Piezoelectricity and What Became of it

by Johannes Wagner (1993)

The Present

With a gentle click the lighter starts up and a silent but hot flame burns. The escaping gas is ignited by electricity that does not come from any battery, from any outlet.

What happens? A button opens the valve of the liquid gas container. At the same time, it tensions a spring mechanism that strikes a ceramic block when it tips over. The ceramics carries two metallic electrodes. The short, mechanical impact displaces electrical charges inside this ceramics, which gather on the electrodes. A high electrical voltage is generated on them, which triggers the spark. The spark from the electrode to the nozzle on the valve ignites the gas-air mix. The energy for ignition was supplied by the force of the pressing finger.

The core of the igniter is a mechanical-electrical transducer made of a special ceramic, piezoelectric ceramic. This material directly converts mechanical energy into electrical energy.

The opposite effect is also applied. In many devices, beepers with piezoelectric membranes are installed.

This effect, the piezoelectric effect, has now been known for 117 years. It has provided the employees of our company with their income for about 4 decades, in addition to other physics.

The Name

Piezoelectricity has been known for quite a long time - judging by our fast-moving time scale. This is supported by the fact that the determining word for pressure (piezo) originates from Greek. This effect was thus discovered and named in a time in which the scientifically researching people were humanistically educated and perhaps read the ancient Greeks in the original text. The phenomenon of electricity must have been already known and at least measuring or detection devices to it, otherwise this effect could not have been discovered.

If the discovery had been more recent, it would certainly have become something like “pressure electricity”. But also from this it is recognizable that the old Greeks have prevailed. They are really very old, but their conceptual world still surrounds us. The eponymous amber (ελεκτρον) is now no longer an object of research for electrical engineers, it is only used for jewelry. I think of the beautiful, thick chain of my grandmother, but also of the much sought-after and famous Prussian “Amber Room”.

A connection between the amber necklace of my grandmother and the electricity from the socket does not exist for me. I keep it more with the factually considered electrical engineering, with the gentlemen Volta, Ampere, Ohm, just like with Gauss, Siemens, Weber, Tesla, to whom in the electrical units of measurement monuments were erected.

The Discovery

Piezoelectricity as the study of natural materials, the production and dissemination of artificial materials can be used to illustrate the course of a field of knowledge very well.

Electrical properties of tourmaline were already known. Tourmaline, a precious stone, heated in an ember bed, attracted particles of ash and also repelled them. This electrical characteristic was also known from other electrically charged bodies. Because of this temperature-dependent electricity, it was also suspected that it was dependent on pressure. After many aberrations, in which essentially frictional electricity was described, the legendary Curie brothers discovered this effect on tourmaline. That was in 1880, later they found this peculiarity also on quartz and other crystals. They called the property polar electricity. A year later, the name “piezoelectric effect” was proposed. That apparently caught on. The reciprocal effect - applying an electrical voltage causes the crystal to move - was first predicted in 1881 and found in experiment shortly thereafter - again by the Curie brothers. Both must have been very skilled experimenters and had fabulous resources at their disposal.

The Vita

The effect, the ignition source of the lighter described in the beginning, rested in a few laboratories as a curiosity of special substances, most of which were very hard and had crystal properties. Better known became tourmaline and quartz. Crystal science continued to search. Famous people dealt with the theory e.g. Lord Kelvin. But only in 1954 Max Born found a solution in principle to derive the piezoelectric constants from the crystal lattice.

The technical application was hesitant. It started with piezoelectric resonators, i.e. with the reciprocal piezoelectric effect.

A trigger was the investigation of underwater communication with ultrasound, certainly a consequence of World War I and the then new submarines. The first publications on this subject date back to the 1920s. The military application led to secrecy, it became quiet.

Nevertheless, work continued. It was realized that piezoelectric resonators could be used to control frequency generators, forming the core of very accurate and largely temperature-independent time and frequency standards. The first civil application of these resonators was in oscillators of radio transmitters. This made it possible to keep frequencies stable in the increasingly dense broadcasting landscape. From my apprenticeship I still know oscillating crystals from left-over stocks of the German Wehrmacht, built into a plug-in steel housing like that of a steel tube of the “11” series. Do you know the old tubes as amplifier elements at all?

