Mechanical Drives

Mechanical drives are used to move the component on a translation stage to its desired position. Two basic types of mechanical drive are used with precision stages: manual drives and stepper-motor drives. Both types used a helical-screw mechanism to convert rotational motion into linear travel. These drives can move components over long distances, constrained only by the size of the manual drive or, in the case of stepper motors, the length of the leadscrew. The range and resolution of the various drives and stage technologies were shown previously in figure 8.9.

Mechanical drives with helical-screw mechanism

MICROPOSITIONING USING MANUAL DRIVES

Adjustment screws are one of the most economical methods for positioning an optical component. CVI Melles Griot uses fine-thread adjusters with pitches of 0.5, 0.3, and 0.25 mm/turn depending on the resolution required. Typically, these adjusters are made from stainless steel and are inserted into threaded brass bushings. For the most precise applications, hand-lapped threads are created by working in a stainless screw/brass thread pair.

Manual drives are the simplest, most straightforward way to control a stage. Rigidly mounted to the stage, they provide up to 50 mm of travel and have resolution as small as 50 nm. A variety of manual actuators is shown in figure 8.12.

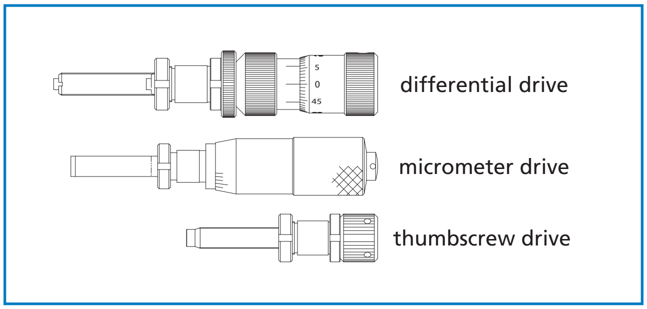
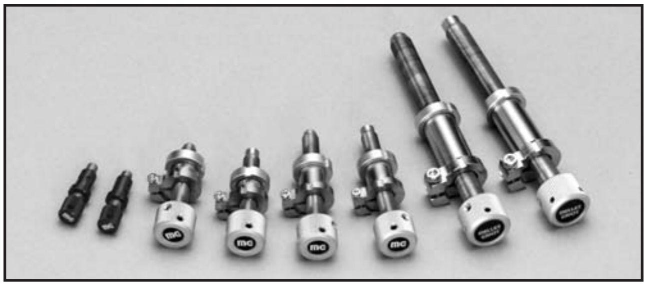


Figure 8.12 **Various types of manual drives including differential micrometers**

Thumbscrews are the least expensive of the manual positioners. They can provide resolution of a few microns, but they are not very repeatable because they do not have a mechanism for indicating the actual position.



Thumbscrew drives

Standard micrometers are designed for precise, repeatable positioning. They are essentially thumbscrews with a very fine thread and are equipped with a vernier scale so that precise displacements can be made and read down to 10μm.

Differential micrometers use dual-thread movement to provide both long travel and very precise positioning with resolution as fine as 50 nm. They are more costly than thumbscrew or micrometer drives but are necessary when high-resolution, manual positioning is required. A perfect example of just such a requirement comes with single-mode fiber alignment where a focused laser beam is being aligned to a fiber core dimensioned in microns.

Micrometer drives

With direct drives, the length of the thread on a shaft determines the length of travel; the pitch of the thread, coupled with the diameter of the drive knob, determines the resolution. Differential drives use compound shafts to provide extended travel with ultrafine positioning. The outer shaft, which acts in the same manner as a direct drive, provides long travel with a resolution determined by the pitch of the thread. The intermediate shaft has an outer thread with a negative pitch and an inner thread with a positive pitch which is slightly less than the outer pitch. The inner (push) shaft is constrained to longitudinal motion with respect to the outer shaft. When the outer shaft is turned, the other two shafts rotate with it, and the unit behaves like a thumbscrew. When the intermediate shaft is turned, the longitudinal motion is determined by the differential motion produced by the positively pitched and negatively pitched threads, resulting in resolution as low as 50 nm. Both types are available with micrometer markings.

WORM-SCREW AND LEADSCREW DRIVES

A worm-screw drive is a mechanism in which the circular motion of a screw of relatively small diameter, referred to as the worm, is used to rotate a larger gear wheel with an axis of rotation that is perpendicular to the axis of rotation of the worm screw. In this manner, it is possible to achieve a high velocity ratio between the rotation rate of the worm screw and the rotation rate of the gear wheel. Such mechanisms also make it possible to achieve higher load capacities and higher torques. A desirable characteristic of this type of mechanism is that it can be offered in a compact form and package. Many goniometer- and rotary-type stages utilize this mechanism in their designs.

