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Chapter

Piezoelectricity and Its Applications

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Abstract

The piezoelectric effect is extensively encountered in nature and many synthetic materials. Piezoelectric materials are capable of transforming mechanical strain and vibration energy into electrical energy. This property allows opportunities for implementing renewable and sustainable energy through power harvesting and self-sustained smart sensing in buildings. As the most common construction material, plain cement paste lacks satisfactory piezoelectricity and is not efficient at harvesting the electrical energy from the ambient vibrations of a building system. In recent years, many techniques have been proposed and applied to improve the piezoelectric capacity of cement-based composite, namely admixture incorporation and physical. The successful application of piezoelectric materials for sustainable building development not only relies on understanding the mechanism of the piezoelectric properties of various building components, but also the latest developments and implementations in the building industry. Therefore, this review systematically illustrates research efforts to develop new construction materials with high piezoelectricity and energy storage capacity. In addition, this article discusses the latest techniques for utilizing the piezoelectric materials in energy harvesters, sensors and actuators for various building systems. With advanced methods for improving the cementations piezoelectricity and applying the material piezoelectricity for different building functions, more renewable and sustainable building systems are anticipated.

Keywords: piezoelectric effect, ferroelectricity, actuators, sensors, buzzers

1. Introduction

Technical application of Piezoelectricity phenomenon first discovered by Pierre and Jacques curie and Jacques curie in 1880 [1] and thereafter soon understood from the crystallographic point of view had a very slow start because for decades only a few suitable materials were available. In spite of their small piezoelectric effect, quartz crystals continue to dominate as components for frequency control since the early days of radio engineering [2], this is due to their extremely sharp resonance curves, which are stable with respect to temperature and aging. The first ferroelectric material, Rochelle Salt [3] was found out to the suitable for broadband applications in the year 1920.Stability problems encountered with these crystals,

which are produced from aqueous solutions, restrict their application to phonograph pick-ups.

Over the past period the spheres of application of piezoelectric materials in modern techniques have been considerably enlarged. In this relation the requirements to their properties are continuously growing. A great number of the piezoelectric materials have been developed in several countries, yet research in this field is still in active. The efforts of researchers are concentrated on the problem of purposeful development of the materials with desirable combination of their properties. The wide spread application of the piezoelectric effect is based on ferroelectric ceramic materials can be attributed to three main facts:

1. The Piezoelectric effect particularly large in the ferroelectrics.

2. Ceramics can be produced cost effectively. Most of these materials are either impossible or at best very difficult to produce in mono crystalline form.

3. Ceramic materials offer a high degree of variation concerning geometrical shaping on the one hand and physical properties on the other hand by virtue of mixed-crystal formation, creation of differing grain structures, and interaction of various ferroelectric or non- ferroelectric phases.

At present piezoelectric materials based on Barium Titanate ($BaTiO_3$). Lend Zirconate-Lead Titanate (PZT) solid solutions and multi component solid solutions relating to the Perovskite type crystal structure and containing, as a rule, lead titanate or lead zirconate, are mainly used [3].

Most of the improvements in the properties for particular application in the piezoceramics have been achieved either by partially replacing the constituent atoms by other atoms or doping with a small quantity of purity additives. Broadly speaking, all these methods may be considered to the control the ceramic characteristic properties by impurity doping.

Piezoelectricity is the additional creation of an electric charge by the applied stress; this is the direct piezoelectric effect. The charge is proportional to the force, and it is therefore of opposite sign for compression and tension. In terms of dielectric displacement D (charge Q per unit area A) and stress T, it may be written as.

$$D = Q/A = dT \tag{1}$$

There is a converse effect. An applied field E produces a proportional strain S, expansion or contraction depending on polarity.

$$S = dE \tag{2}$$

Therefore, the piezoelectric constant ‘d’ (Piezoelectric strain coefficient) which is numerically identical for both direct and converse effects.

$$d = D/T = S/E \tag{3}$$

Another frequently used piezoelectric constant is g (piezoelectric voltage coefficient), which give the field produced by a stress and is related to the ‘d’ constant by the permittivity (ε).

$$g = d/\varepsilon \tag{4}$$

Additional piezoelectric constants which occasionally used are 'e' which relates stress T to field E, and 'h' which relates strain S to field E.

$$T = -eE \tag{5}$$

$$T = -hS \tag{6}$$

Actual definitions are.

$$d = (\partial S/\partial E)_T = (\partial D/\partial T)_E \tag{7}$$

$$g = (-\partial E/\partial T)_{D=} (\partial S/\partial D)_T \tag{8}$$

$$e = (\partial T/\partial E)_{S=} (\partial D/\partial S)_E \tag{9}$$

$$h = (-\partial T/\partial D)_{S=} (-\partial E/\partial S)_D \tag{10}$$

For ceramics and crystals the elastic, dielectric and piezoelectric constants may differ along different axes. For this reason, they are expressed in tensor form.

