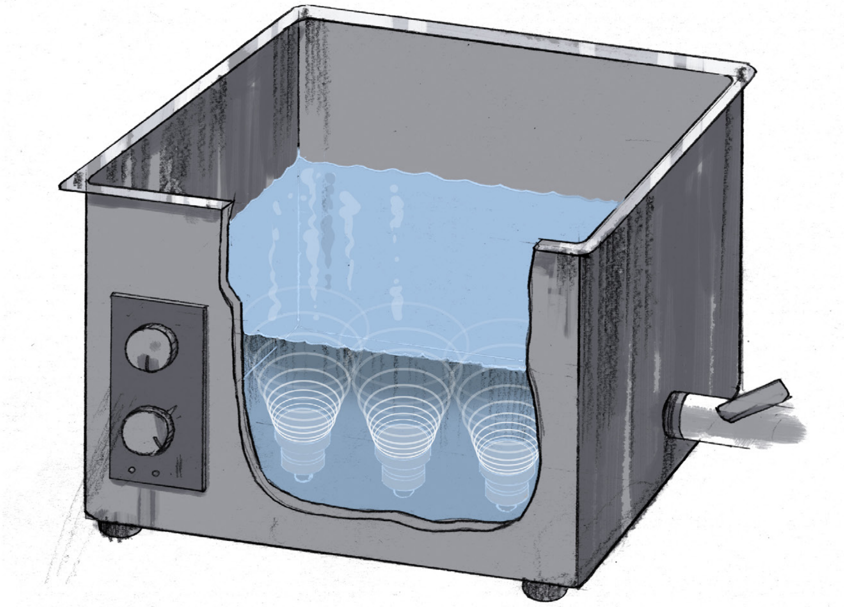


How is the Piezoelectric Effect Used to Generate Ultrasound?

Piezoelectricity is an electromechanical phenomenon found in certain asymmetric crystal structures such as quartz and various polycrystalline ceramics. When a piezoelectric material is exposed to physical stress, it will polarize and generate a voltage across its surface. This conversion of mechanical energy into electrical energy is known is the *direct piezoelectric effect*. Similarly, exposing a piezoelectric material to an electric field will cause it to deform, either expanding or contracting, depending on the direction of the field. This is known as the *converse piezoelectric effect*. If exposed to an electric AC signal, the piezoelectric material will start to vibrate as it alternatingly contracts and expands, thereby emitting *sound waves*.

What is sound?

In essence, sound is pressure waves emitted by a vibrating object. The number of waves produced over the course of a second by a vibrating object is known as the sound's *frequency* (*f*) and is measured in hertz (Hz). Thus, if an object emits 20 waves per second, it has a frequency of 20 Hz. To the human ear, sound frequency manifests as *pitch*. Higher frequencies result in high-pitch sounds, e.g., a whistle, whereas lower frequencies are perceived as low-pitch sounds, e.g., rolling thunder. The audible frequency range for the human ear is around 20 Hz to 20000 Hz (20kHz).

What is ultrasound?

Sound with a frequency above 20 kHz is known as *ultrasound*. When propagating sound encounters a boundary between materials with different *acoustic impedances* (*Z*), a portion of the waves is reflected back (*R*) while the remainder will pass through. The larger the difference in acoustic impedance between the two materials is, the more waves are reflected back:

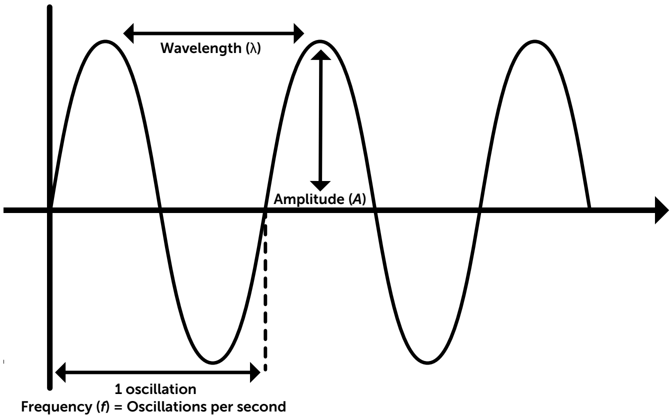
$$R = \left| \frac{Z2 - Z1}{Z2 + Z1} \right|$$

