Piezoelectric All-Rounder

Sensor, Actuator or Both?

The Piezo Effect

By the end of the 19th century Jacques und Pierre Curie had already discovered that an electrical potential could be generated by exerting force on a quartz crystal. They named this phenomenon the “piezoelectric effect” from the Greek word “piezo” meaning "to press". Later they realized that electric fields cause deformation of piezoelectric materials. This is known as the “inverse piezo effect”.

The direct piezo effect can be used in sensing applications, while the inverse effect is employed in actuators. In the correct combinations, piezoelectric materials can thus be used to create the most versatile of devices.

With the DuraAct Patch Transducer (Fig. 1), a very versatile piezoelectric device which will find wide application both in industry and in research is now commercially available. This compact unit can be used either as sensor or actuator: its uses range from energy harvesting to self-regulating adaptronic systems (see Adaptronics: New Technology with a Bright Future on p.4).

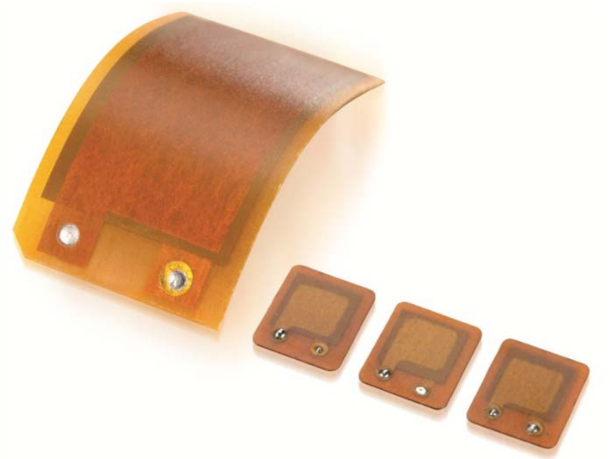

Fig. 1 Sensor, actuator or both: multi-talented piezo-electric elements

Design and Working Principle

DuraAct patch transducers are based on a patented development by the German Aerospace Center (DLR). The transducers are fabricated by INVENT GmbH in Braunschweig, the piezoceramics used are provided by PI Ceramic.

The finished devices are marketed exclusively by PI Ceramic from their headquarters in Lederhose. Despite their versatility, the design and working principle of the piezoelectric patch transducers is easy to understand (Fig. 2).

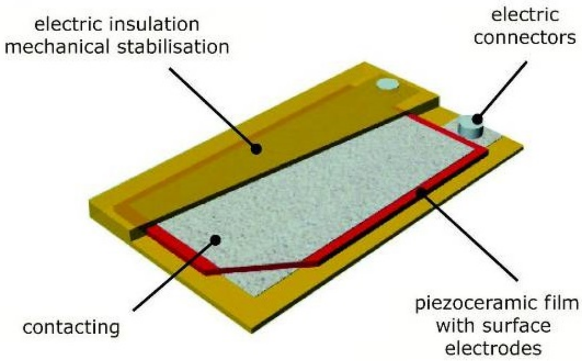

Fig. 2 Schematic design: at the heart of the transducer is a piezoceramic film with an electrically conductive layer applied to each side. This construction is then embedded in a flexible polymer strip

At the heart of the transducer is a piezoceramic film with an electrically conductive layer applied to each side. This construction is then embedded in a flexible polymer strip. The advantages of this design are multiple: the piezoceramic is electrically insulated, mechanically preloaded, and, out of the basically brittle ceramic, a unit is created which is so robust that it can be affixed to surfaces with curvature radii as low as 12 mm (Fig. 3).

Fig. 3 Curvatures with radii as low as 20 mm are easily accommodated

The transducers can simply be glued to a surface, or they can be integrated directly into a structure or structural material. Custom transducer geometries are also possible, as is customization of the curvature, dimensions and thickness of the ceramic, to fit the specific application. The same is true for the properties of the ceramic depending on the operating temperature and the configuration of the electrical connections.

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Actuators Exploit the Inverse Piezo Effect...