A leadscrew drive is a simple and cost-effective means of using the motion of a screw inside a nut to achieve translation. As the screw rotates inside of the nut, the nut tends to move in a direction parallel to the direction of the axis of the screw. If a load is mounted on top of, or somehow attached to the nut, it will also move in the same direction along with the nut resulting in a translation motion of the load. Leadscrew drives offer the advantage of being suitable for long-travel mechanisms which also require quick motion adjustment characteristics. Because of this, leadscrews are typically used in the design of long-travel stages.

Long-travel stage with leadscrew drive

POWERED MICROPOSITIONING USING STEPPER MOTORS

Stepper motors utilize a technique called *microstepping* which achieves unrivaled performance in resolution, repeatability, range, and accuracy for the cost of the system. Although other methods might provide certain advantages in one area of performance, this technology provides the best overall performance in many high-resolution applications.

A stepper motor can be used to drive a precision leadscrew to generate a linear or rotary motion, or it can be used to directly drive a rotating stage. Stepper motors, developed from brushless dc motor technology, consist of a cylindrical rotor with many ferromagnetic teeth equally spaced around its circumference. In hybrid stepper motors, these teeth may be permanent magnets. The rotor is suspended by bearings in a cylindrical enclosure lined with several sets of electromagnets, called poles, or stators. Each electrically common set of poles is called a phase. Two- and four-phase stepper motors are the most common types.

Figure 8.13 is a simplified schematic of an idealized two-phase hybrid stepper motor. Each phase consists of four sets of poles (stators) arranged at 90 degrees, with the two opposing pairs of poles wound in opposite directions. As labeled in the diagram, the plus and minus stators become opposite magnetic poles when current flows through the phase. Note that the teeth of the eight stators are successively staggered by a quarter of the tooth pitch. When current flows through the A phase and the B current is zero, the induced magnetism of the A phase causes the rotor teeth (north poles) to align with the A stator teeth (position 0 in the figure). A single step is achieved by switching the current to the other phase where the rotor teeth are attracted to the nearest new minimum energy positions. Depending on which direction the current flows through the B phase, the step may be in a clockwise $(+1)$ or counterclockwise (-1) direction.

The total number of steps per revolution is determined by $4nt$, where nt is the number of teeth around the rotor. For example, the motor could have a rotor with 100 teeth, or 400 steps per revolution. Motor speed is controlled by varying the rate of current switching.

Stepper motors offer advantages over dc servo motors and piezoelectric devices. The stepper motor is driven by a series of current steps (see figure 8.14) which can be counted so that the final position is known well within a resolution of one step without an encoder. By using microstepping techniques, these steps can be accurately subdivided into many smaller steps of equal size, increasing resolution. Servo feedback signals are not required but can be used if desired.

Stepper motors always have at least one phase partially or fully energized so that there is no tendency of the positioner to drift or creep when stationary. Because dynamic torque is greater at low pulse rates, stepper-driven devices can accelerate relatively large loads without stalling. These devices are capable of resolution close to that of piezoactuators but have much better accuracy and vastly superior repeatability. Although sophisticated drive circuits are needed, there is no reason why a stepper system cannot be driven at speeds comparable to, or faster than, any other high-resolution device.

