developed and established a further hybrid drive concept for other applications such as those for inspecting semiconductors.

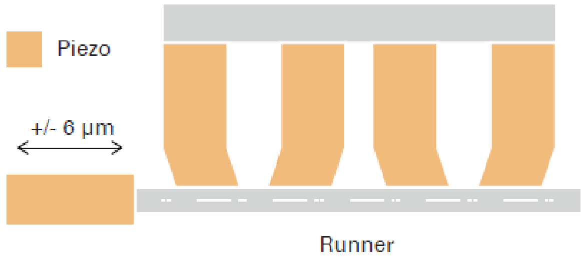


Fig. 2 Hybrid concept with piezo walking drive and piezo actuator (image: PI)

A PiezoWalk® drive that offers long travel ranges with high stiffness, is combined with a PICMA® actuator for high dynamics applications (see Fig. 2). The advantage in this case is, depending on the design of the PiezoWalk® drive, the possibility of realizing high holding forces. In this case, the high dynamics of the PICMA® drive is important for fast focusing of the object to be scanned.

4 Hybrid Concept with Electric Motor and Piezo Actuator

PI is working on a project together with engineers and astronomers from the European Southern Observatory (ESO), which will result in the world's largest terrestrial telescope on the 3000-meter-high Cerro Amazones in the Atacama desert in Chile (see Fig. 3).

Fig. 3 The European Extremely Large Telescope (ELT) will be the largest terrestrial telescope for scientific evaluation of electromagnetic radiation in the visible and near-infrared wavelength range (image: ESO)

The telescope's revolutionary design consists of a main mirror (M1) with a diameter of 39 meters, which is divided into 798 independent mirror segments. Each mirror segment has a diameter of 1.4 m and is positioned by three independent hybrid drives with a nominal travel range of ±5 mm (see Fig. 4).

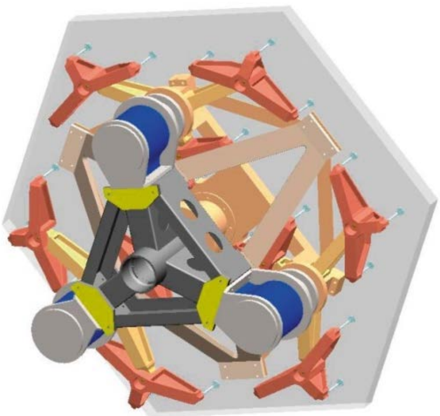


Fig. 4 Depiction of a main mirror segment, the three hybrid drives are shown here in blue (image: ESO)

Fig. 5 Conceptual design of the M1 Segment Subunit (Image: ESO)

Considerable masses must be moved for this: Each mirror segment including its support weighs approximately 250 kg. Due to the different alignments of the telescope, a total of 2,394 actuators need to be able to move and hold loads with push/pull forces between 463 N and 1050 N (see Fig. 5).

One of the most important tasks of the telescope will be to supply the sharpest possible images of the universe, which researchers can use to search for Exoplanets, i.e., planets that exist beyond the solar system. Therefore, the greatest technical challenge will be to move the mirror segments over the entire range with a maximum position deviation of 2 nm.

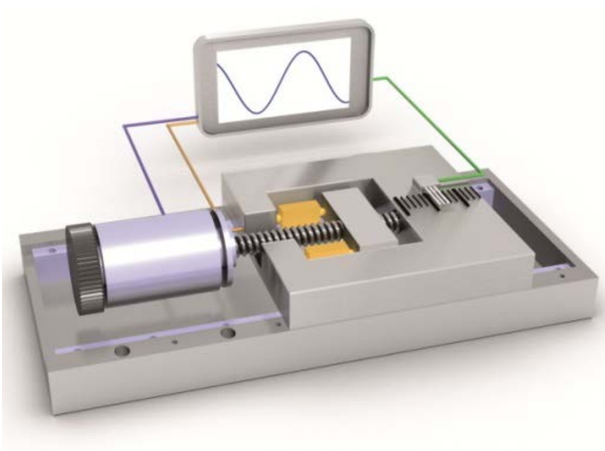


Fig. 6 The electric motor is suitable for heavy loads and long travel ranges. In conjunction with a piezo drive, the hybrid system also provides additional positioning accuracy in the subnanometer range (image: PI)

In order to achieve this high path accuracy, PI developed a hybrid concept where a motor drive screw that is suitable for heavy loads and long travel ranges, is combined with a piezo actuator (see Fig. 6). Serial combination of both very different drives results in a powerful and high-precision positioning system (see Fig. 7).