The electrical design is basically that of a plate capacitor. The ceramic serves as dielectric between the two metalized surfaces which act as the plates. When an electric potential is applied, a field with lines running through the ceramic perpendicular to the plates is created. This causes a contraction of the ceramics at 90° to the field lines, i. e. the piezo ceramic contracts evenly in the plane. This deformation can be transmitted to structural elements, where, when attached to only plane, it causes the structure to bend (Fig. 4). The force is transmitted over a surface, not just at discrete points as with conventional actuators, making reinforced force transmission points superfluous.

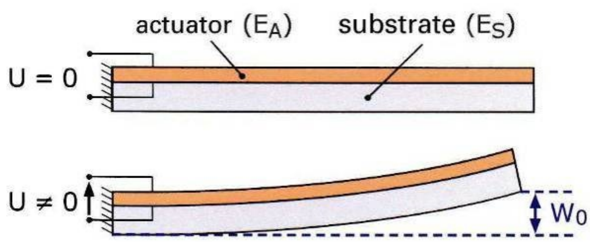

Fig. 4 *For actuators the inverse piezo effect is employed; the way these piezo actuators are affixed to the substrate makes them operate as benders*

The patch transducers can also operate well under high dynamic loads. Because the transducer motion depends on solid-state crystalline effects and involves no sliding or rotating parts to cause wear, failure rates are very low. Their life expectancy is over 10^{10} cycles, giving them an excellent fatigue resistance rating.

DuraAct patch transducers are currently available in standard sizes with ceramic thicknesses of 0.1 mm, 0.5 mm and 0.8 mm.

The contractions obtained with the maximum operating voltage is 400 µm/m, 650 µm/m or 800 µm/m, respectively. The operating temperature range goes from -20°C to +120°C (-4°F to +248°F).

Because of their high bandwidth, reaching into the kilohertz range, patch transducers together with the appropriate control electronics, can be used as precision, high-dynamics positioning elements with submicrometer accuracies.

... While Sensors Use the Direct Piezo Effect

Conversely, when the transducer is subjected to deformation, an electric potential is generated, making it possible to use the element as a sensor (Fig. 5). The changes in electric field in reaction to deformations of the piezoceramic are extremely rapid, allowing measurement of vibrations in the kilohertz range.

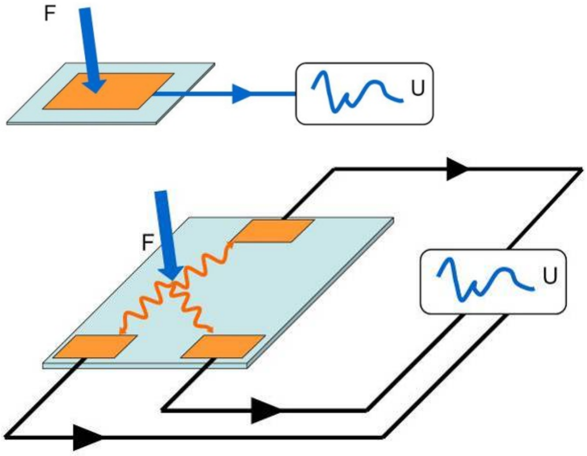

Fig. 5 Classical application of the direct piezoelectric effect in a sensor: the smallest motion of the substrate is transferred to the transducer where it produces an electric signal proportional to the displacement

When integrated in a servo-control loop, patch transducers give very good results in applications like vibration control. There, a sensor signal from the transducer is used to control a separate damping system.

Patch transducers can also be used in the area known as structural health monitoring (Fig. 6). In those applications, they are integrated in the structure to be monitored, e.g. part of a machine or an airplane wing, where they detect possible degradation.

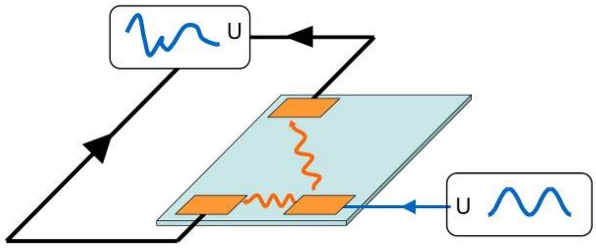

Fig. 6 Wide areas can be monitored when an array of modules is affixed to the surface; some act as actuators and some as sensors to pick up auto-resonance effects. Comparison to a reference signal made under ideal conditions then provides information about the current condition of the part

Energy Autonomy and Adaptive Systems

Another interesting application area is energy harvesting. The conversion of up to kilohertz mechanical vibrations into electricity can yield power in the milliwatt range, sufficient for running small circuits for LEDs, sensors or micro-power transmitters. In such constellations, the patch transducers act as tiny generators (Fig. 7).

