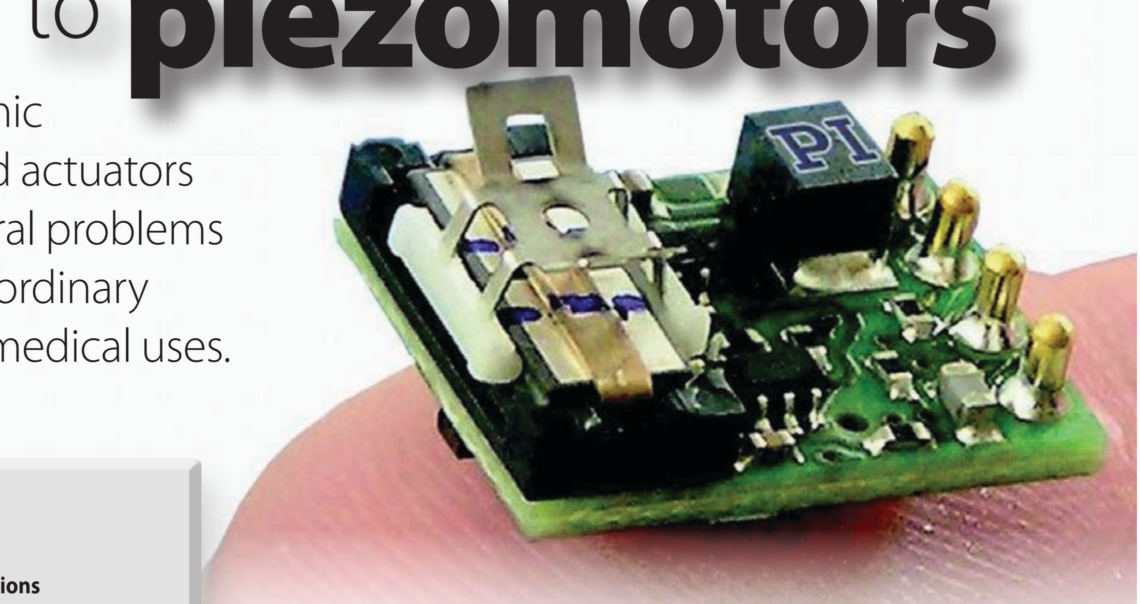
Medical-device makers warm up to piezomotors

Piezoceramic motors and actuators avoid several problems that beset ordinary motors in medical uses.



A miniature piezo-linear motor mounted on the left side of the circuit board can reach velocities of 200 mm/sec. The right side of the board holds the motor-drive electronics.

Authored by:
Jim McMahon
President
Zebra Communications
Simi Valley, Calif.

Edited by **Robert Repas**
robert.repas@penton.com

Key points:

- Piezoelectric motors and actuators are not affected by electromagnetic fields.
- Piezo devices can reach accelerations of more than 10,000 *g* and response times of less than 0.01 msec.
- The efficiency of piezoelectric motors is not reduced by miniaturization.

Resources:

Pari Pharma, *www.paripharma.com*

Physik Instrumente L.P., *www.pi-usa.us* **Circle 621**

Zebra Communications, *www.zebracom.net*

Tiny Motors Make Big Moves, *tinyurl.com/38p4yym*

Micro Moves, *tinyurl.com/3xnc5h4 [Open in new window]*

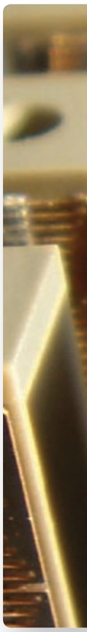
Piezoelectric motors and actuators have many advantages over conventional electromagnetic (EM) motors for medical equipment. Current medical applications for piezoelectric devices include ultrasonic emitters, artificial fertilization, medical nanomicroliter pumps, micromonitoring, surgery devices, and MRI-compatible robots. They are particularly useful for pick-n-place systems as used for microdose dispensing, cell penetration and cell imaging in cytopathology, and medical material handling.

Piezoelectric actuators

A piezoelectric (or just piezo) actuator is a solid-state device that uses the change in shape of a piezoelectric material when an electric field is applied to create motion. A piezoelectric-ceramic element produces mechanical energy in response to electrical signals, and conversely, is capable of producing electrical signals in response to mechanical stimulus.

