Introduction to Nanopositioning Motors

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EXFO Burleigh Products Group has almost three decades of experience as one of the world's leading producers of ultra-high-precision motors for nanopositioning. We were pioneers in the development of piezoelectric-based submicron linear positioning technology. In this article, we've distilled years of expertise to provide background on nanopositioning motors.

Nanopositioning Basics

Positioning is the act of moving an object from its present location or orientation in space, to some other location or orientation. Most real-world situations have a few additional requirements. For example, the object will have mass, and the positioning system will have friction. It may be necessary to maintain a fixed position while external forces are applied, or acceleration and velocity may need to be constrained.

Any positioning application requires an actuator -- a device that provides the forces necessary to accomplish motion. A typical positioning task might require that parts be moved on an assembly conveyer and then deposited near a worker. In this example, the actuator is the conveyer belt. Such a system might also include sensors for control of the velocity of motion and to locate the load at particular locations. The scale of such a system would be many meters and the resolution of parts location would be on the order of a centimeter.

Precision positioning operates on a much finer scale than described above. In most instances, the range of motion is limited to less than one meter, with resolution requirements on the order of tens of microns. Devices incorporating precision positioning elements include lathes and milling machines. These are generally driven by electric motors coupled to leadscrews. Sensors generally are used to provide control of velocity and position.

Nanopositioning refers to positioning tasks that require much smaller increments of motion with a required resolution of less than a few microns. This requirement for extreme precision results in the need to consider many more factors during system design, which may be safely ignored in lower-resolution systems. The use of position sensing is very common in nanopositioning applications.

Nanopositioning Motors

There are two methods of creating linear motion for nanopositioning applications: motors that produce rotary motion and convert it to linear motion, or inherently linear motors. The largest number of available systems are based on rotary motors. EXFO's expertise is in linear motors. The most common systems are based on rotary motors; EXFO's expertise is in linear motors.

Conventional Motors

Rotary motors used in micropositioning are all based on electromagnetic attraction and repulsion. The most common rotary motors are DC servomotors and stepper motors, each having its specific peculiarities in operation.

In both systems, the most common method of converting the motor's rotary motion to linear motion is via the use of leadscrews. A leadscrew drive consists of a precisely turned screw and a matching nut. A micrometer is an example of a manual leadscrew. The screw pitch (spacing between threads) determines many of the performance characteristics of the drive. For example:

Resolution = pitch x smallest rotation
Speed = pitch x rate of rotation
Distance = pitch x total rotation

DC Servomotors

DC servomotors typically are permanent magnet field/wound rotor motors. They provide linear torque/speed characteristics and are easily controlled by varying the voltage applied. For a constant load, the speed of a DC servomotor is directly proportional to the applied voltage. This permits very good speed control through the use of DC power amplifiers. More sophisticated systems incorporate feedback control, using tachometers as speed sensors.

Since DC motors do not provide intrinsic position indication, they commonly are equipped with shaft-mounted rotary encoders that produce signals indicative of incremental motion and direction. The control system must convert this rotary motion information into linear motion results using conversion factors based on the system's mechanical transmission. The full torque of the motor is available to hold position under load with this type of control. The ultimate resolution of a DC servomotor system is determined by the encoder resolution, system inertia, static friction and dynamic friction.

Stepper Motors

Stepper motors are inherently digital in operation. They can generate full torque at low speeds and have the ability to hold position under applied load. Changing the direction of current flow through the windings of the stepper motor generates rotation in fixed increments. The maximum rotational speed of the motor is limited by the time constant of the control winding.

Stepper motor controllers are sophisticated devices capable of providing the waveforms required to operate these motors. Control of the acceleration of the motor and of the load is required to ensure that the motor will respond to the switching frequency. In systems where the load may vary over a wide range, rotary incremental encoders are used to monitor the actual motion. The ultimate resolution of a stepper motor system is determined by the minimum motor step size and the system static friction. A refinement in some controllers is micro-stepping, which improves mechanical resolution by varying the value and direction of the winding current.

Another feature of some controllers is software compensation for various types of leadscrew errors. This is accomplished by mapping the actual position of a load, using a laser interferometer, while counting motor steps in the usual manner. The actual positions are stored in a software look-up table and used to correct the position during normal operation. This calibration may depend on the loading of the motor, due to the effects of backlash and compliance. Periodic recalibration may be needed to compensate for wear as the system ages.

Inchworm Motors

EXFO Inchworm® motors are fundamentally different from most other motors used for nanopositioning in that they are true linear motors. They achieve motion via the action of piezoelectric elements that change dimensions under the influence of electric fields.

The unique properties of their construction and operation include: the elimination of backlash, almost instantaneous acceleration (full speed within a micron of starting), extremely high mechanical resolution (about 4 nm) and dynamic speed range of 500,000:1.

Another interesting and useful feature of Inchworm motors is that the piezoelectric materials used to generate motion present almost a pure capacitive load to the driving electronics. When stopped, they dissipate almost no energy and, therefore, no heat. This property is useful in a number of critical applications and offers a unique advantage in ultra-high-vacuum applications.

Inchworm motors consist of three PZT (lead-zirconium-titanate) elements -- two configured to clamp a precision shaft, and the third, located between them, which controls the spacing between the clamps. The principle of operation is shown in Figure 1.

