

# Micro moves

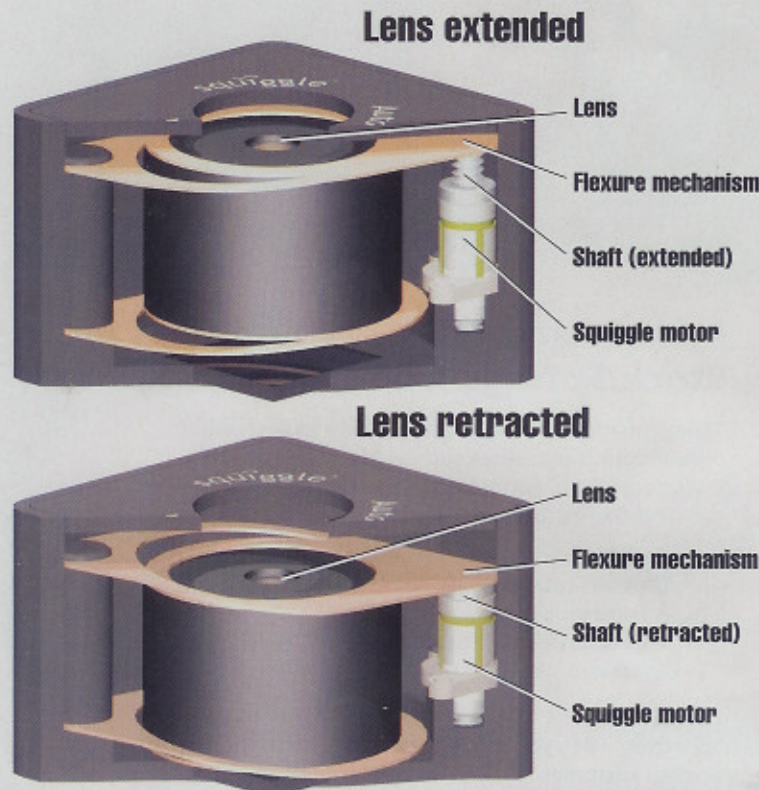
**Motors that can precisely position loads with micrometer-scale accuracy are now inexpensive enough for consumer electronics.**

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Nearly all mobile phones made today have built-in cameras. But there is a problem with these novel devices. They produce mediocre pictures, mainly because they have fixed optics. So the industry is now racing to improve image quality through use of motorized auto focus and optical zoom.

The task of motorizing a phone-camera lens is nontrivial. Ordinary electromagnetic motors are just too big for a cell phone and suck up too much power. That's why designs now on the drawing board adjust lenses via a different kind of motor that employs piezo materials to synthesize motion. Piezomotors employed in cell phones will make possible a lens system able to rival the performance of stand-alone digital cameras. The first of these devices will probably hit the market next year.

Piezomotors and piezoactuators are not new developments. Versions of them have long



**The Squiggle motor can power tiny movable lens assemblies for auto focus and optical zoom in cell-phone cameras. Here, the motor must be integrated with a lens-translation mechanism, typically a slide or flexure. The end of the Squiggle screw moves the lens mechanism with precise speed and micrometer resolution. The mechanism incorporates position sensing to produce controlled steps. The camera's CMOS image sensor, Hall-effect, optical, or potentiometer devices may do the position sensing. Motor-drive electronics may sit on a single ASIC device. New Scale is currently working with several IC makers to create customized ASIC chips for cell-phone cameras.**

served in such tasks as generating sonar signals and precisely positioning microscope slides. But recent advances have

brought costs down enough to make piezomotors candidates for consumer electronics. The same economics open up possi-

bilities for innovative applications in numerous other fields and particularly in medicine.