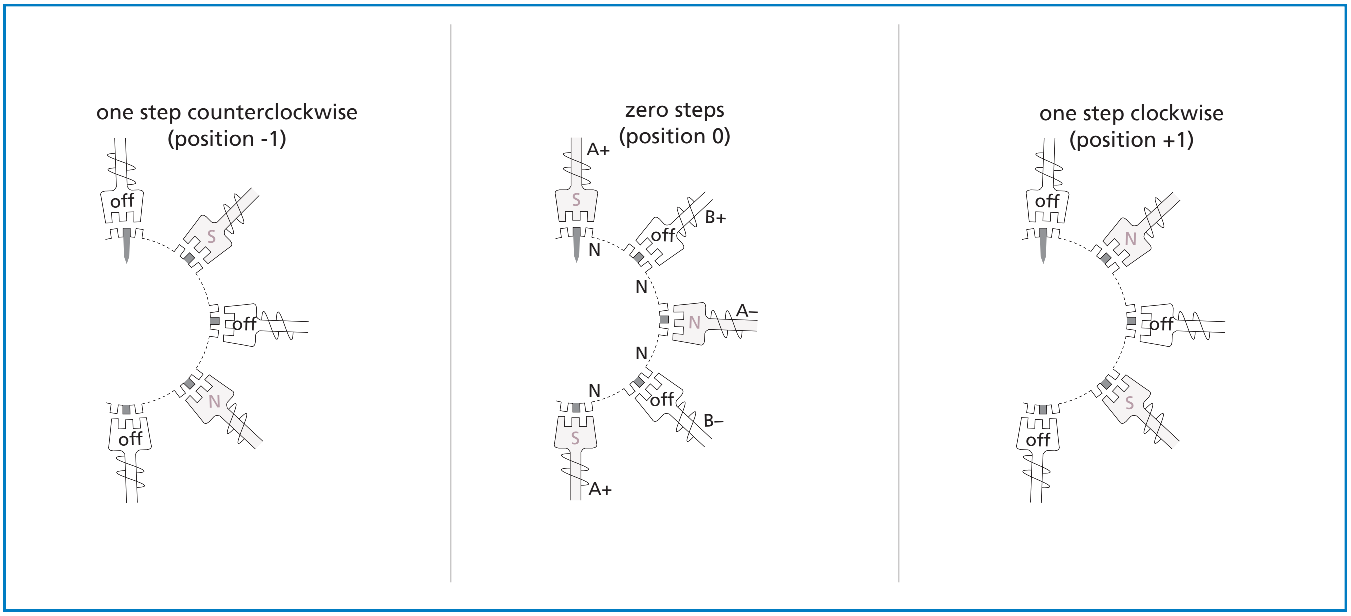


Figure 8.13 **Schematic diagram of a two-phase hybrid stepper motor showing how switching current between the phases causes the rotor to move by one step**

The principle by which the amplitude and direction of the current flowing in the electromagnetic coils within the motor change is termed commutation. A stepper motor has no internal commutation as does a brushed dc motor design. Instead, by applying current to the electromagnetic windings, stepper motors are able to move in a continuous point-to-point positioning manner. At rest, when no current is applied, there is an inherent holding or detent torque, which prevents drift.

Many stepper motors have a rotor with 50 teeth. Each tooth is an individual magnet. At rest, these magnets align themselves with the stator poles in a natural detent position, providing a large detent torque if the power is removed. If the stator poles are energized in sequence, the rotor follows the changing magnetic field, and the motor rotates.

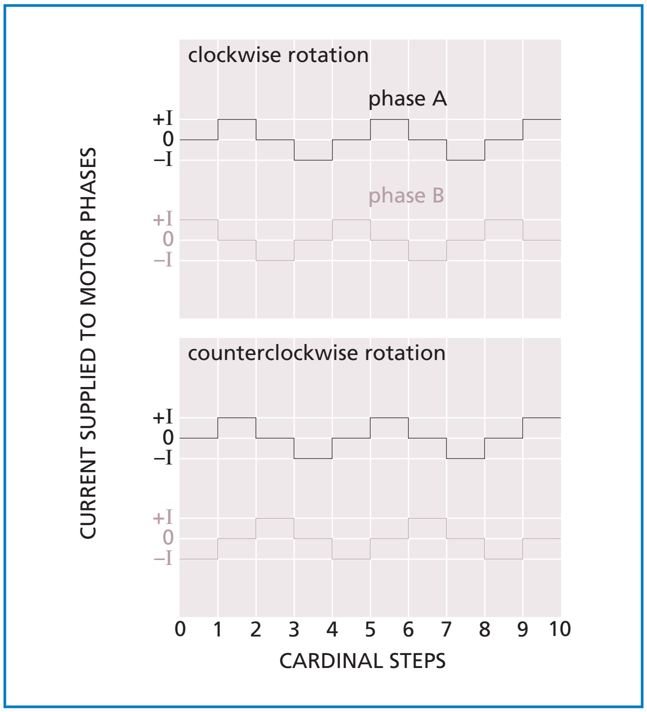
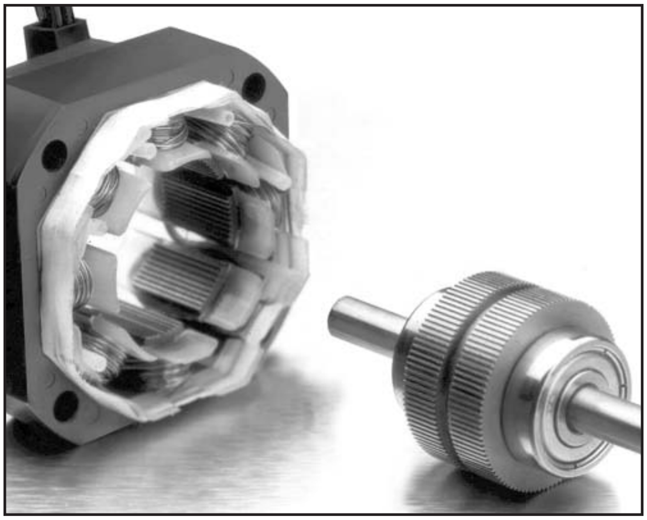
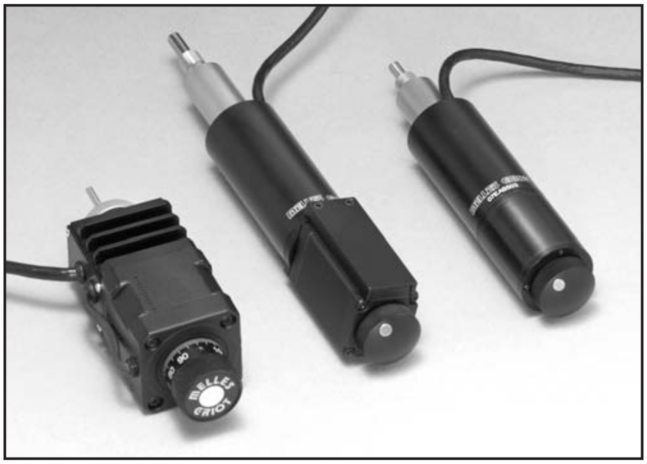