The hydrostatic strain constant d_h is related to d_{33} and d_{31} as follows:

$$d_h = 2d_{31} + d_{33} \tag{11}$$

$$\text{where } d_{33} = (\partial D_3/\partial T_3)_E = (\partial S_3/\partial E_3)_T$$

$$d_{31} = (\partial D_3/\partial T_1)_E = (\partial S_1/\partial E_3)_T$$

Possibly the best single measurement of the strength of a piezoelectric effect is the electromechanical coupling factor K. When an electric field is applied, it measures the fraction of the electrical energy converted to mechanical energy (or vice versa when a crystal or ceramic is stressed). The actual relationship is in terms of K^2

$$K^2 = \frac{\textit{Electrical energy converted to mechanical energy}}{\textit{Input electrical energy}}$$

$$K^2 = \frac{\textit{Mechanical energy converted to electrical energy}}{\textit{Input mechanical energy}}$$

The piezoelectric, elastic and dielectric constants of poled ceramics are strongly temperature dependent. Heating through the Curie point destroys the effect of poling and causes the piezoelectric properties to disappear [4]. If the sample is heated to just below the Curie point the piezoelectric properties are degraded. A remanant piezoelectric effect produced by polling an initially random orientation ceramic is a strong evidence for ferroelectricity 90^0 walls contribute to the piezoelectric effect since their movement is accompanied by dimensional change and not 180^0 walls because there will be no dimensional change [5]. Ferroelectric materials with high Curie temperature are highly desirable to construct transducers for high temperature piezoelectric applications.

2. Piezoelectricity

Certain crystals become electrically polarized (i.e electric charges appear on their surfaces) when stressed. This phenomenon discovered in 1800 by Pierre and J. Curie is called the piezoelectric effect and the crystals as the piezoelectric crystals Quartz, rochelle salt, tourmaline are the familiar piezoelectric substances.

The inverse effect–that these crystals become strained when polarized has also been observed.

Piezoelectric strains are very small, and the corresponding electric fields are very large. In Quartz for example a field of 1000 V/cm produces a strain of the order of 10^{-7}. Conversely small strains can produce large electric fields.

To understand the origin of the piezoelectric effect, the distribution of the ionic charges of a crystal about their lattice sites. Normally, the distribution is symmetrical, and the internal electric field is zero. But when the crystal is stressed, the charges are displaced. In a piezoelectric crystal this displacement distorts the original charge distribution in such a way that it is no longer symmetrical - for a quartz crystal. A net polarization results in such crystals and when observing the piezoelectric effect. In other crystals, on the other hand, the distribution of charges maintains its symmetry even after the displacement - for a non piezoelectric crystal. Such crystals exhibit no net polarization and hence no piezoelectric effect [6].

It follows that the piezoelectric effect is related to crystal symmetry. The symmetry element involved is essentially the center of inversion. A crystal can exhibit piezoelectric effect only if its unit cell lacks a center of inversion. This is because when there is no center of inversion, only then the charge distribution is distorted so as to produce polarization. However if the center of inversion is present, there is no charge distortion hence no polarization.

It can be proved that of the 32 crystal classes, 21 are non centro symmetrical but since one of these 21 is highly symmetric in other respects, it is piezoelectrically excluded, leaving only 20 piezoelectric classes. However, all crystals belonging to these 20 classes are not observably piezoelectric - in some crystals the piezoelectric effects are too small to be detectable. Thus, the lack of inversion center is a necessary but not sufficient condition to guarantee piezoelectricity.

Piezoelectric effect is extensively used to convert the electric energy into mechanical energy and vice-versa i.e. the piezoelectric substances are used as electromechanical transducers. For instance it is an electric signal that is applied to one end of a quartz rod, the variations in strain generated in the rod in consequence of the effect propagate down the rod constituting what is known as mechanical wave or an acoustic wave. Another important application of piezoelectrics is their use as highly stable oscillators for frequency control [7]. If a quartz crystal is subjected to an alternating voltage at one of its resonant frequencies the crystals will suffer expansion and contraction alternately in consequence of the effect and thus the oscillations of the crystals will be set up. The frequency of these oscillations depends on the dimensions of the specimen and the elastic constants of the material and is stable. Specially cut quartz discs are generally used for this purpose.

Ferro electricity versus piezoelectricity [8]:

1. In piezoelectricity the crystal is polarized by the application of an external stress whereas in ferroelectricity the source of polarization is the dipole interaction energy itself.

2. Both the phenomena occur in noncentrosymmetric crystals, which are 20 in number. Piezoelectricity occurs in all the 20 crystals whereas ferroelectricity only in 10 namely those which provide a favorable axis of polarity.