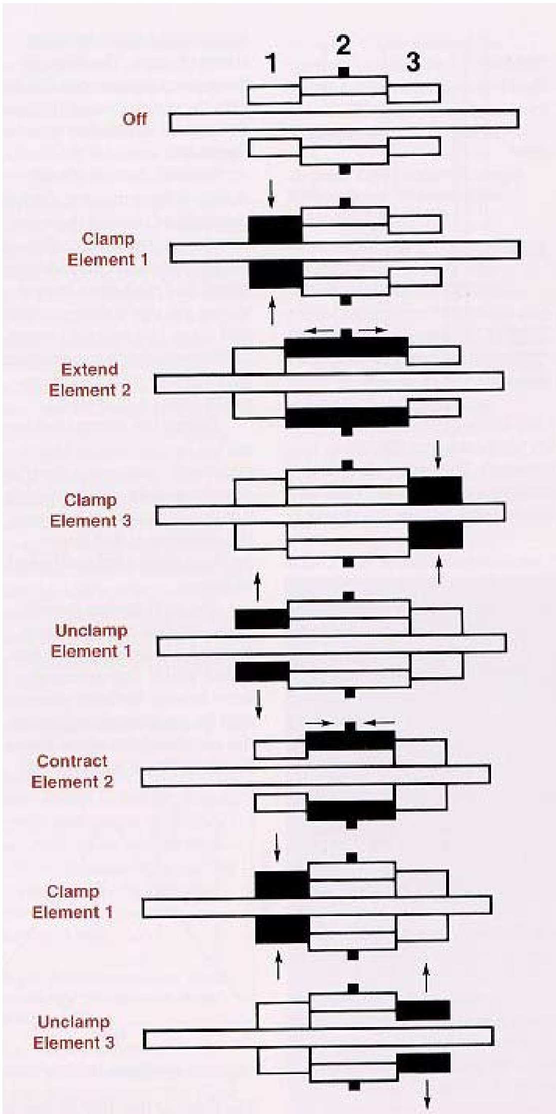

Figure 1. *The secret to EXFO's positioning precision. Sequential clamping, unclamping, extension and contraction of the PZT elements create a smooth linear motion profile without leadscrews or complicated mechanical coupling schemes.*

When a voltage is applied to the first PZT element, it clamps the shaft. Then an increasing staircase voltage is applied to the center PZT element, causing it to change length in discrete steps of approximately four nanometers each, thus causing the shaft to move forward. The staircase may be stopped or reversed on any step. At the top of the staircase, a voltage is applied to the third PZT element, causing it to grip the shaft. Then the voltage is removed from the first PZT element, causing it to release the shaft. The staircase starts downward, again moving the shaft forward, until it reaches its lower limit, at which point the first PZT element is activated again, the third PZT element is released, and the staircase starts again.

The sequence can be repeated any number of times for a total travel limited only by the length of the shaft (see Figure 2). It is the "clamp-extend-clamp-unclamp-retract" motion (similar to that of a measuring worm) that gave the Inchworm motor its name.

Inchworm motors are mounted at the middle of the center PZT element, such that the shaft moves right or left depending on the clamping sequence. Each full extension of the center element moves the shaft about two microns.

EXFO also offers a variety of highly specialized Inchworm motors, with performance characteristics tailored to popular applications. Ultra-high-resolution motors that can move 1.0 nanometer per step, or even 2.5 angstroms per step, are readily available.

EXFO also offers Inchworm motors specifically designed for ultra-high-vacuum applications (10^{-11} torr).

Since the size of individual steps is a function of voltages and motor loading, the Inchworm motor is inherently an open-loop device. As such, it is necessary to use an encoder to gain information about speed and location.

In almost all cases where closed-loop motion is required, Inchworm motors are used with optical encoders. These directly measure the actual motion of the Inchworm shaft or of the load itself.

EXFO offers a variety of encoding and mounting options to suit most applications.

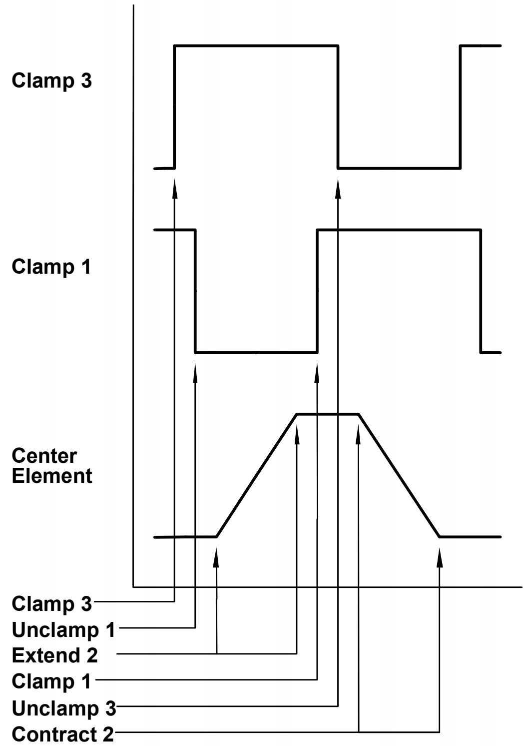

Figure 2. *Inchworm motor drive signals*

Conclusion

To learn more about how EXFO's nanopositioning products can work for you, give us a call: 585-924-9355. Our product specialists can answer your nanopositioning questions and would be happy to discuss your application requirements.

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