Figure 8.14 **Current-switching patterns of typical two-phase stepper motor for both directions of rotation**



A disassembled stepper motor showing the stator and rotor



Stepper-motor drives

This type of motor (shown in figure 8.15) displays a high detent torque, as well as excellent dynamic and static torques. High stepping rates can also be achieved. The presence of two windings on each stator pole enables the poles to be either a magnetic north or south depending on the direction of current flow.

Microstepping Mechanism

Microstepping offers a significant improvement to the resolution of a conventional stepper-motor drive. Standard steppers alternate the current direction in one coil every step, resulting in a step size that could be, for example, in the order of 1.8 degrees (i.e., from detent to detent). In microstepping, the current is increased in one coil as it decreases in the other, and the new rotor position is somewhere between the two coils, and the step size is a defined fraction of a full step. This offers two main benefits: increased resolution without adversely affecting top speed and smoother low-speed motion.

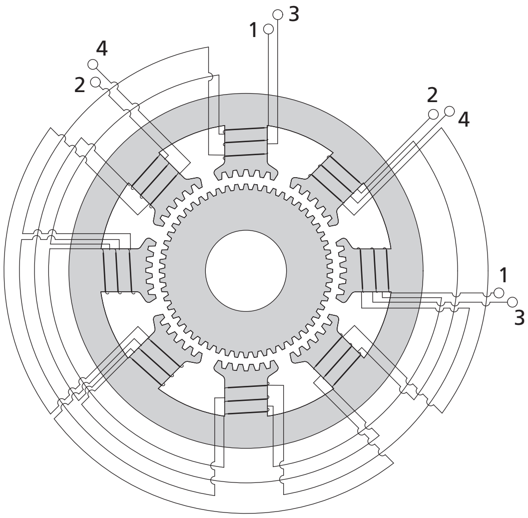


Figure 8.15 **Schematic diagram of stepper motor showing the pole connections**

Increased resolution is achieved in the following fashion, which is presented here only as a general example to explain how the mechanism operates. For a standard full step motor with a leadscrew thread pitch of 1.0-mm , a shaft rotation speed of 30 revolutions per second generates a velocity of 30 mm per second and gives a resolution of 5 μm. A divide by 10 microstepper supplies the same 5-micron resolution with a 10-mm leadscrew but with a velocity of 300 mm per second. Alternatively, the resolution can be increased to 1.0 micron with a 2-mm leadscrew or 0.5 micron with a 1-mm leadscrew.

Smoother low-speed motion is another advantage of microstepping. Stepper motors move in discrete angular steps and inherently produce noise and vibration if operated at low step rates. Microstepping reduces the step size and increases the frequency for a given rotation rate, thereby producing smoother operation at low speed.