3. All ferroelectrics are therefore piezoelectric but all piezoelectrics are surely not ferroelectric for example Tourmaline is piezoelectric but not ferroelectric at all.

4. The piezoelectric coefficient is the ratio of the setup charge to the stress applied to a crystallographic axis. The ferroelectrics have very large piezoelectric coefficients.

The phenomenon of piezoelectricity was discovered just over a hundred years ago by the Curie brothers, Pierre and Jaques. The science of Piezoelectricity has proceeded at an uneven face in these one hundred years. Periods of rapid progress have been followed by periods of slow development and sometimes even by periods of no development (Incidentally, this is characteristic of all branches of science). Every time that piezoelectricity has appeared to be exhausted as a science, the discovery of new piezoelectric effects or new piezoelectric materials initiated a new stage of rapid development and opened up new areas for the application of piezoelectricity. Piezoelectricity is currently enjoying a great resurgence in both Fundamental Research and Technical applications.

Piezoelectricity is one of the basic properties of crystals, ceramics polymers and liquid crystals. There are several ways to describe the piezoelectric effect [9]. Perhaps the most common definition is that a material is piezoelectric if the application of an external mechanical stress causes the development of an internal dielectric displacement. This displacement is manifested as an internal electric polarization or a surface electric charge Because of the way in which the elastic stress and dielectric displacement transform during coordinate axis rotation (**Figure 1**) the piezoelectric constants describing the linear relationship form a third order tensor. A simplified mathematical formulation of the piezoelectric effect is given below. More detail treatments of the piezoelectric effect and Converse effect can be found in texts.

It should be noted that the piezoelectric effect is strongly linked to the Crystal symmetry. All crystals are arranged into 32 point groups. Crystals belonging to the 11 centro symmetric point groups cannot show a piezoelectric effect. Crystals belonging to the non centro symmetric point group O also do not exhibit a piezoelectric effect. Nearly all other non metallic crystals belonging to the remaining 20 point groups exhibit a piezoelectric effect of some magnitude, although some of the effects are very small.

The piezoelectric phenomenon can be described as.

$$P_i = P^0{}_i + {}_{jk}Ed_{ijk}\, T_{jk} \tag{12}$$

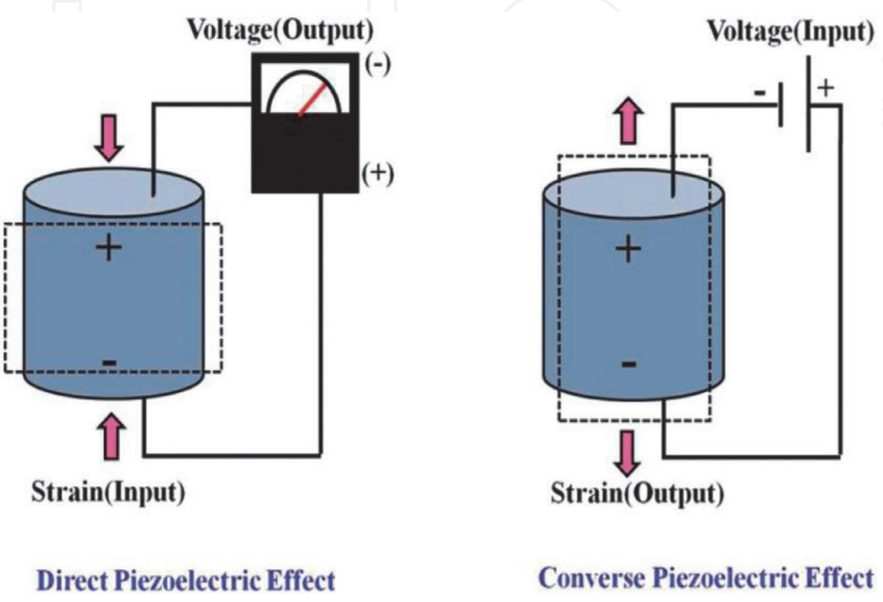


Figure 1.
Piezoelectric effect.

Where P_i is a component of the polarization vector, P^0_i the spontaneous polarization and T_{jk} is the stress tensor component. The coefficient d_{ijk} are called the piezoelectric Coefficient and are third rank tensor components.

Piezoelectric materials that are currently receiving much scientific attention include piezoelectric semiconductors, such as gallium arsenide, which have a wide range of interesting properties [10]. An existing goal with these materials is to integrate the piezo device and the semiconductor components on the same substrate. The last decade has witnessed an explosive expansion in research on surface acoustic waves. Most recently, the research has concentrated on layered systems containing piezoelectrics. Another important application of surface acoustic waves has been the development of miniature high-frequency "bulk structure" filters using Lithium niobate and Lithium tantalate crystals for use in consumer electronic applications.