The use of piezoelectric materials dates back to 1881 when Pierre and Jacques Curie observed that quartz crystals generated an electric field when stressed along a primary axis. The term piezoelectric derives from the Greek word "piezein," meaning to squeeze or press, relating to the electricity that results from pressure applied to a quartz crystal.

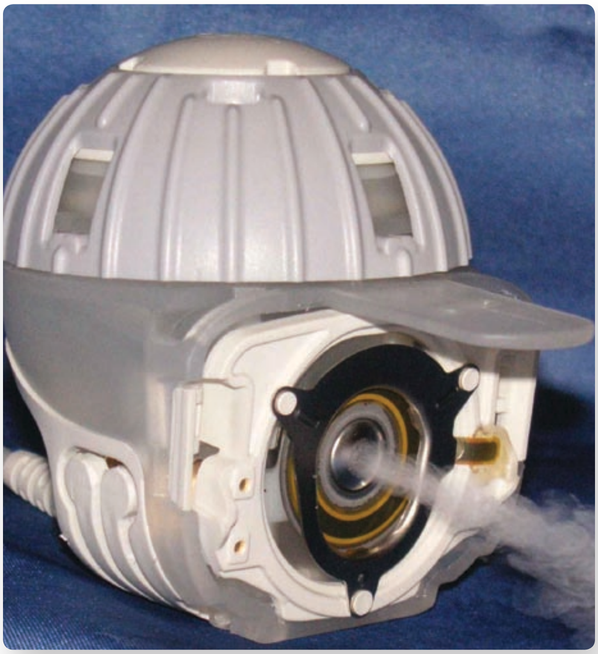
Piezoelectric ceramics consist of ferroelectric materials and quartz. Piezoceramic elements typically start as high-purity powders of piezo materials such as PZT (plumbum, zirconate, titanate) that are pressed to shape, fired, electroded, and polarized. Polarization uses high electric fields to align the material



domains along a primary axis. Piezoelectric actuators in their basic form produce small displacements, but generate huge forces. The minute size of the displacement is the basis for the high precision motion they can deliver.

Long travel ranges use a clever arrangement of multiple actuators or the operation of a single piezo element at its resonant frequency. These types of piezomotion devices are called piezomotors.

Two piezomotors in particular seem to work best for medical applications. The first is an ultrasonic piezo-linear motor, also called a resonant motor. The second is a piezostepper motor. Both versions provide unlimited travel or movement, yet both are different in their design, specifications, and performance.

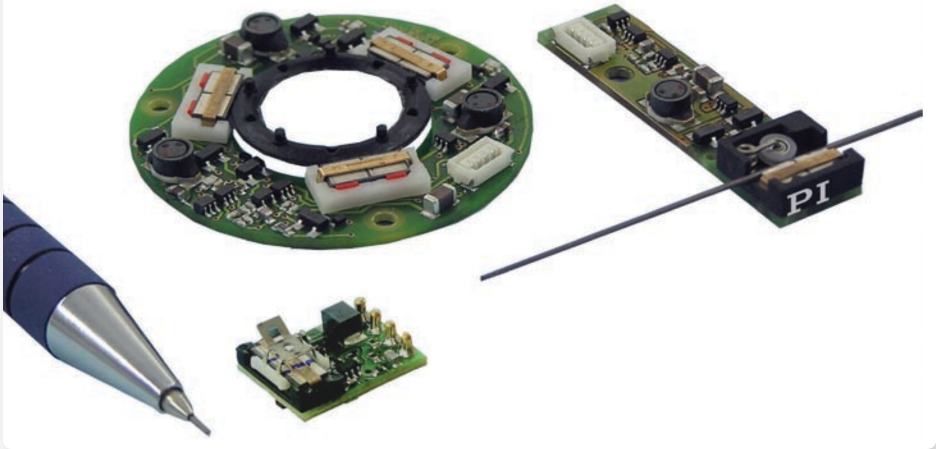


The atomizer head of a Pari Pharma eFlow Rapid Electronic Nebulizer uses an annular piezotransducer to atomize liquids for aerosol delivery of medications.