The potential of piezomotors might best be understood by examining one specific design that, among other things, will be used to adjust cell-phone camera lenses. Called the Squiggle motor, its limit of miniaturization is essentially determined by the ability to machine a tiny nut and screw. Squiggle motors with a cross section of  $2.4 \text{ mm}^2$  and a length of 6 mm are currently in production. At this size, the Squiggle motor offers 10 times better precision and consumes less power than electromagnetic motors able to do the same job. Like all piezoelectric devices, the motor creates motion using ultrasonic vibrations that are beyond the range of human hearing. Thus it operates quietly.

#### PIEZO MECHANICS

Piezoelectric ceramics change shape when subjected to electric fields. The typical piezoelectric material used in actuators and motors is dubbed PZT for the lead, zirconium, and titanium oxide that comprise it.

There is a distinction between piezoactuators and piezomotors. A typical PZT actuator is made up of stacks or plates of piezoelectric ceramic that directly support the load. Actuators directly use the material's changing shape to displace a load. They produce movements (strokes) that are typically  $<100 \mu\text{m}$ . Even the largest of them produce a stroke of much less than 1 mm. The amount of stroke available is directly proportional to the height of the PZT stack. And there is a practical limit to the stack size. Larger stacks tend to have high capacitance and more side-to-side

movement and thus are harder to control.

There are a couple of problems that make PZT actuators tough to use in consumer goods. PZT ceramics are fragile and sensitive to such shock loads as arise from a fall to the floor. This pretty much keeps them out of "droppable" products like cell phones. And PZT actuators only maintain their position when energized. They are electrically equivalent to capacitors and work from voltages that typically hit over 1 kV. All in all, the electronics needed to drive PZT actuators can be bulky and power hungry. This makes them problematic for use in battery-operated devices.

Piezomotors differ from piezoactuators in ways that let them avoid the drawbacks of fragility, limited stroke lengths, and power draw. Piezomotors tend to be more rugged because they isolate the PZT material from the load. They translate small PZT resonant vibrations into a larger, continuous mechanical motion that is potentially unlimited. But the precision of these moves is still measured in nanometers. Piezomotors also use highly efficient and miniaturized drive electronics and hold position with zero voltage and power.

Piezomotors are being viewed with new interest as designers of consumer and medical products pursue smaller products and longer battery life. Conventional electromagnetic motors run out of steam when put in extremely small packages. The problem is that more and more of the electrical drive power gets converted into heat rather than to mechanical motion. The impact on power



Squiggle motors can be supersmall. This model measures just  $2.4 \times 2.4 \times 10 \text{ mm}$ .

drain is obvious. And lower efficiency also means lower reliability because less torque is available to overcome friction in micro-gear mechanisms.

To make matters worse, smaller electromagnetic motors must also operate at higher rpm to generate enough mechanical power for practical work. The gear ratio reduction involved can be significant. The corresponding gear train tends to be complex, further reduces efficiency, and degrades precision.

Piezomotors typically eliminate any need for gear reduction because they drive loads directly. One way to understand the way a piezomotor generates motive force is to examine the patented Squiggle motor. It can move with 1,000 times more precision than an electromagnetic motor while hitting nanometer resolutions. In contrast, electromagnetic motors struggle to give micrometer resolution.

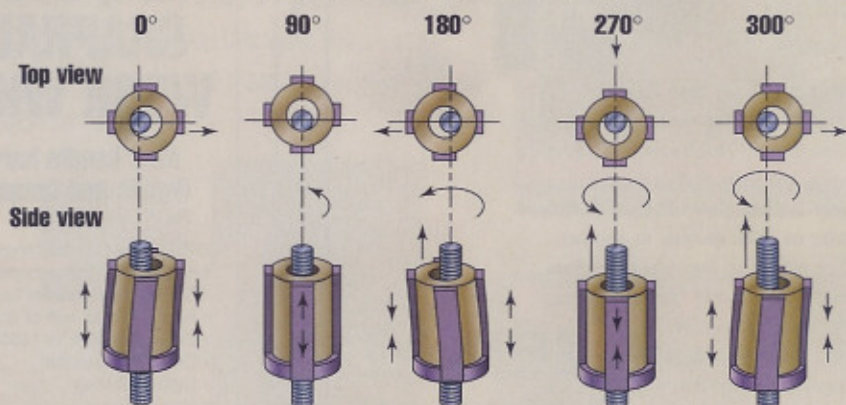
The Squiggle motor consists of piezoelectric actuators oriented longitudinally along a tube, a threaded nut, and a mating screw. Typically there are four piezoactuators which take the form of plates oriented so they lay every  $90^\circ$  on the tube surface. Alternating electric-drive signals are applied to these plates, positive drive on one side, negative on the other. This expands one plate and contracts the opposing plate.