Research into "bulk structure" surface acoustic wave resonators is currently a very active area. Piezoelectric Polymers, thin films and composites are becoming increasingly important. This is evidenced by a series of recent International conferences devoted to PVF_2 and other piezoelectric polymers.

Since piezoelectricity was first discovered the applications of piezoelectric materials have mushroomed. Langevin's work opened the large field of ultrasonics, which now includes detection, nondestructive evaluation, acoustic electricity, acousto optics, and imaging, signal processing, physical acoustics, medical acoustics etc.

Early Works By Cady and Nicolson lead to frequency control including resonators, oscillators and filters [11]. This field initially utilized low frequencies about 100 kHz. As time progressed, higher frequencies were needed and used. The majority of the presently mass produced high frequency piezoelectric filters are based on the Onoe theory of the multimedia resonator. It should be noted that the Onoe theory was inspired by Schockley's theory of energy traps.

Today piezoelectric devices are found in television sets, radios, wristwatches, small computer games, automobiles etc. Many communications and navigation systems used large numbers of very precise piezoelectric resonators for frequency control, generation and selection.

It can be observed that even with quartz the original piezoelectric material, the rate of improvement of the properties of these devices is still in an accelerating phase. For instance, the stability of quartz frequency sources has improved by an order of magnitude every five or six years.

Piezoelectric materials have always played a very significant role in acoustics. In recent times, they have found widespread application as generators, transmitters and detectors of surface acoustic waves.

Of the many biological materials which exhibit piezoelectricity bone belongs to the best investigated ones. Bur has measured various complex piezoelectric constants of bovine bone as a function of frequency, temperature and relative humidity. The presence of water in bone in some piezoelectric constants gives rise to the occurrence of piezoelectric relaxation in others it shifts the relaxation frequency as does the temperature. This piezoelectric relaxation has been qualitatively explained by the two-phase model too. The losses in this case are attributed to a Maxwell Wagner dispersion, which occurs as a result of ionic conduction.

It may appear that the physical mechanism of piezoelectric relaxation by electrical and mechanical interactions between different phases is different from the piezoelectric relaxation as described in the preceding chapters. The basic elements of the piezoelectric relaxation however, are compatible for molecular point defects for two-dimensional defects like domain boundaries and for three-dimensional defects as are the finely dispersed to phase materials. In any case there is a coupling

between electrical and mechanical losses, which can be described by the relaxation of defects which are simultaneously as well electric as elastic dipoles. The heterogeneous system entails a higher degree of complexity, example superposition of uncoupled losses, losses by electric conduction, local field effects orientation distributions and others. Therefore the theoretical treatment is clearer in the two-phase model.

Piezoelectric ceramics are prepared for fabricating the electromechanical transducers used in the mechanical frequency filters that find application in long-haul Communications systems. These ceramics have to satisfy specifications that can only be met by utilizing all the possibilities offered by the physical effects of the ferroelectric materials. The required positive temperature coefficient of the frequency constant is realized with the aid of elastic anomalies in the region of ferroelectric phase transitions.

Quartz resonators have been adapted for communications, but in recent years mostly for wrist watches and clocks since the quartz-oscillator circuit which incorporates a piezoelectric quartz crystal resonator has a very stable frequency. Thanks to quartz resonators, time accuracy of wrist watches has been improved rapidly. Quartz resonators for wristwatches and clocks amount to over 60% of total quartz resonators manufactured in Japan. This paper touches upon the characteristics, details of technical advancements, the analysis methods, the manufacturing technique and finally the future trend of quartz resonators for wristwatches.

Recently electronic wrist watches have spread far and wide, small and beautiful ones with high accuracy and many functions in particular. It owes development of various watch parts including the Integrated circuit. Among them the development of the quartz resonator for wristwatches, which produces the time (frequency) standard, is especially splendid.

Elastic vibration of a quartz resonator is transformed into electric Vibration by piezoelectricity because quartz crystal is stable against the ambient temperature, elapsed time and other various environments; frequency of a quartz resonator oscillator is extremely stable. Therefore it has been used in the fields of wireless communications and recently adapted for wrist watches and clocks. It shows the percentage of quartz resonators by fields produced in Japan. As described, quartz resonators for wrist watches and clocks amount to 64.6% of the total number and 40.4% of the gross sales.

3. Applications of piezoelectricity

All the electrical devices nowadays are just not limited to electrical connection in between them but have this piezoelectricity as a common thing in all applications. Cell phones, diesel fuel injectors, grill igniters, ultrasonic transducers, acoustic guitar pickups, vibration sensors, certain printers, and musical greeting cards etc. utilizes piezoelectricity. The additional development of manmade piezo materials which includes piezoelectric ceramics.

