Piezo Elements for a Multitude of Sensor Applications

From Level Measurement to Adaptive Systems Technology

The Piezo Effect

Piezoelectric materials can produce an electric voltage when a force is applied to them (piezo effect), and they can change their dimensions when an electric field is applied (inverse piezo effect). They convert mechanical power into electrical power and vice versa; they are also referred to as transducers. While the inverse piezo effect can be used for actuator applications, the direct piezo effect or a combination of both effects lends itself to the manufacture of sensors. The piezo effect is based exclusively on displacements within the crystal lattice of the piezoelectric element. It is therefore not subject to any mechanical friction or wear in the classical sense and is highly sensitive. Even the smallest deformations directly produce a measurable charge displacement, and conversely, a small electrical voltage produces an immediate displacement of an actuator. This opens up a multitude of potential applications, starting with ultrasonic, force or acceleration sensors up to complex adaptive systems.

Generating and detecting ultrasound, for example, is a classic piezo application because piezo elements start to oscillate when an AC voltage is applied. The short response times and the resulting high dynamics allow high oscillation frequencies of up to 20 MHz. Ultrasound is sound with frequencies above the range of human hearing frequencies, in other words starting at around 16 kHz. This frequency range is used for many purposes in industry, medical engineering, and research. Applications range from distance measurement and object recognition, filling level or flow measurements, through high-resolution material tests, up to medical diagnosis and therapy. Piezoceramics can be cost-effectively manufactured in any shapes and thus offer tailor-made solutions for different applications.

Flexible in Respect to Frequency and Design

The piezo elements from PI Ceramic are suitable for a multitude of ultrasonic applications. These can be generally classified in mainly sensor applications for frequencies of up to 20 MHz and power ultrasound, in which the energy densities are higher.

Here, the piezo elements carry out considerable mechanical work; they crush kidney stones for example or remove plaque, provide the mechanical energy for cleaning baths as well as for industrial welding and bonding. The typical frequencies of power ultrasound are between 20 and 3000 kHz.

Fig. 1 Many variants of piezo elements are possible, e. g. tubes, disks, benders, shear elements or translators, which makes it easy to adapt them to the respective application

With piezo components, different geometric variants and resonant frequencies can be realized in addition to the material selection for the respective application (Fig. 1); components such as piezoceramic rings, piezo tubes and shear elements with standard dimensions can be delivered on very short notice on the basis of semifinished products in stock. Geometries beyond the standard dimensions are also available upon request.

PI Ceramic furthermore ensures integration in the final product. This includes the contacting of the elements according to customer specifications as well as mounting in provided components, gluing or potting of the ultrasonic transducers. To measure the flow, filling level and force or acceleration, customized sensor components are manufactured that can be easily integrated in the respective application.

Level Measurement

The application areas of piezoelectric components in industrial sensors vary widely: ultrasonic delay measurement, for example, uses the direct as well as the inverse piezo effect. A typical application is the measurement of filling levels (Fig. 2). The piezo transducer is placed outside of the medium to be detected and works as a transmitter and receiver. It emits an ultrasonic pulse that is reflected by the filling medium. The propagation time required is a measure of the distance travelled in the empty part of the container. This makes non-contact measurements possible in which the filling level of liquids as well as of solids, e.g. in silos, can be measured through distance measurement. The resolution or accuracy depends on how good the ultrasonic pulse is reflected by the respective surface.

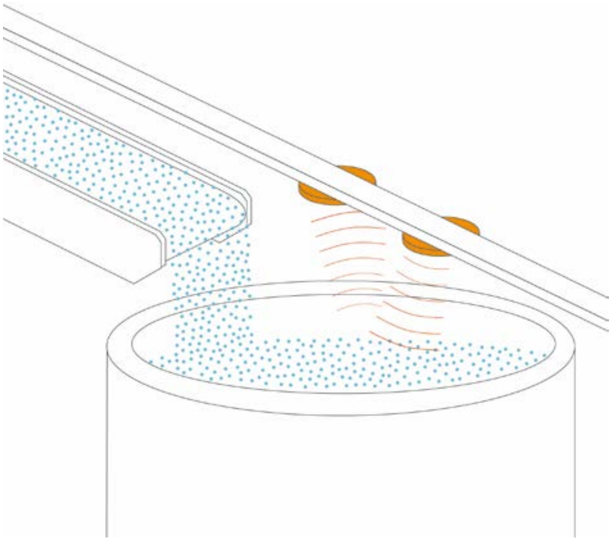

Fig. 2 A typical application for propagation time measurement is the measurement of filling levels

Piezo elements can be used as level switches in so-called submersible transducers or tuning-fork sensors (Fig. 3). These are then placed at different heights of the container. The piezo transducers excite a tuning fork at its natural frequency.