The plates work together in pairs to rapidly bend the housing. The tube vibrates at its resonance frequency so its end moves in an orbital fashion. This orbital motion moves a nut affixed to the end of the tube in a "hula hoop" motion at a fixed (above 20 kHz) resonant frequency. The nut is threaded on a screw shaft. So it translates the tube's orbital motion into linear motion of the screw.

The drive frequency is fixed and set to the resonant frequency of the tube. The speed of the screw depends on factors that include the amplitude of the orbit, the amount of force acting on the shaft, and the coefficient of friction and surface finish of the threads. If there is no slip between the nut and shaft, movement per cycle is proportional to the amplitude of vibration. In general, the amplitude of the drive signals control-screw speed.

Similarly, the phase of the drive signals determines the direction in which the screw rotates. Reversing the phase makes the tube orbit in the opposite di-

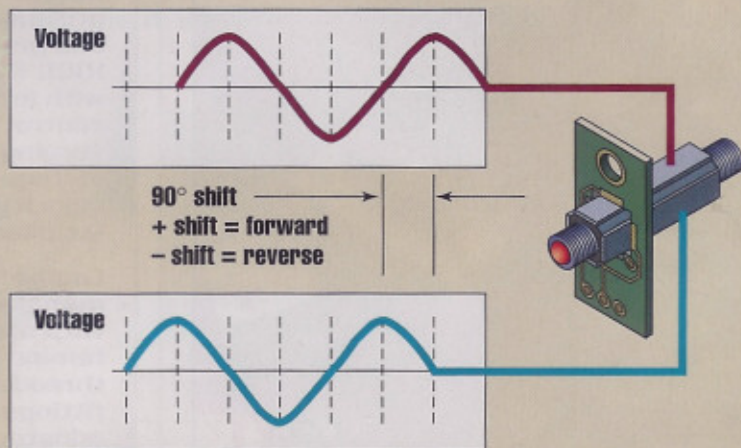
### Typical motion sequence



In Squiggle motors, piezoelectric actuators create ultrasonic vibrations in a tube, which makes a threaded nut at the end of the tube vibrate in an orbital fashion. The nut threads onto a screw shaft, translating the orbital motion into linear motion of the screw. Drive signals  $90^\circ$  out of phase with each other drive two sets of piezo actuators to produce the orbital motion. Reversing the phase relationship lets the device move the shaft in the opposite direction.

### Corresponding signal polarity and timing

(Shown exaggerated for clarity)



rection and thus reverses the screw shaft movement.

At resonance the amplitude of the orbit amounts to only a few micrometers. But each cycle adds together in creating continuous bidirectional screw movement. The screw motion has high preci-

sion, with stiffness and stability.

A point to note is that thread friction is an essential part of the drive operation. A step command to the Squiggle motor immediately moves the threaded shaft. This contrasts with electromagnetic motors, which connect to

the screw through couplings and gears. A step command to an electromagnetic motor must first move the gears, then the coupling, then the shaft. Gear and thread friction work against this motion and create wind-up, backlash, and position error.

Also of interest is that when the power to the Squiggle motor is off, the screw stays in its last spot. So the motor can move in small bursts and hold its position indefinitely. This, of course, can be a benefit in applications powered by batteries.