The amount of energy carried by sound is determined by the frequency and the *amplitude* (*A*) of the sound's waves. As frequency and amplitude increase, so does the energy, and therefore ultrasound contains more energy than lower-frequency sound of equal amplitude. This makes the reflected waves of ultrasound easier to detect.

How is the Piezoelectric Effect Used to Generate Ultrasound?

How do piezoelectric devices generate and utilize ultrasound?

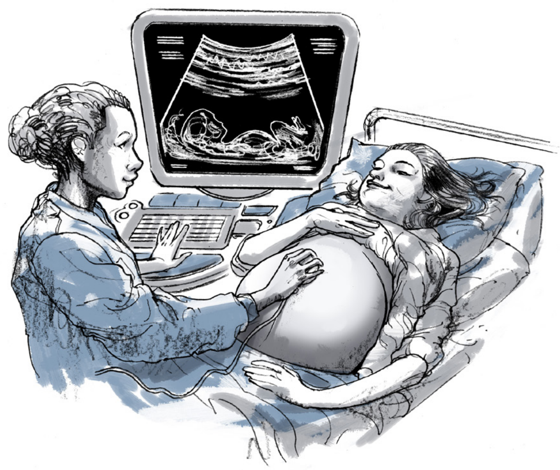
Piezoelectric can be made to vibrate via the converse piezoelectric effect to the point where they start emitting ultrasonic waves. At the same time, they can register mechanical energy, such as sound, and convert it into electrical energy by means of the piezoelectric effect. Devices that convert one energy type into another via one or both piezoelectric effects, are called *piezoelectric transducers*. These devices enable a wide range of ultrasound technologies.



Propagating sound wave.

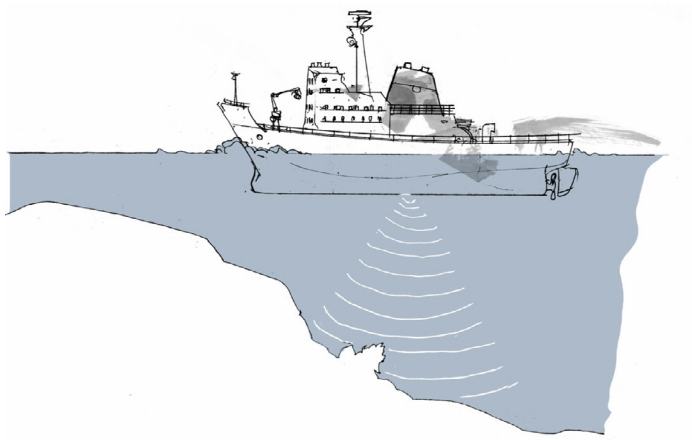
Ultrasound imaging in diagnostic medicine

Ultrasound is used in several field of diagnostic medicine. A well-known application is the ultrasound imaging of a human fetus inside a womb, carried out with scanning equipment enabled by a piezoelectric transducer. before scanning commences, a lubricant is typically applied to the patient's abdomen in order to improve the acoustic matching between the scanner head and the skin tissue. Once applied, the piezoelectric transducer can start to generate ultrasonic waves, emitting them into the body. As the waves come into contact with tissue, bone etc., some of them are reflected back and registered by the transducer, allowing it to convert them into an electric signal which can be used to generate an image of the womb and fetus. Matter with a high degree of acoustic impedance will appear brighter on the image, as it reflects a larger portion of ultrasonic waves.