How it moves

Ultrasonic piezoelectric motors use ultrahigh-frequency acoustic vibrations on a nanometer scale to create linear or rotary motion. Though identified as acoustic energy, the frequency of the vibration is far beyond human hearing. Large travel ranges at high speeds typically use ultrasonic linear drives. The 50-nm resolutions they exhibit makes them a better alternative to electromagnetic motor-spindle combinations. The ultrasonic drives are substantially smaller than conventional EM motors, and they don't need the drivetrain elements that convert rotary to linear motion.

Piezoelectric linear motors use a rectangular monolithic piezoceramic plate as the stator element, segmented on one side by two electrodes. Depending on the desired direction of motion, one of the electrodes is excited to produce high-frequency eigenmode oscillations (one of the normal vibrational modes of an oscillating system) from tens to hundreds of kilohertz. Attached to the plate is an alumina friction tip called a pusher that presses against the moving portion, the rotor of the motor. As the piezo plate vibrates, the pusher produces microimpulses against the rotor and drives it either forward or backward. Each oscillation creates only a few nanometers of movement, but the number of vibrations per second is so high that the rotor appears to move with a smooth motion over a virtually unlimited travel range.

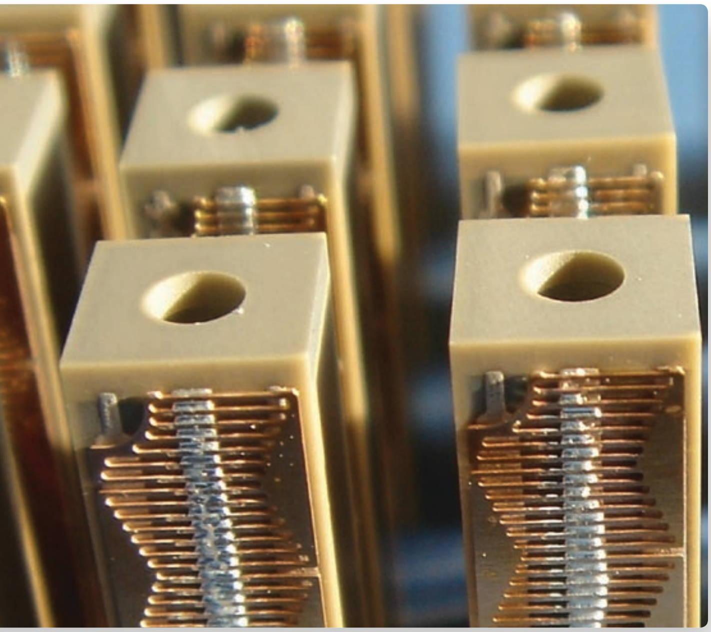


Various-shaped piezo devices serve specific purposes. Two linear stages (bottom and right) flank a circular rotary stage that uses three pushers that rotate the center collar.

Today's ultrasonic resonant motors, such as the PILine model developed by **Physik Instrumente,** Auburn, Mass., are characterized by speeds to 500 mm/sec. Such motors can produce accelerations to 10 *g*. The motor mechanisms are also stiff, a prerequisite for their fast step-and-settle times of a few milliseconds with resolutions to 0.05 µm.

Piezo-stepper-linearmotors usually consist of several individual piezoactuators and generate motion through a succession of coordinated clamp/unclamp and expand/contract cycles. Like the resonant motor, each extension cycle provides only a few microns of movement. Continuous motion arises from the high operating frequency that can create speeds up to 10 mm/sec.

Unlike the ultrasonic piezomotors that function through vibrations, piezo-stepper motors like Physik's PiezoWalk can achieve forces of up to 700 N (155 lb) with picometer (ρm or 1×10^{-12}-m) resolution. A resolution of 50 ρm (0.00005 µm) has been demonstrated. The motor can perform extremely high-precision positioning over long travel ranges. When it reaches position, it can switch



Stacks of encapsulated piezoceramic material will drive a rod actuator arm through the circular hole at the top of the stack.

to a highly dynamic motion system for tracking, scanning, or active-vibration suppression. Both the ultrasonic piezomotors and piezo-stepper motor can operate in the presence of strong magnetic fields or at low temperatures.