Fig. 7 Very stiff hybrid linear actuator with a diameter of approx. 200 mm with an overall length of approx. 285 mm (image: PI)

4.1 Piezo Actuators Position with Subnanometer Accuracy

Precision motion that results when an electrical voltage is applied to a piezoelectric material is of particular importance for nanopositioning. The electrical power is converted into mechanical energy directly inside the crystalline solid state, which means that there are no rotating or frictional parts.

The piezo actuators not only work with high precision but are also maintenance and wear free. They can move large loads with weights up to several tons. Electrically, they act as capacitive loads and need virtually no power in static operation. The behavior in the power circuit is very much like an electrical capacitor. Similar to capacitors, they don't generate any heat in a static condition.

The lifetime of piezo actuators are also convincing: In the case of PICMA® multilayer actuators (see Fig. 8), the active layers consist of thin ceramic films and are surrounded by an all-ceramic insulating layer that protects the actuators against air humidity and failure from leakage current. The monolithic piezoceramic block of such an actuator is very reliable even under extreme ambient conditions and high temperature differences.

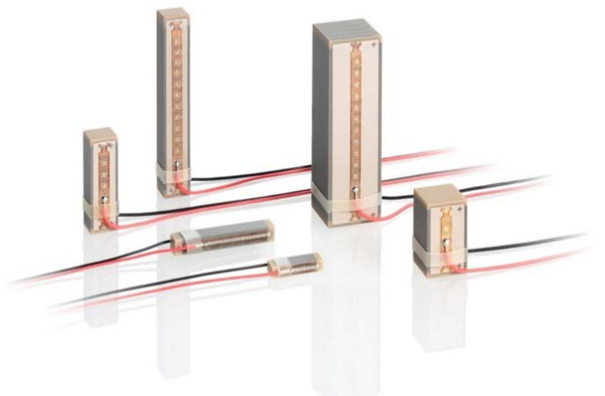


Fig. 8 All-ceramic insulated, high-power piezo actuators: Durable even under difficult operating conditions in industry, life science, and microscopy as well as in medical technology and research (image: PI)

The piezo actuators used in the hybrid drive for the telescope segments are also encapsulated in sealed metal bellows filled with nitrogen (see Fig. 9) in order to reach the 30-years lifetime necessary in the adverse ambient conditions in Atacama desert at an altitude of 3,000 m.

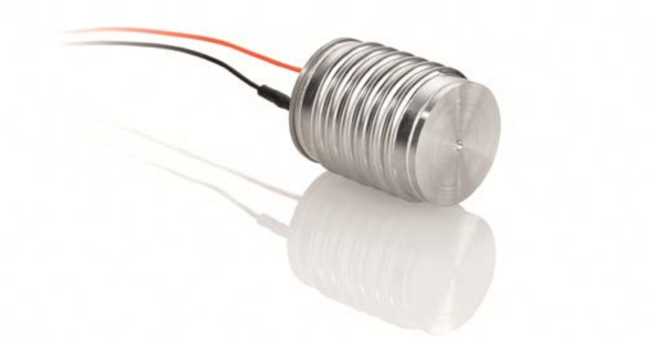


Fig. 9 An encapsulated PICMA® linear actuator of part of the hybrid drive concept (image: PI)

4.2 A High-Resolution Sensor for Both Drive Systems

A further feature of the hybrid drives is the common high-resolution sensor, which helps to control both drives simultaneously and continuously. This is the only way to implement the high resolution of the piezo actuators over the entire travel range.

The high-resolution sensor is an incremental optical encoder that is placed near to the drive axis (Fig. 10). It operates at a resolution of 0.1 nanometers and is also not sensitive to the changing environmental conditions prevailing at the telescope's location in the Atacama desert.

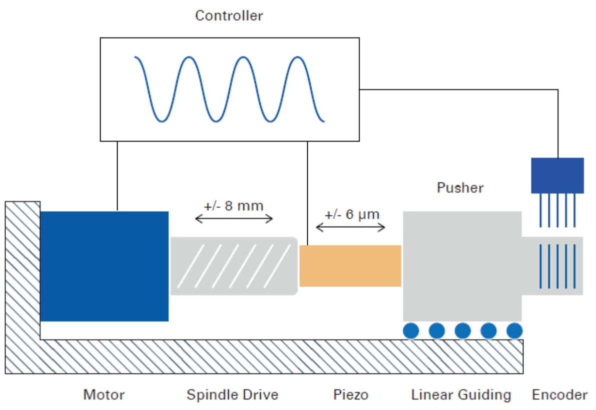


Fig. 10 Schematic diagram of the hybrid drive. The common control with one single high-resolution linear encoder allows an extremely constant velocity with high positioning accuracy (image: PI)

The motor drive screw is suitable for heavy loads and long travel ranges starting at a few millimeters and going up to one meter. The piezo actuator provides a nominal displacement of approximately 0.1 to 0.15 % of the actuator length but nevertheless achieves a positioning accuracy in the subnanometer range with one high-resolution sensor and can therefore compensate for the inaccuracies of the motor drive screw.