When it comes into contact with the medium, the resonant frequency shifts and the shift is electronically analyzed. This method is very reliable and completely independent of the type of filling medium.

Fig. 3 Example of a tuning fork for filling level measurement

Air Bubble Detection and Flow Measurement

In monitoring dosing and filling systems, it is often necessary to ensure an undisturbed flow without air or gas bubbles. This is done with so-called ultrasonic bubble detectors. The piezo elements in these sensors serve to generate and receive ultrasonic waves. The sensors are mounted on the outside of tubes and operate without coming into contact with the transported medium; they therefore do not interfere with the flow rate, nor is there any danger of contamination, and a continuous quality monitoring is ensured.

Similar advantages are found with flow measurement. This is based on the time difference during the alternate transmission and receiving of ultrasonic pulses in and against the flow direction (Fig. 4).

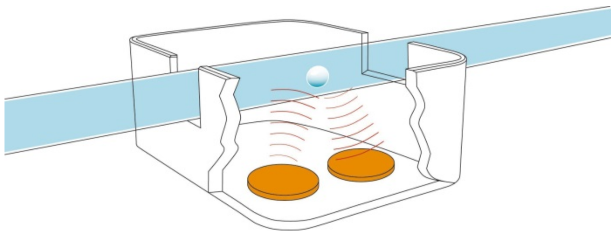

Fig. 4 The flow measurement is based on the alternate transmission and receiving of ultrasonic pulses in the direction of flow and in the opposite direction

Here, two piezo transducers operating as both transmitter and receiver are arranged diagonally to the direction of flow. When using the principles of the Doppler effect, the phase and frequency shift of the ultrasonic waves which are scattered or reflected by particles of liquid are evaluated.

The frequency shift between the reflected wavefront emitted and received by the same piezo transducer is proportional to the flow speed. Many other tasks can be effectively solved in a similar way, such as object recognition or high-resolution material tests.

Acceleration Sensors and Force Transducers

Ultrasound does not always play a role in sensor applications of piezo elements. A typical example of this is piezoelectric acceleration sensors. At their heart is a piezo element that is connected to a seismic mass. If the overall system is accelerated, this inert mass amplifies the mechanical deformation of the piezo disc and thus increases the measurable voltage created by the piezo effect.

The sensors detect accelerations in a broad range of frequencies and dynamics with an almost linear characteristic over the complete measurement range. They are suitable for measuring dynamic tensile, pressure and shear forces. They can be designed to be very stiff and can also measure highly dynamic forces. The very high resolution is also typical.

A Combined Discipline: Adaptive Systems Technology

A special type of sensor application is energy harvesting. With the DuraAct patch transducer (Fig. 5), a very versatile piezoelectric device is now commercially available that will find wide application both in industry and in research. A special manufacturing method makes the ceramic extremely bendable, which allows it to be attached to moving structures, where it gets deformed and thereby generates charge transfers that can be used as electric energy.

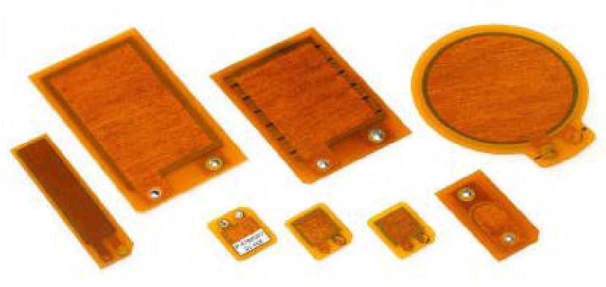

Fig. 5 Sensor, actuator or both: DuraAct piezoelectric elements

Another current example are adaptive systems technology solutions, in which the DuraAct transducer can be used as both sensor and actuator. These systems can be used to measure interfering vibrations and compensate them at the same time. In turn, Structural Health Monitoring involves generating vibrations and measuring their propagation in material structures. A changed vibrational pattern shows failures in the structure even before fissures arise, e.g. in machine parts, bridges, wings, etc.

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 bending radii as low as 20 mm (Fig. 6).

Fig. 6 Bending radii of up to 20 mm can be easily realized with DuraAct patch transducers

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 for this structure, as is customization of the shape and thickness of the ceramic to perfectly fit the specific bending radius required. The same is true for the electrical connections. Once again, piezoelectric elements prove their versatility, which will continue to open up further areas of application for them in sensor technology.

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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.

PI Ceramic GmbH in Lederhose, Thuringia, Germany