Types of actuators

There are a number of different piezoactuators and motor types currently available. Simple piezoactuators expand proportionally in relation to the drive voltage and are typically classified as stacked, shear, tube, or bender. The stacked actuator is the most common type. It develops a high force with fast response over a short travel. The shear actuator works best for lateral motions, such as fast, *XY* systems. It develops high force at high frequencies, but travel is typically limited to 20 µm. Tube actuators mostly serve in microdispensing applications and AFM scanners. Although the bender actuator can reach several millimeters of travel, its low force and low frequency limits its use.

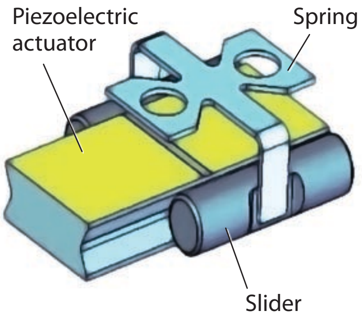
The virtually frictionless flexures and motion amplifiers used with flexure-guided piezoactuators give longer travel with an extremely straight motion. The motion is basically proportional to the drive voltage and integrated multiaxis systems are available. The “frictionless” operation minimizes wear and tear over an extended motion range of 2 mm or more.

As referenced earlier, ultrasonic-friction motors are based on high-frequency oscillation of a piezoplate (stator) to give unlimited high-speed motion with response times in the tens of milliseconds. This oscillation transfers to a slide or rotor via friction but this limits resolution typically to 50 nm.

Likewise, piezo-stepping motors basically possess unlimited motion range by an accumulation of small controllable steps. Direct piezo actuation can develop picometer resolution using a dither mode while generating forces to 155 lb for off-the-shelf units. This motor has a fast response of less than 1 msec with high stiffness.

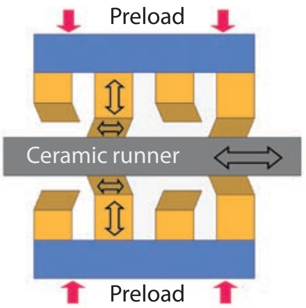
UItrasonic transducers use plate or disk-driven piezo elements with a high frequency at resonance. These ac-

Miniature ultrasonic motor



This miniature ultrasonic motor has only four parts, an ultrasonic piezoresonator and two lateral sliders pressed against it by a spring doubling as the moving carriage. The load is mounted directly to the carriage spring.

PiezoWalk Principle



In one type of piezoactuator, the PZT material consists of two levels that move at right angles. In a typical operation, the base material extends to push the tip against a ceramic runner. The tip is them powered to push the runner in the desired direction. Voltage is removed from the base to release the runner, and the tip them returns to its normal position.

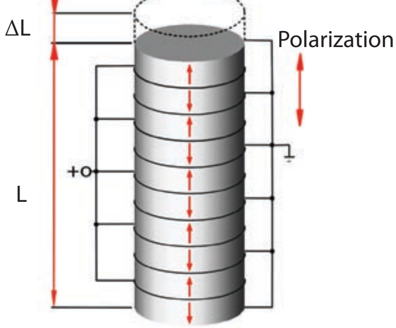
tuators are typically used as sensors, transducers, or in nebulizers.

Improved performance

Piezoelectric motors make medical devices smaller, more precise, lighter, and easier to control. For example, piezomotors are smaller and more compact than electromagnetic motors, yet can provide a greater force. The efficiency of electromagnetic motors falls as their dimensions shrink because more of their electrical power gets converted to heat. The efficiency of piezoelectric motors stays virtually constant. For the same volume and weight, the stored energy density of a piezomotor is 10× greater than that of an electromagnetic motor. The most advanced piezomotors are found in compact, high-speed micropositioning stages smaller than a matchbox. The smallest piezomotor-driven stages are currently found in autofocus devices for cell-phone cameras.