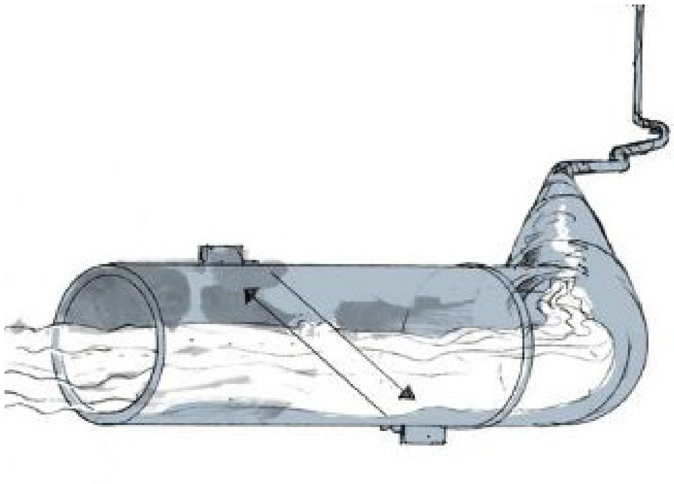
Ultrasound in underwater acoustics

One of the earliest practical applications of piezoelectricity was the underwater *sonar* (Sound/ Sonic Navigation and Ranging). originally created by the French physicist Paul Langevin during World War I as a means to detect and combat enemy submarines, the core principles of this technology are still used today in fishing, seafloor mapping and underwater oil/gas excavation. As with ultrasound imaging, a piezoelectric transducer will emit ultrasonic waves into the water as the waves will bounce off the sea floor and other underwater objects. Usually, a separate *piezoelectric hydrophone* will register the reflected waves and generate a electric signal to produce imagery.



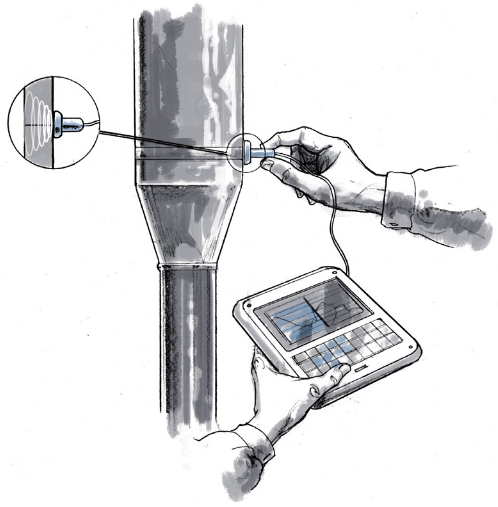
How is the Piezoelectric Effect Used to Generate Ultrasound?

Ultrasound in flow measurement



Ultrasound can be used to characterize and measure the velocity, volume and/or mass flow of moving liquids and gases. Ultrasonic flow meters are immensely important to industrial flow systems such as water distribution networks and oil/gas pipelines since they are capable of detecting system malfunctions or leaks immediately. Two commonly used ultrasonic flow meters are the *Doppler flow meter* and the *transit time meter* (also known as a *time-of-flight meter)*. The Doppler flow meter utilizes a piezoelectric transducer to emit ultrasonic waves into the flow and subsequently register their echo as they collide with particles and bubbles in the fluid. Due to the relative speed of the particle, the frequency of the reflected wave will shift - this is the Doppler effect. The piezoelectric transducer can the determine the state of the flow based on the discrepancy in frequency between the emitted and the registered wave. The transit time meter, on the other hand, employs two transducers, placed diagonally to the direction of the flow. The transducers operate alternatingly as emitter and receiver. Due to the superposition of sound propagation speed and flow speed, the ultrasonic waves will travel faster when moving in the same direction as the flow, and slower when moving against it. By comparing the upstream and downstream transit time of the waves, the state of the flow can be determined.