It was war again that accelerated development. From 1942 dates a French publication describing piezoelectrically excited quartz elements as transmitters and also receivers of ultrasound for measuring depth and locating objects in water. Paris, the place of publication, was occupied by the German Wehrmacht at that time. It is not known to me which side of the war opponents used these results faster and more consistently and what influence the piezoelectric effect had on the end of the war.

After the end of the war started by Germany, which had turned large parts of Europe and especially German cities into piles of rubble, a stormy development for the described effect began. Proposals came from crystal physics. From the internal structure of the crystals and the thus defined location of the charge carriers, it is possible to deduce whether pressure or temperature changes the charge distribution. In addition to the well-known materials quartz and tourmaline, other monocrystals were discovered. However, only some of them gained economic importance. In my job I got to know quartz, lithium niobate and seignette salt. Seignette salt had attained such importance that the Russian-speaking world spoke of “seignette electricity”. A Russian book with this title is still on my bookshelf.

During and after the war, many companies were established in Europe and the USA in the field of aviation and the developing rocket technology. The need for minimum weight with maximum propulsion power demanded that the material properties of elasticity and strength be exploited to the limit. The demands of nuclear technology developed in a similar way. Vibration measurement plays a major role in reactor safety. These challenges were met by measurement technology. Probably all known transducer mechanisms were tested for their applicability. In the field of vibration measurement, the piezoelectric effect has had a prominent place up to now. Which other transducer type allows a dynamic range of more than 6 orders of magnitude? The multitude of manufacturers and different transducer types speak for it. The transducer materials are also offered in different kinds by many companies. One of the decisive factors for success was that the piezoelectric effect also occurs with special ceramics, which, in contrast to piezoelectric single crystals, could be produced much more easily. As polycrystalline structures, ceramics has no natural piezoelectricity. In a polarization process, the small polar regions, called domains, which are tangled after sintering, are aligned in a high-voltage electric field.

Many publications for understanding and application followed. Important cornerstones were

- The extensive writings of Maso, in which the coefficients of the materials were published,
- The patent of W.P. Kistler, which was important for the application of the piezoelectric effect:
  Measuring amplifier for measuring electric charge. Swiss patent 267431, Bern 1950,
- Many investigations of newly mixed piezoceramics with special properties.

Good long-term stability, minimum temperature coefficients, piezoelectric stability against depolarization, high Curie point, temperature-stable frequency properties, production from simple and inexpensive raw materials are only some of them.

At the Technical University of Dresden scientific work on piezoelectric problems continued for many years. The last dissertation work was submitted in 1971 and completed with “magna cum laude”. It dealt with quasi-static force conversion using piezoceramics and explained problems in the low-frequency range. This is the reason why piezoelectric force measurement has to struggle with many errors and can only be used under very limited conditions. As a side branch, a (non-practical, because not illustrative) model for pyroelectric effects was described.

An important book was “Piezoelektrische Messtechnik” by J. Tichy and G. Gautschi, published by Springer in 1979. This book was probably the last important publication on the subject measuring with piezoelectricity.

At the same time, there were many publications on the reciprocal piezoelectric effect. Micrometer steps for the production of microelectronic circuits had to be mastered. For this purpose, micromotors with piezoelectric drive elements were invented. They are now established as the youngest child of piezo applications.

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The Destiny

Since then, I saw mainly publications of manufacturers about their products. It is quiet in the field, it is scientifically exhausted, it no longer explores new scientific territory. The study of properties resulted in applications. The effect that became known as a curiosity is now common knowledge. Science has turned to other mechanisms of action. Research is concerned with optical and micromechanical objects.

The consequence is that there are no longer any spectacular gains to be made. The technology no longer belongs to high-tech. More and more manufacturers are offering it. The application is becoming broader. It ranges from microdrives to gas lighters, ultrasonic exciters, accelerometers, telephone microphones and beepers. The new manufacturers no longer need to invest in research. In many cases, they don't know hidden ifs and buts of the matter. They never heard of the nine-line nine-column matrix with all coefficients, fortunately with a large number of zeros. They handle the material impartially, often with success and to the detriment of the companies investing in research.

Only a new product, a technology that is new to the market brings short relief from the pressure of competition for the entrepreneur. Competitors, of course, are not asleep, and so the research spiral continues to spin endlessly. Centrifugal force throws off the weak.

Familiar quotations characterize these conditions: “You snooze, you rust.” Or the many-voiced song of the angels (Did Goethe know the laws of the market?) “Whoever strives, we can redeem”.

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