The applications of piezoelectricity includes the following fields:

- Piezoelectric Motors
- Actuators in Industrial Sector
- Sensors in Medical Sector
- Actuators in Consumer Electronics (Printers, Speakers)

- Piezoelectricity Buzzers
- Instrument pick-ups
- Microphones
- Piezoelectric Igniters
- Nanopositioning in AFM, STM
- Micro Robotics (Defense)

3.1 Piezoelectric effect works with sensors and motors

To start with, the electric cigarette lighters and gas grills have a high voltage power source when compared with other applications of the piezoelectric effect. In these cases, a hammer strikes a piece of piezo material, which then produces enough current to create a spark that ignites the flammable gas in its presence. However, in other applications like sensors, the hammer is typically replaced by other forms of energy like sound waves - including ultrasound, as hammer is an exciter of the piezo material.

When these are working with sensors, piezo materials will detect even some of the minute disturbances and anomalies, which will make them unique and idealistic devices in industrial nondestructive testing and medical imaging.

In the other perspective, piezoelectric motors can perform highly precise and repeatable movements. This inbuilt makes them excellent devices (**Figure 2**) for the precision movements of sensitive optical devices like telescopes and microscopes.

3.2 Piezoelectric sensors in industrial applications

The industrial sector contributes its applications with piezoelectric sensors for a variety of uses. Some common, everyday uses include:

3.2.1 Engine knock sensors

Engine manufacturers are every now and then facing challenges related to the control of engine devices. Under some non-supporting situations, gasoline engines are susceptible to an undesirable phenomenon known as detonation. When the

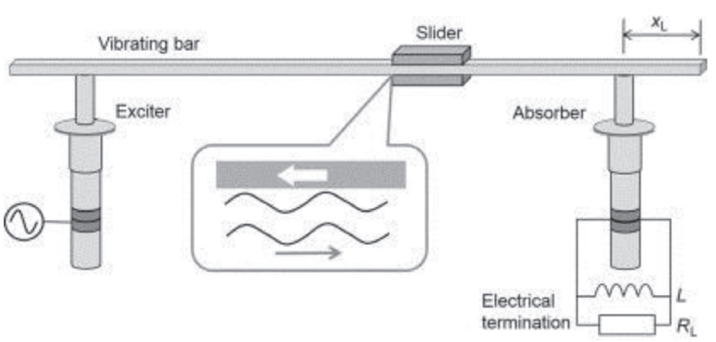


Figure 2.
Traveling wave motor.

process of detonation occurs, the air/fuel charge explodes instead of burning smoothly thereby damaging the engine. Eventually, this is why the designed engines with conservative operational margins at the expense of efficiency — it was to avoid this notorious problem.

With the advancement of the better control systems, the relevant engine parameters may be adjusted in real-time to maximize efficiency and power. If detonation begins to occur, piezoelectric knock sensors can be employed to sense the detonation before it becomes problematic. This gives control systems time to make the required adjustments.

3.2.2 Pressure sensors

In almost all the applications the measurement of dynamic pressure changes, using piezoelectric pressure sensors yields more reliable results than using conventional electromechanical pressure sensors (**Figure 3**). The reason behind this is that piezoelectric devices have a high frequency response and signal conversion without any need of bellows, diaphragm, or any type of mechanical linkage in conjunction with a strain gage or displacement sensor.

3.2.3 Sonar equipment

Sonar Equipment depends especially on piezoelectric sensors to transmit and receive ultrasonic "pings" in the 50-200 kHz range. Along with an ideal frequency response for such applications, piezoelectric transducers have a high power density that enables large amounts of acoustic power to be transmitted from a small package. For instance, a transducer that is only 4″ (100 mm) in diameter may be capable of handling power output greater than 500 watts.



Figure 3.
A piezoelectric pressure sensor.

3.3 Piezoelectric actuators in industrial applications

In this times when piezoelectric sensors are highly valuable to the industrial sector, the industry also makes use of piezoelectric actuators for a variety of applications:

3.3.1 Diesel fuel injectors

In the last decade, regulations on emissions from diesel engines have become increasingly stringent. In addition to this, customers continue to demand quieter engines with improved power and torque curves. In order to meet these stringent demands for compliance and performance, engine manufacturers have resorted to using precisely timed and metered injections of fuel during the combustion process [12].

Besides the working of other applications in piezoelectric devices, a single fuel injector may switch fuel flow with pressures exceeding 26,000 psi (1800 bar) on and off several times in rapid succession during a single power stroke. Such precise control of high-pressure fluid is made possible by using piezoelectric actuators controlling small valves within fuel injectors.

Equipment which involves diesel engine emissions have become increasingly stringent, yet customers' demands for quieter engines with improved power output has led the world's leading firms in fuel injection technologies to invest in extensive research and development. To fulfill the customers demands while remaining compliant and ahead of regulatory pressures, Piezo Diesel Injectors were developed to reduce emissions by making the combustion of fuel within the cylinder more efficient. Such technological progress leads a new phase with possibilities of improved performance and reduced emissions through precisely timed and metered injections of fuel during the diesel combustion process.

