Piezo Motor Based Medical Devices

Piezo motor technology is still in its relatively early stages of application development, but is already demonstrating the tremendous value and functionality it offers in medical devices. These motors are very small, yet enable long-range and precise motion. This article reviews several solutions in which piezo motor technology is enhancing the capabilities of medical devices.

By Ralph Weber

The piezoelectric effect is used in one of two ways: applying a mechanical stress to piezoelectric materials produces an electrical charge; or conversely, an applied electrical charge produces a mechanical strain or motion in a piezoelectric material. Since its discovery in 1880, the piezoelectric effect has evolved from a laboratory curiosity to a mature technology. Piezo sensors and actuators are common in sonar systems, proximity sensors, pressure sensors, ink jet printers, speakers, microphones, and many other applications.

Recently, engineers have developed various techniques to magnify the tiny deflections of piezo actuators to create longer range motion. These devices, commonly known as piezo motors, have long been used for microscopy and nanopositioning applications in medical research labs. Motors such as the piezo stepping drives from Physik Instrumente, with high force and precise positioning, are an excellent fit for these applications.

Ralph Weber is the director of the Standard Products Division of New Scale Technologies Inc. He is responsible for product management of the company's piezoelectric micro motors and miniature position sensors. Weber can be reached at 585-924-4450 x131 or rweber@newscaletech.com.

Recent design innovations have created piezo motors with dramatically smaller size, greater robustness and improved manufacturability. With these improvements, piezo motors are now expanding into applications such as hand-held clinical diagnostics systems and implantable medical devices.

An example of this piezo micro motor technology is the Squiggle motor from New Scale Technologies Inc. (Figure 1). The patented piezoelectric linear Squiggle motor uses piezo ceramics to create ultrasonic standing wave vibrations in a threaded nut, which directly rotates a screw.[1] This unique operating principle "wraps" the vibration motion of the nut around the screw threads to directly produce linear movement without additional mechanical conversion. The result is a tiny motor, less than 2.0 × 2.0 × 6.0 mm in size and weighing less than 2.0 grams, capable of producing up to 30 gram force linear push force with sub-micrometer position resolution and velocity control. It is controlled by an ASIC driver, which can be powered by a 3V lithium battery. ASIC communication is via an I2C interface.

The introduction of new multilayer co-fired piezoelectric ceramic elements, developed by TDK-EPCOS, into the Squiggle motor will eliminate the need for an external voltage boost circuit, reducing the total size of the motor drive circuitry to about 3.0 × 3.0 mm.

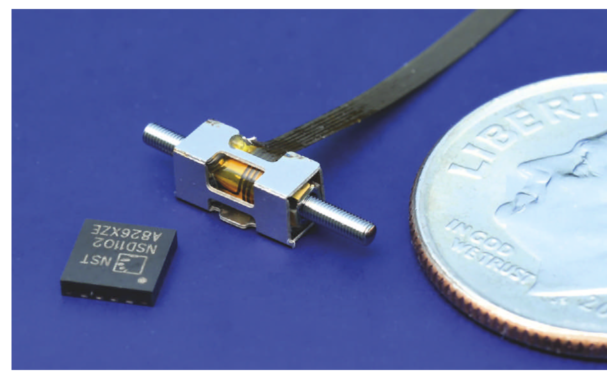


Figure 1: Piezo micro motors such as New Scale's Squiggle motor are being designed into novel medical diagnostic systems, surgical tools, and implantable devices.

This motor has 10 times higher stored energy density than an electromechanical micro-motor and can therefore be one-tenth the size for equivalent performance. In addition, it has fewer parts, does not generate electromagnetic noise, and can be readily made for MRI compatibility.[2]

Piezo Motors for Micro and Nanofluidics

The precision and unique power-to-size ratio of piezo motors make them useful for precision pumping of microliter and nanoliter volumes of fluids; for example, in laboratory devices utilizing lab-on-a-chip elements and point of care devices, such as insulin metering pumps. The piezo micro pumps currently available generally employ flexing diaphragms and peristaltic motion, creating pulsed pressure flows in the nanoliter range.[3-6]

Using piezo motors in a reciprocating piston micropump design can overcome several of the limitations of existing designs. It provides quiet operation, no pressure pulses, much greater output pressure and flow, and robust priming and pumping of fluid that contains air bubbles or particles.

Dr. Kwang W. Oh of the SUNY Buffalo Nanobio Sensors and Microactuators Learning Laboratory is developing a miniature pump based on this reciprocating piezo motor design for use in lab-based assay fluidic delivery.[7] Applications include polymerase chain reaction as well as potential application in point of care testing, diagnostics, and delivery systems.

The basic pump design features two reciprocating pistons. Each piston is driven by a linear Squiggle piezo motor to precisely control the fluid dispense rates (Figures 2A and 2B).