Finally, the Squiggle-motor design avoids the problem of fragile piezo material touching the load. Only the screw tip is in contact with the load, and it makes this contact through a friction tip. This arrangement protects the piezo ceramic from shock and helps makes the motor suitable for use in portable devices.

Squiggle motors can also replace micromotors in "smart" clothing for commercial and military uses. One example is in the "smart" running shoe that automatically adjusts insole stiffness based on the terrain and the wearer's stride. Other applications being tested include automated household valves and adaptive optics for defense and astronomy.

As the demand for smaller, more precise, and more reliable motors rises, you can expect to see piezomotors appearing in these and many other applications. **MD**

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## Implantable motors?

The small sizes and quiet operation of piezomotors make them candidates for implantable and wearable medical devices. Equally important is the negligible heat generated during their operation. Another plus is that a simple and elegant design with few moving parts translates into high reliability and long life.

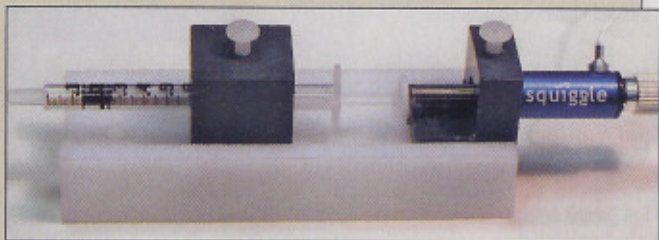
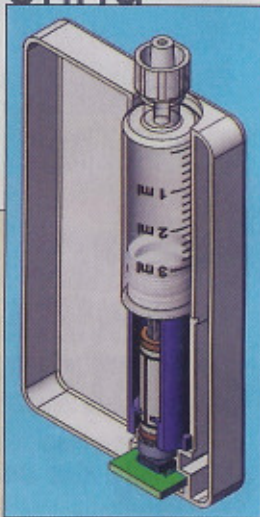
Perhaps of greatest interest to medical-device makers is compatibility with magnetic-resonance imaging (MRI) systems. Squiggle motors can

be made entirely of ceramics and other nonferrous materials. Unlike electromagnetic motors, they generate no magnetic fields when operating. This means Squiggle motors are unaffected by strong MRI magnetic fields, and their operation won't interfere with MRI images. Thus patients with implants incorporating a Squiggle motor can get an MRI scan.

Similarly, Squiggle-motor-powered devices can work near MRI machines. An example is remote-controlled robotic surgical devices that assist in MRI-guided procedures. Here Squiggle motors could precisely position tools under real-time visual control, as in intracranial procedures to treat brain tumors.

Squiggle motors may also let patients get wearable drug pumps, as for insulin, that are smaller and more comfortable. A design concept using a Squiggle motor for a wearable drug pump uses the motor's drive screw to directly push the syringe. High precision and high drive stiffness enable more precise dosing, permitting use of smaller reservoirs and more concentrated drugs. There is less "overshoot" if a line is temporarily blocked (occluded).

A design concept illustrates how a Squiggle motor might serve in a wearable drug pump. The motor drive screw directly pushes the syringe to dispense the drug.



Squiggle motors dispense magnetic resonance (MR) contrast media to animals during MR imaging in a setup similar to the one depicted here at the Preclinical Imaging Facilities of the Roswell Park Cancer Institute. The motor screw pushes the syringe plunger with high precision. The assembly can sit within the magnetic bore of an MR scanner to minimize catheter length. (Biophan Technologies distributes the New Scale motors exclusively in the medical market.)

The motor easily produces tiny steps at rates ranging from micrometers per minute to micrometers per hour for basal and bolus drug delivery, and also moves at millimeters per second for reservoir replacement and priming. An optional magnetic rotary encoder measures each step with submicrometer accuracy for 0.01-unit dosage control. It is possible to sense overforce errors, which indicate blocked drug flow, based on reduced shaft rotation or by directly measuring the magnetic sensor gap.

The input power for each per basal dosage step is a few millijoules. Batteries will last about three months at this rate in typical uses.