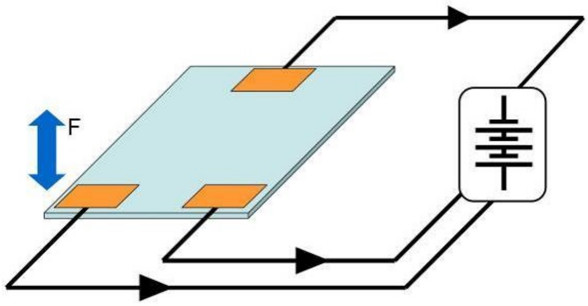

Fig. 7 The absorbed mechanical energy is converted to electrical energy; this makes the patch transducer into a mini-generator with which energy-autonomous systems can be built

For structural health monitoring, for example, this could make for a totally wireless system made up of simple elements. The transducer acts as a deformation sensor and at the same time supplies power to a mini-transmitter which sends the data to a nearby structure-monitoring station.

This is the better part of an energy-autonomous monitoring and warning system, in which external power and batteries are unnecessary.

For the applications described so far, the transducers are made with a single piezoceramic layer. It is equally possible, however, to fabricate multilayer elements, which in turn open up new and interesting possibilities. In actuators, multiple layers operated in parallel can increase the force generated for the same operating voltage. If the layers are operated independently, then the transducer can be operated as a sensor and actuator at the same time, i.e. without the delay inherent in switching a single-layer device from one mode to the other.

With appropriate electronics, an adaptive system can be built which detects mechanical shock or vibration and also damps it out. Compatible control electronics can be found in the extensive product palette of Physik Instrumente (PI). In addition, customized versions can be provided at any time.

Adaptronics: New Technology with a Bright Future

The young technology of adaptronics has been attributed the brightest of prospects. With adaptronics systems, undesired noise and vibrations can be suppressed, and material flaws in structures from machine parts to bridges can be detected before they become dangerous cracks.

Intelligent, adaptive, “smart” materials with integrated actuators and sensors open new horizons for designers and product developers. The concept of adaptronic materials is modeled on the behavior of biological systems, which are capable of reacting intelligently to changing environments.

Possible applications range from automotive, industrial engineering, medical technology, metrology to aeronautics and aerospace. In this context, piezoelectric patch transducers like the DuraAct described here can expect wide application.

Conclusion

DuraAct patch transducers are very versatile piezoelectric elements which can be used as both sensors and actuators. When used as actuators the transducers change shape, when a voltage is applied, and generate useful forces. Used the other way they convert mechanical deformation into measurable electric charge and thus act as sensors. In both cases the transducers consist basically of a piezoceramic film, which can be adapted to meet application-specific requirements such as bending radius, nature of the ceramic and design of the electrical connections.

The patch transducers can also cope with high dynamic loads for an average lifetime of more than 10 billion cycles.

They have low susceptibility to wear and faults because the transducer operates on the basis of crystalline solid state effects, i.e. they do not contain moving parts. In addition to their use as sensors or actuators, DuraAct patch transducers can also serve as mini-generators. For the so-called "energy harvesting" the transducers convert mechanical oscillations into electric voltage and thus provide a self-sustaining monitoring and warning system.

More information on DuraAct piezoelectric patch transducers is available at:

http://www.piceramic.com

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PI Ceramic in Brief

PI Ceramic is considered a global leading player in the field of piezo actuators and sensors. The broad range of expertise in the complex development and manufacturing process of functional ceramic components combined with state-of-the-art production equipment ensure high quality, flexibility and adherence to supply deadlines.

Prototypes and small production runs of custom-engineered piezo components are available after short processing times. PI Ceramic also has the capacity to manufacture medium-sized to large series in automated lines. PI Ceramic, a subsidiary of Physik Instrumente (PI) GmbH & Co. KG, is located in the city of Lederhose, Thuringia, Germany.