This pump can achieve nanoliter flow resolution and a uniform flow rate of up to 60 microliters per minute. The flow rate remains accurate independent of high system back pressure. The small size of the system greatly reduces the waste of expensive reagents.

A proof-of-concept pump system using the 1.8 × 1.8 mm Squiggle motor has been tested in Dr. Oh's lab and incorporates a microfluidic valve design using two additional Squiggle motors as active check valves. The fluid channels for pumping and for valve actuations are incorporated in a small, multilayered PDMS structure. Miniature Tracker position sensors will be implemented to further control the motor position for added precision.

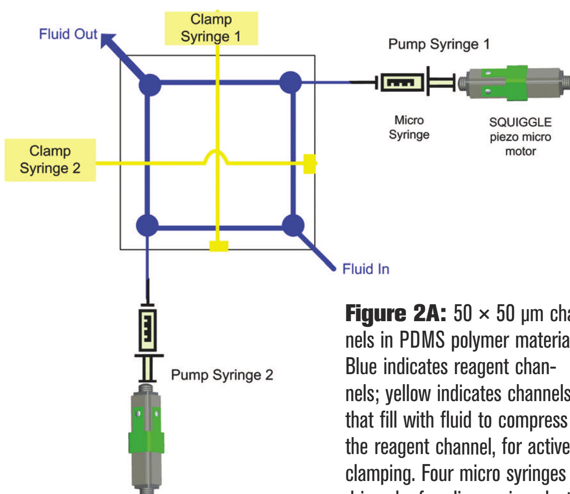
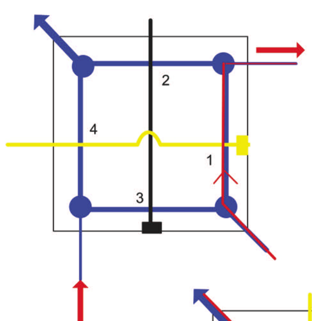
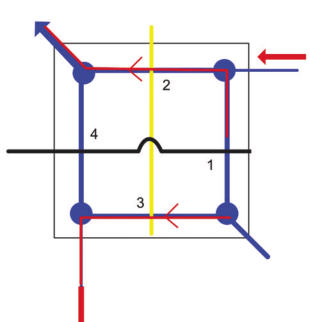


Figure 2A: 50 × 50 µm channels in PDMS polymer material. Blue indicates reagent channels; yellow indicates channels that fill with fluid to compress the reagent channel, for active clamping. Four micro syringes are driven by four linear piezoelectric micro motors (Squiggle motor). The pump syringes will also employ Tracker position sensors for additional precision in the flow rates. The small size of the pump allows the system to be used in battery-operated, handheld devices.





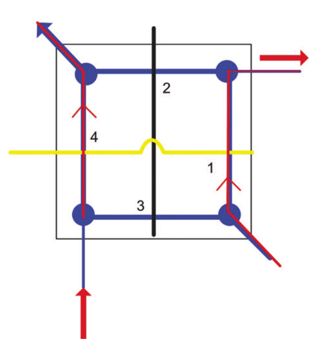


Figure 2B: Step 1 (top): Pump syringe 1 retracts. Pump syringe 2 extends. Clamp syringes close channels 2 and 3. Channel 1 fills. Step 2 (middle): Pump syringe 1 extends. Pump syringe 2 retracts. Clamp syringes close channels 1 and 4. Channel 2 empties and channel 3 fills. Step 3 (bottom): Pump syringe 1 retracts. Pump syringe 2 extends. Clamp syringes close channels 2 and 3. Channel 1 fills and channel 4 empties. Repeat steps 2 and 3. This reciprocating piston design provides high force, precise flow rates, and good performance with fluid containing contaminants or air bubbles.

Implantable Devices

Piezo motors are of interest for implantable devices due to their small size and high precision, as well as due to the fact that the piezo ceramics are inherently non-magnetic. Some areas of significant opportunity include implantable drug delivery systems, orthopedics, and audiology.

Piezoelectric transducers are in use in middle ear implants, such as those created by Envoy Medical. The transducers convert external sound to an electrical signal that is amplified and transmitted via piezo elements as sound energy directly to the inner ear.

Piezo motors are being investigated to provide the longer range motion needed to adjust the initial applied load of the transducer on the ossicular chain, which is critical to optimal performance of the implant. Manual adjustment during surgery turns out to be quite difficult; moreover, the adjustment needs to be refined as juvenile patients grow. An actuator to replace the manual micrometer used for this purpose must be less than 2.0 mm diameter, have positioning accuracy better than 5.0 micrometers, a travel of 1.0 mm, and a force of 100 mN. Researchers at the Fraunhofer Institute and University of Tübingen have demonstrated active positioning technology that can be applied *in situ* for this purpose. The fine tuning of the loading could be performed post-operatively using a Squiggle piezo motor (Figure 3).[8] An additional benefit of the Squiggle motor's design is the self-locking screw that holds its position when power is turned off.