Ultrasonic non-destructive testing (NDT)

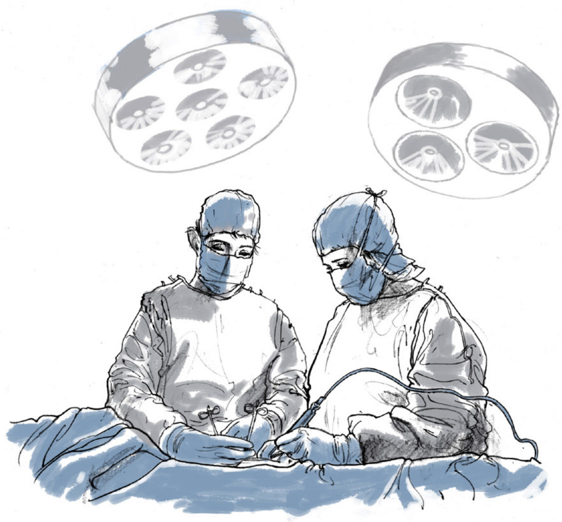


Ultrasound is used non-destructive testing to (as the name suggests) test various materials such as plastics, ceramics and metals (in particular weld joints) for potential defects and flaws without damaging or destroying them in the process. The procedure involves exposing the testing material to ultrasonic waves and registering either the waves that passed through the material, or the waves that were reflected by it. As the ultrasonic waves react to the boundaries between mediums with different acoustic impedances, small cracks and pockets of air that could compromise the integrity of the material can be detected.

How is the Piezoelectric Effect Used to Generate Ultrasound?

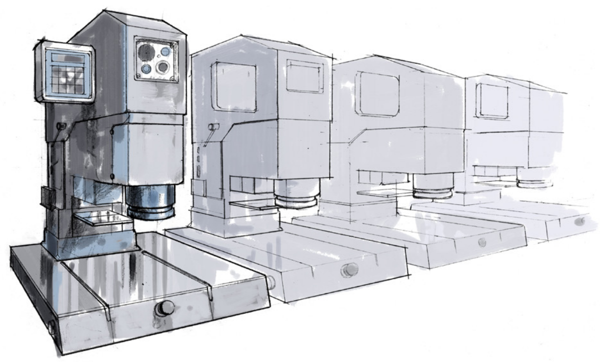
High-Intensity Focused Ultrasound (HIFU)

High-intensity focused ultrasound is used in therapeutic medicine to perform non-invasive surgical procedures. A piezoelectric focusing bowl, typically made of a polycrystalline ceramic material such as PZT, can converge beams of powerful, high-frequency ultrasound onto a pinpointed location inside the human body, not unlike how a magnifying glass converges light beams. This is a common way of ablating kidney stones into smaller pieces so they can pass through the bladder. In recent years, HIFU has also seen increased use in treatments of early-stage tumors. Additionally, HIFU is becoming an popular choice for dermatological and cosmetic procedures, capable of smoothing out wrinkles and tightening skin.



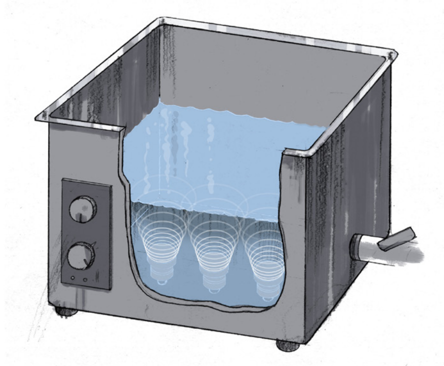
Ultrasonic welding

Ultrasound can also be used to weld together plastics as absorption of the high-energy waves will cause the joint parts to melt. It is even possible to weld together metals using ultrasound without having the materials reach their melting points. Instead, the welding occurs as surface oxides of the metals disperse under high pressure.



Ultrasonic cleaning

Ultrasound is often used to clean and maintain small and intricate objects such as delicate machine parts or jewelry that would not be able to sustain more common methods of cleaning. The procedure involves lowering the object in question into a cleaning liquid which is then exposed to ultrasonic waves generated by a piezoelectric actuator. The micro-bubbles in the liquid will start to vibrate under the effect of the waves and eventually separate the filth from the cleaned object without damaging its surface.



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