3.3.2 Fast response solenoids

Some processes require quick and precise mechanical actuation that is difficult, if it is not satisfied by that process it uses electromagnetic solenoids to achieve. While speed may not always be a concern, power consumption or compactness of size is the most prominent one. In accordance with this, piezoelectric actuators are often able to fill the niche as they provide fast response and low power consumption in small packages, compared to electromagnetic solenoids.

3.3.3 Optical adjustment

Some optics needs to be adjusted or modulated with a wide frequency response and with a minimum number of moving parts. Piezoelectric actuators are often employed in such applications where they provide fast and accurate control over a long service life:

- The angle of a mirror or diffraction grating may need to be precisely varied according to an electrical input. Such applications are often encountered in optical or physics experiments.

- Earth-based telescope arrays are subject to atmospheric distortion, and spacecraft optics are subject to movement and vibration. In such cases, optics

may need to be adjusted (shaped or contoured) in real-time by means of a control system. This will compensate for aberrations that would otherwise impede image resolution.

- Some fiber optic converters rely on piezoelectric actuators to modulate the output of a laser.

3.3.4 Ultrasonic cleaning

Piezoelectric Actuators also contribute to ultrasonic cleaning applications. To perform ultrasonic cleaning, objects are immersed in a solvent (water, alcohol, acetone, etc.). A piezoelectric transducer then agitates the solvent. Many objects with inaccessible surfaces can be cleaned using this methodology.

Piezoelectric ultrasonic cleansers (**Figure 4**) provide capabilities such as ultrasonic breaking up of kidney stones and removal of dental plaque. They are used to conduct precise measurements to identify flaws and other anomalies detected between transmitters and receivers of ultrasonic waves.

3.3.5 Piezoelectric motors

One advantage of using piezoelectric materials is that their characteristics are precise and predictable. Thus, expansion and contraction of a piezoelectric actuator can be precisely controlled as long as the supply voltage is controlled. Some motor designs take advantage of this fact by using piezoelectric elements to move a rotor or linear element in precise increments. Precision on the order of nanometers can be achieved with some piezo motor designs. Piezo motors work at a wide range of frequencies but typically work best in a low frequency range.

In addition to their inherent precision, piezoelectric motors can be used in environments with strong magnetic fields or cryogenic temperature — environments where conventional motors are unlikely to work. These unique challenges are present in MRI machines, particle accelerators, and other similar environments.

3.3.6 Stack actuators

Multiple piezoelectric elements will be stacked to replace the displacement achieved for a given voltage. These types of devices are known as stack actuators (**Figure 5**), and they are employed in variety of specialty applications. Compared to



Figure 4.
Piezoelectric ultrasonic cleansers.

conventional electromagnetic actuators, stack actuators have the following unique advantages:

- They can function at cryogenic temperatures or in environments with strong magnetic fields.
- They can produce a large amount of force in a small package
- They can respond almost instantly to input with high rates of acceleration.
- They can achieve extremely high degrees of precision.
- They only consume power when work is actually being performed.

These actuators find their uses in proportioning valves, electrical relays, optical modulation, vibration dampening, and other applications requiring fast or precise control of movement.

3.4 Piezoelectric sensors in medical applications

3.5 Ultrasound imaging

Piezoelectronic Transducers are often used in medical Ultrasound Equipment. Advances in equipment over the decades have enabled improved monitoring of pregnancies and facilitated minimally invasive surgical procedures (**Figure 6**).



Figure 5.
Piezoelectric stack actuators.

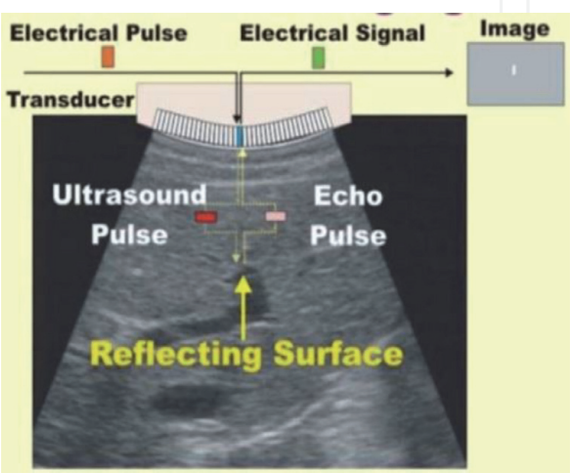


Figure 6.
Ultrasound imaging.

