The piezo effect and its applications

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The **piezoelectricity** effect describes the interplay of mechanical pressure (Greek: piézin – compress, press) and electric voltage in solids. It is based on the phenomenon that electric charges occur on the surfaces of certain materials when they deform.

The way in which many living organisms use piezoelectricity is very interesting: Bones act as force sensors. When force is applied, bones produce electric charges proportional to the internal loading. These charges stimulate and cause new bone material to build up, which results in strengthening the bone structure in those places where internal displacement is most severe. This results in loading-specific minimum structures and thus an excellent weight-to-strength ratio.

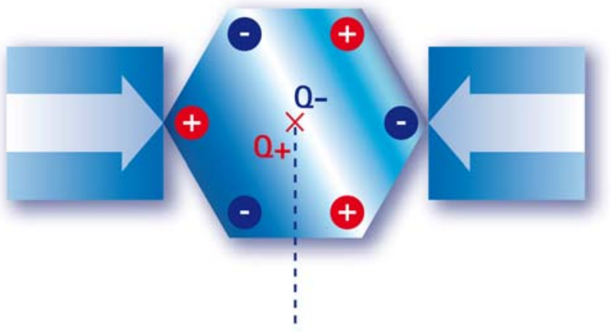

Fig. 1: Piezoelectric effect: voltage is produced by an applied force on certain materials

Discovery

The electrical properties of tourmaline (the precious stone attracts ash particles when heated in a glowing fire) have been known for many years. Temperature-dependent electricity led Coulomb and Becquerel to suspect that there was also pressure-dependent electricity. They worked at this theory, but could not yet provide any proof. After many false starts, where usually what was being described was frictional electricity, in 1880, the brothers Pierre and Jacques Curie finally discovered the piezoeffect on tourmaline.

They could prove by experiment that a surface voltage developed as soon as mechanical pressure was applied to the crystal. A little later, they also found this property in other crystals, such as quartz and topaz.

The two brothers called their discovery polarelectricity, although this expression soon gave way to the name piezoelectricity. In 1881, Gabriel Lippmann predicted the converse piezoeffect, that is, the deformation of the crystal because of an applied electrical field. The Curie brothers agreed with Lippmann. Ultimately they were also able to prove this by experiment. Looking back, the achievement of the Curie brothers is truly remarkable, when you think of the resources he had available. They succeeded in proving the piezoeffect with tinfoil, glue, wire and magnets, but their most important asset of all was their keen insight.

Materials

Two important groups of materials are used for piezoelectric sensors: piezoelectric ceramics and single crystal materials. Ceramics (such as PZT) are produced by sintering processes and have a piezoelectric constant that can be two orders of magnitude higher than that of the crystal materials. Unfortunately, this high sensitivity is associated with poorer long-term stability. Imagine that piezoelectric ceramics are like a magnetized iron bar (or a music cassette). The magnetization is additionally "impressed" and cannot be changed.

Single crystal materials (such as tourmaline, quartz, gallium phosphate: GaPO4) are just the opposite. Here the specific structure of the crystal lattice is responsible for the effect. In general, crystals are less sensitive, but have significantly higher, virtually infinite long-term stabilities.

Fig. 2: Gallium phosphate (GaPO4) stands out due to its very high, long-term stability

Some of the materials used - particularly gallium phosphate and tourmaline - have excellent stability over wide ranges of temperature, making it possible to extend the field of application for piezoelectric crystals to almost 1000 °C.

All piezoceramics and tourmaline are not only piezoelectric, they are also pyroelectric. This means that a charge signal is released not only by a change in pressure, but also by a change in temperature. A property not possessed by materials such as quartz and gallium phosphate, which is why they are particularly suitable crystals for measurement.

Applications

This principle of measurement has only been in use since the nineteen forties and is now a sophisticated technology with outstanding, inherent reliability; so that now the piezoeffect is used successfully in numerous, critical fields of application, such as for medical, aviation or nuclear technology.

The rise of piezoelectric technology is based on a number of inherent advantages. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals. Although piezoelectric sensors are electromechanical systems that react to pressure, the measuring elements show virtually no deformation (they are typically only compressed by a few micrometers).

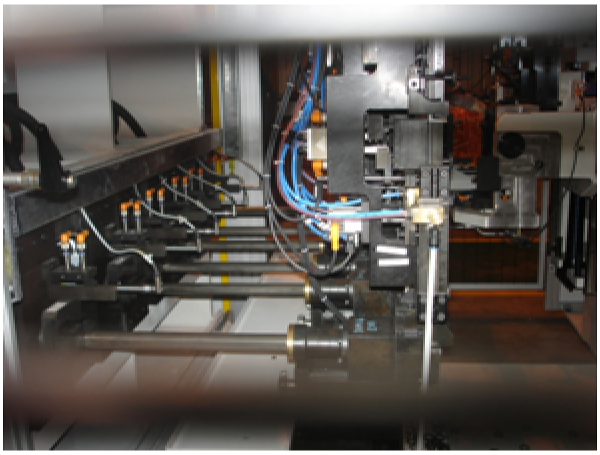

Fig. 3: Piezo technology is ideal for monitoring industrial processes

This is one reason for the robustness of piezoelectric sensors, for their very high natural frequency and excellent linearity, even under difficult operating conditions. Neither is piezoelectric technology susceptible to electromagnetic fields and radiation.

One disadvantage of piezoelectric sensors is their use for true static measurements. A static force results in a defined amount of charge on the surface of the piezoelectric material. Working with conventional electronics and materials that are not perfectly isolating causes a continuous loss of charge, which ultimately leads to continuous signal decay. Increased temperatures create an additional drop in the internal resistance, so that only materials with high internal resistance can be used in such measurement conditions.

It would be wrong to assume that piezoelectric sensors can only be used for very fast processes or under moderate conditions. There are numerous applications where measurement takes place under quasi-static conditions, although this is certainly the domain of strain gage technology.

Certainly the way in which the measuring elements are used is a very clear distinction between the strain gage application and the piezo technique. Strain gages are installed on structures that deform when force is applied. So the bulk of the force goes through the structure. Because of the rigidity of the crystals, piezo measurement technology is based on the fact that the force mainly flows through the measuring elements. The high stability of the single crystals allows piezo sensors to be very compact in design.

This minimal crystal deformation is also the ideal condition for good sensor linearity, as slight displacement only causes insignificant changes to the force flow. Combine this with the stability of the measuring elements and you have transducers with corresponding overload safety and long-term stability.

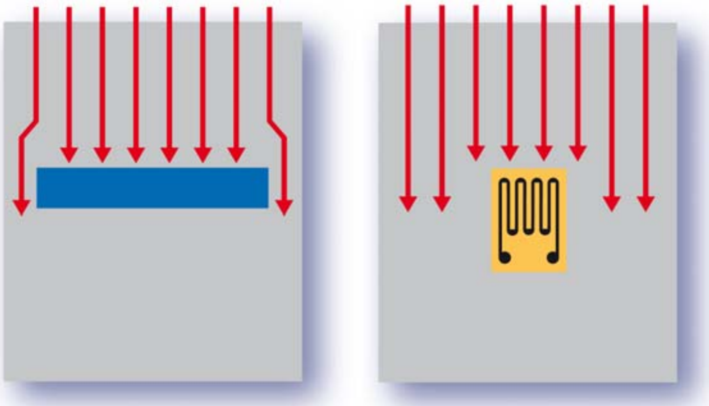

Fig. 4: Differences in the force flow for a structure with a piezo sensor and a structure with an installed strain gage