The drive screw is driven by a brushless high-torque motor via a high-ratio reduction gearhead.

The gearhead ensures zero-play operation and guarantees a constant transmission ratio. The motor can therefore be very small even though large masses have to be moved. The high transmission also supports self-locking of the motor when at rest.

A dedicated controller controls both drives simultaneously and also controls the high-resolution position measuring system. The servo algorithms consider the motor and the piezo system as a single drive unit and compare the actual motion with a calculated trajectory.

The control principle of the hybrid drive is easy to understand (Fig. 11): The motor voltage is derived from the control voltage of the piezo. The greater this voltage, the faster the motor runs. When the piezo expands, the motor drives the drive screw in the same direction. In this way, the rough positioning of the drive screw is supplemented by the fine positioning of the piezo. At the same time, the drive screw always moves the piezo near to its zero position automatically. This gives it the best chance of correcting the position in both directions. In this way, relatively long travel ranges can be combined with an extremely high positioning accuracy.

The characteristics of these types of hybrid drives are not only useful for telescopes but are always a practical solution when a position needs to be detected with high precision and moved repeatedly over long travel ranges or when a target position needs to be reached with nanometer precision. Other typical applications areas include for example, measuring technology or surface inspection, semiconductor manufacturing, microscopy, and laser technology.

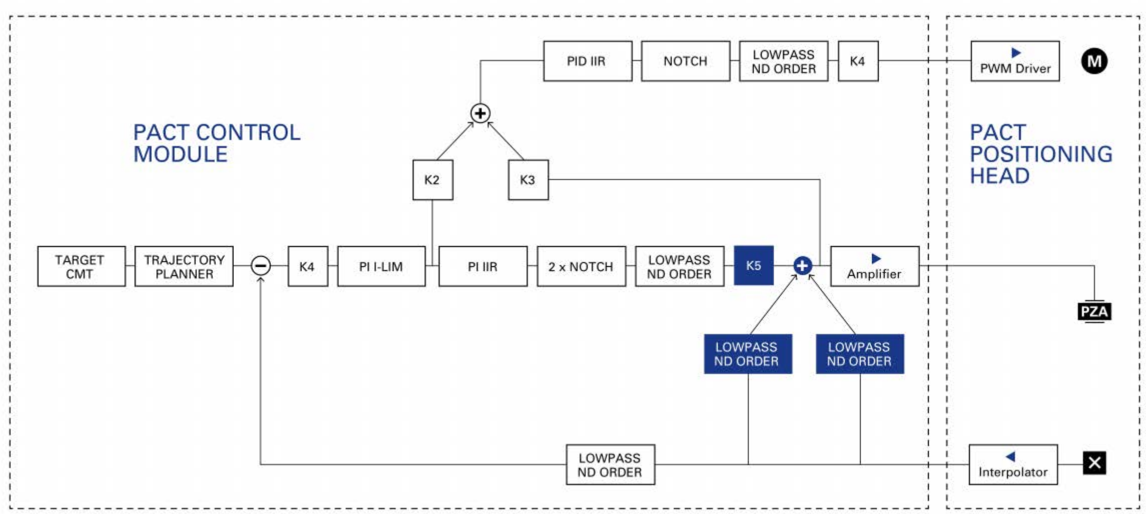


Fig. 11 The controller structure (image: PI)

5 Author

Oliver Dietzel, Team Leader for Project Management Corporate Platform Development at Physik Instrumente (PI) GmbH & Co. KG

6 About PI

Well known for the high quality of its products, PI (Physik Instrumente) has been one of the leading players in the global market for precision positioning technology for many years. PI has been developing and manufacturing standard and OEM products with piezo or motor drives for more than 40 years.

Continuous development of innovative drive concepts, products, and system solutions and more than 200 technology patents distinguish the company history today.

PI develops, manufactures, and qualifies all core technology itself: From piezo components, -actuators, and motors as well as magnetic direct drives through air bearings, magnetic and flexure guides to nanometrological sensors, control technology, and software. PI is therefore not dependent on components available on the market to offer its customers the most advanced solutions. The high vertical range of manufacturing allows complete control over processes and this allows flexible reaction to market developments and new requirements.

By acquiring the majority shares in ACS Motion Control, a worldwide leading developer and manufacturer of modular motion controllers for multi-axis drive systems, PI can also supply customized complete systems for industrial applications that make the highest demand on precision and dynamics. In addition to four locations in Germany, the PI Group is represented internationally by fifteen sales and service subsidiaries.