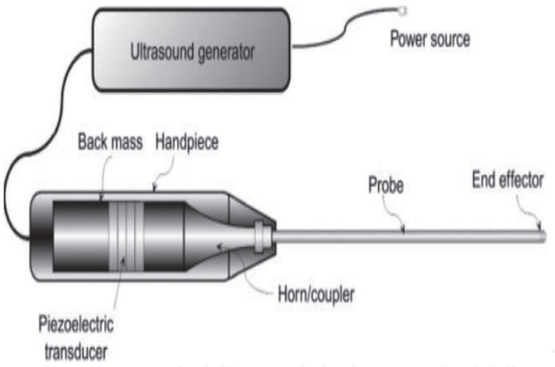


Figure 7.
Ultrasonic procedures.

3.6 Ultrasonic procedures

Some non-invasive medical procedures rely on the use of focused ultrasonic waves to break up kidney stones or destroy malignant tissue (**Figure 7**). Additionally, the advent of the harmonic scalpel has enabled surgeons to simultaneously incise and coagulate tissue during a surgical procedure without the need for cauterization. This leads to less tissue damage, less blood loss, and faster healing times [13].

3.7 Piezoelectric actuators in consumer electronics

Consumer electronics and technology that is sold in stores throughout the country, has piezoelectric actuators used in them.

3.7.1 Piezoelectric printers

There are two main types of printers that use piezoelectric actuators:

3.7.1.1 A dot-matrix printer

In a piezoelectric dot matrix printer (**Figure 8**), piezoelectric actuators in the printer head move needle-like pins that "poke" through a strip of ink tape (similar to a typewriter) against a piece of paper in various patterns to form characters. For most applications, the use of dot-matrix printers has been superseded by other technologies. However, a dot-matrix printer is the only printer technology capable of generating duplicate and triplicate carbon-copy printouts.

3.7.1.2 Inkjet printer

In a piezoelectric inkjet printer, piezoelectric actuators in the printer head act on small diaphragms or otherwise change the geometry of an inkwell so that ink droplets are forced out of an orifice onto paper. This is one of the dominant technologies in the printer market to date (**Figure 9**).

3.7.2 Piezoelectric speakers

Piezoelectric speakers are featured in virtually every application that needs to efficiently produce sound from a small electronic gadget. These types of speakers



Figure 8.
A dot-matrix printer.

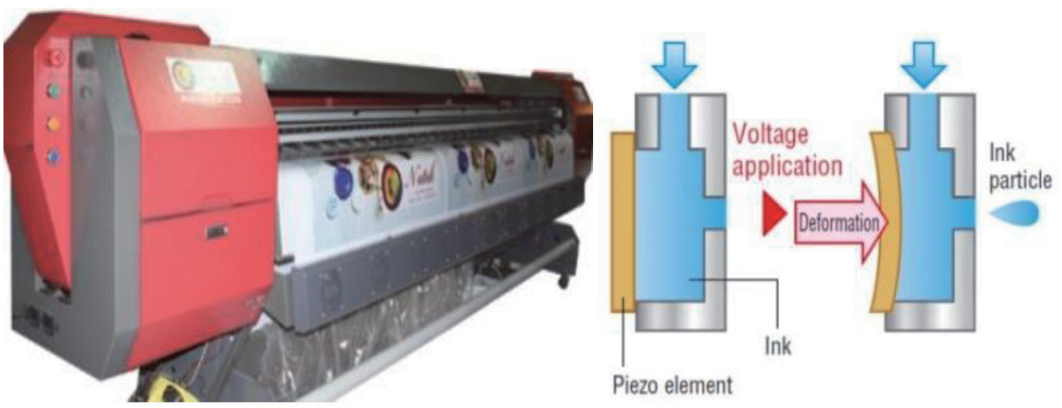


Figure 9.
Inkjet printer working.

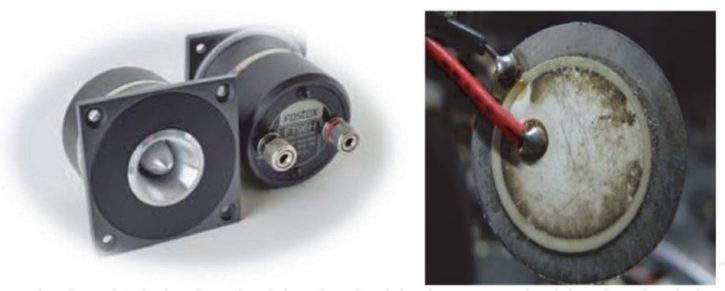


Figure 10.
Piezoelectric speakers.

are usually inexpensive and require little power to produce relatively large sound volumes. Thus, piezoelectric speakers (**Figure 10**) are often found in devices such as the following:

- Cell phones
- Earbuds
- Sound-producing toys
- Musical greeting cards
- Musical balloons

3.7.3 Piezoelectric buzzers

Piezoelectric buzzers are similar to piezoelectric speakers, but they are usually designed with lower fidelity to produce a louder volume over a narrower frequency range. Buzzers are used in a seemingly endless array of electronic devices.