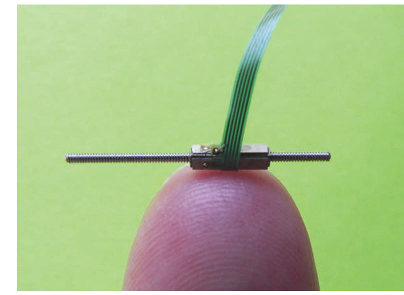


Figure 3: The Squiggle motor tested for positioning of implantable hearing aids is only 1.8 × 1.8 × 6 mm and locks into position when the power is turned off.

Piezo Motors in Surgical Robots

The unique properties of piezo systems are already being harnessed for surgical applications. For example, a piezosurgery system from Mectron uses high frequency piezo-generated oscillations between 24,000 and 29,500 kHz, modulated with a low frequency of 10 to 60 Hz, to enable specialized cutting tips to modify bone structures while minimizing soft tissue damage. These systems are designed for fine bone sculpting in procedures such as orthodontic surgery and maxillary sinus surgery.

Using the piezo motors for longer travel, a team led by Dr. Cameron Riviere of The Robotics Institute at Carnegie Mellon is developing a miniature mobile robot called the HeartLander for minimally invasive cardiac surgery. The HeartLander attaches to the surface of the heart using suction and travels in an inchworm fashion across the heart, under the pericardial sac. Piezoelectric Squiggle motors onboard the robot—selected for their small size and robust performance high axial forces—provide propulsion and control (Figure 4).

The HeartLander has been demonstrated to move over the surface of a pig's beating heart and can deliver an injection to a positional accuracy of 1.0 mm. This NIH-funded project is paving the way for minimally invasive cardiac procedures such as heart monitoring, placement of sensors or pacemakers, injections, and eventually surgical procedures.[9]

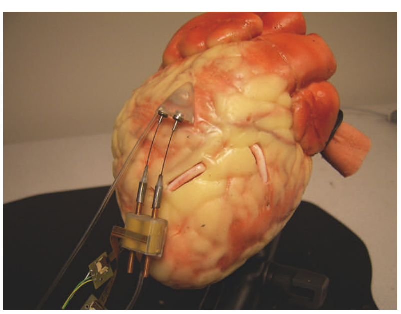


Figure 4: Photograph of the HeartLander OMNI prototype on a plastic beating heart model (synthetic pericardium not shown).

Conclusion

Piezo motor and actuator technologies are advancing at a rapid rate. This expansion in materials and configurations will open up new avenues for implementation in medical devices. Advances such as lower voltage, multilayer piezo actuator devices, and miniaturization of the drivers for these actuators will be key enablers and will pave the way for additional medical applications. New unique and exotic piezo materials derived from a class of materials called electroactive polymers may also open up new avenues for technical advances. The leaps that are occurring in this technology, the rapidly expanding integration flexibility, and utility of the technology will ensure a place for piezo motors and actuators in the medical and life science fields.

References

[1] US Patents 6,940,209; 7,170,214; 7,309,943; and 7,339,306.

[2] Kenji Uchino "Nice Little Movers." Medical Device Network Feature: 5-1-2006.

[3] Laser, DJ and Santiago, JG "A Review of Micropumps." *Journal of Micromechanical Microengineering*. 14: 2004; p. R35-R64.

[4] Kwang W. Oh and Chong H. Ahn "A review of microvalve." *Journal of Micromechanics and Microengineering*. 16: 2006; p. R13–R39.

[5] Nguyen, N.T., et al. "MEMS-Micropumps: A Review." Transactions ASME. *Journal of Fluids Engineering*. 124: 2002; p. 384–92.

[6] US Patent US 5,759, 015.

[7] Henderson, David "Novel Piezo Motor Enables Positive Displacement Pump." Technical Proceedings of the 2007 NSTI Nanotechnology Conference. Volume 1-4.

[8] D. Kaltenbacher, et al. "Autonomous Positioning System for Implantable Hearning Aids Using Piezo Motors," *Actuator* 2008; p. 142.

[9] P. Allen, et al. "A Mobile Robot Driven by Miniature Onboard Motors for Cardiac Intervention." 34th Annual Northeast Bioengineering Conference. 2008; 9-10.

ONLINE

For additional information on the technologies and products discussed in this article, see *MDT* online at www.mdtmag.com and the following websites:

- www.newscaletech.com
- small.buffalo.edu
- www.envoymedical.com
- www.fraunhofer.de
- www.uni-tuebingen.de
- www.ri.cmu.edu