The higher force-to-size ratio of piezomotors lets engineers design smaller equipment and instrumentation devices while maintaining or improving performance through a number of different factors. For example, the direct-drive principle of piezomotors eliminates the need for supplementary transmissions or gear trains found with conventional electromagnetic motors. The mechanical-coupling elements otherwise needed to convert the rotary motion of classical motors to linear motion are unnecessary. Elimination of mechanical coupling avoids the usual backlash effects that limit accurate positioning. The intrinsic steady-state autolocking capability of piezoelectric motors also does away with servo dither inherent in electromagnetic motors. Piezomotors can hold their positions to nanometer accuracy even when powered down.

Piezo stack



A piezo stack does just that, stacks different piezo material to extend the overall length and motion.

Piezo devices provide faster acceleration and so can react in a matter of microseconds. Acceleration rates of more than 10,000 *g* with response times of 0.01 msec are possible.

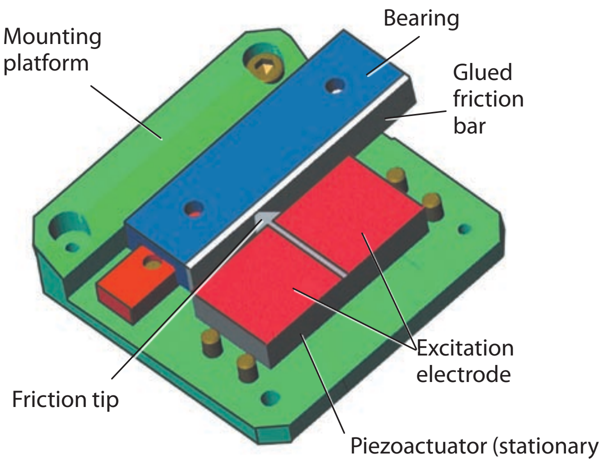
Piezoelectric motors are useful for medical and biotechnology applications as they do not create electromagnetic interference — nor are they influenced by it — eliminating the need for magnetic shielding. This is particularly important for motors within strong magnetic fields, such as those in MRI equipment. Small piezomotors find use in MRI-monitored microsurgery while larger piezomotors rotate patients and equipment. The magnetic fields and metal components in conventional electric motors make it impossible for motorized medical devices to function within MRI equipment.

Because piezomotion depends on crystalline effects and not rotating parts like gears or bearings, piezomotors are virtually maintenance-free and do not need lubrication. Additionally, they can be sterilized at high temperatures, a significant advantage in medical applications.

Static operation, even while holding heavy loads for long periods, consumes practically no power. Also, because miniaturization does not reduce the efficiency of piezoelectric motors, they are still effective in power ranges below 30 W. This makes piezomotors prime candidates for use in battery-operated, portable, and wearable medical devices because they can extend the life of a battery as much as 10×.

When at rest, piezomotors do not generate heat. They also eliminate servo dither and the heat that accompanies it.

In principle, piezomotors are vacuum compatible, a need for many applications in the medi-



Linear piezomotor

A compact piezomotor linear-translation stage uses a single actuator to push a bearing along a mounting-platform guide.

cal industry. They can also continue to operate at cryogenic temperatures close to 0°K.

Piezomotors are also not flammable and, therefore, safer in the event of an overload or short circuit at the output terminal, a considerable advantage for portable and wearable medical devices.

Medical applications

Finally, it is useful to consider medical uses where piezoactuators excel. In Optical Coherence Tomography, piezoelectric motors impart rapid periodic motion to the unit's reference mirror and imaging optics. To create 2D and 3D images from optical-interference patterns, optical fibers must move both axially and laterally during the scan. Piezomotors provide more-precise movements improving image resolution over conventional electromagnetic motors.

Piezoelectric actuators are finding use in transdermal-drug delivery and systems for needle-free insulin injection. End-effect manipulation of endoscope and gastroscope devices also employ piezoelectric devices.

The microrobot bases used with biomedical microtools such as tweezers, scissors, and drills are powered by piezomotors. Confocal microscopy in ophthalmology also uses piezoelectric motors for quality assurance of implants. The optics must move precisely to adjust the focal plane and for surface scanning. Piezoelectric positioning systems are integrated directly into the optics.

As shown, the growing need for accuracy in the micron and nanometer range, miniaturization of components, the dynamics of streamlining, and immunity from electrical interference push the physical limits for electromagnetic drive systems. Piezoelectric motors look to fill the gaps when the older technology hits its limitations. **MD**

RS# 165