3.7.4 Piezoelectric humidifiers

Many cool mist humidifiers use a piezoelectric transducer to transmit ultrasonic sound energy into a pool of water. The ultrasonic vibrations cause fine water droplets to break away and atomize from the surface of the pool where they become entrained in an air stream and enter the desired space.

3.7.5 Electronic toothbrushes

Linear piezoelectric actuators are implemented to vibrate the bristles in some electronic toothbrushes (**Figure 11**).

3.8 Piezoelectricity other applications in daily life

3.8.1 Piezoelectric igniters

This is, perhaps, the most well-known and ubiquitous use of piezoelectricity. In piezoelectric igniters, a button or trigger is used to cock and release a spring-loaded hammer, and the hammer is used to strike a rod shaped piezoelectric ceramic. The sudden mechanical shock to the piezoelectric ceramic produces a rapid rise in voltage that is high enough to jump a sizable spark gap and ignite fuel. Piezoelectric igniters are commonly used for butane lighters, gas grills, gas stoves, blowtorches, and improvised potato cannons.

3.8.2 Electricity generators

Some applications require the harvesting of energy from pressure changes, vibrations, or mechanical impulses. The harvesting of energy is possible by using piezoelectric materials to convert deflections or displacements into electrical energy that can either be used or stored for later use.

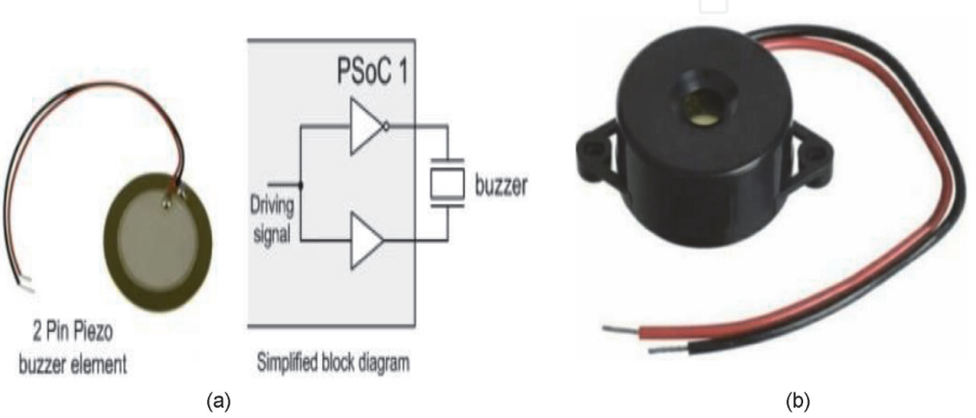


Figure 11.
(a) Piezoelectric buzzer block diagram. (b) Piezoelectric buzzer.

3.8.3 Microelectronic mechanical systems (MEMS)

MEMS devices have become more commonplace as more integrated capabilities are required in smaller packages, such as cell phones, tablet computers, etc. The advantage of MEMS devices is that gyroscopes, accelerometers, and inertial measuring devices can be integrated into chip-sized packages. In order to accomplish such a feat, piezoelectric actuators and sensors are often used.

3.8.4 Tennis racquets

A somewhat unusual application for piezoelectricity integrates piezoelectric fibers into the throat of a tennis racquet along with a microcontroller in the handle. When the tennis player strikes the ball, the racquet frame deflects and generates an electric output that is boosted, reversed, and fed back into the fibers [14]. This is an attempt to cause destructive interference and dampen structural vibration.

3.9 Piezoelectricity in defense applications

The piezoelectricity is used in Defense field for a variety of applications, they are:

3.9.1 Micro robotics

In the field of small robotics, small power-efficient mechanical actuators and sensors are needed. With the use of piezoelectric actuators, building something as small as a robotic fly that can crawl and fly is technically feasible. In fact, a new field of robotic technology known as Micro Air Vehicles aims to build small drones the size of insects or birds that fly using flapping wings (**Figure 12**). They control surfaces just as birds and insects do. These types of feats in miniaturization are possible, in part, by using piezoelectric actuators.

3.9.2 Course-changing bullets

Recently, DARPA invented a.50-caliber bullet that can change course in mid-flight. As absurd as this innovation may sound to some readers, the bullet uses an optical sensor that is mounted on its nose in conjunction with a control system and moveable tail fins to steer itself toward a laser-illuminated target. Although DARPA



Figure 12.
Piezoelectric micro robotics.

has not revealed much about their Extreme Accuracy Tasked Ordnance (EXACTO) bullet, the most likely means of manipulating the tail fins probably involves piezoelectric actuators.

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