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Piezo-Gen - An Approach to Generate Electricity from Vibrations

Raghu Chandra Garimella*, Dr. V.R. Sastry, Mohammed Shoeb Mohiuddin

Department of Mining Engineering, NITK-Surathkal, Mangalore, 575025,Karnataka, India

Abstract

Now-a-days, Generation of Electrical Energy has become a more vital factor in the Power System because of the incremental demands for day-by-day with the population growth in the Electrical Distribution System. Hence, we all knew that Power Generation can be done in much number of ways using different techniques. Many Electrical Professionals developed different technologies for Electrical Energy Generation, which are all frequently fuel consuming apparatus. Here there is a new technique for Generation of Electrical Energy using *Piezo Sensors* from unwanted ground vibrations which may affect the nearby structures or may cause sound pollution. Here with the help of a number of vibratory plates which are well said to be Piezo Sensors, the frequency of different unnecessary vibrations will be converted into Alternating Supply; and then it will be furtherconverted into Direct Supply with the help of Ultra-Fast Switching Diode. The obtained output can be well stored in a Battery for further usage or it can be consumed directly for Loads. Thus, without any Economic Fuel consumption the Electrical Power simply can be generated by utilizing the unwanted vibrations.

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Keywords: Piezoelectric Materials; Piezo Sensors; Polyvinyledene Difluoride; Piezo Electric Generator; Vibrations.

* Tel.: +91 9290796716;
E-mail address: raghuchandhra@india.com

1. Introduction

Piezo-Generation is a new approach to generate Electrical Energy from the sensing cum converting equipment called piezo sensor/piezo buzzer. It mainly works on a principle of Piezo Electric Effect which is creating pressure energy on a crystalline material viz., Quartz Crystal to generate Electricity. Piezo Electric Effect is discovered in 1880 by Jacques and Pierre Curie during studies into the effect of pressure on the generation of electrical charge by crystals (such as quartz).

The word Piezo is derived from the Greek “Piezein”, which means to squeeze or press. The piezo material exhibits both “Direct piezo electric effect” as well as ‘Converse piezo electric effect”. Direct piezo electric effect is the production of electricity when the crystals are mechanically stressed and the converse piezo electric effect is the stress or strain in the crystals when an electric potential is applied. The most common crystals used are lead zirconate titanate crystals.

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The Piezo effect finds many applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances and ultra-fine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, the scanning probe microscopes and everyday uses such as acting as the ignition source for cigarette lighters and push-start propane barbecues.

Piezoelectric materials (PZT) can be used as mechanisms to transfer ambient vibrations into electrical energy that can be stored and used to power other devices. With the recent surge of micro scale devices, PZT power generation can provide a conventional alternative to traditional power sources used to operate certain types of sensors/actuators, telemetry and MEMS devices. In this paper, the dynamics of piezoelectric materials for the use of power generation devices has been experimentally investigated. The objectives of this work are to estimate the amount of power that PZT can generate and to identify the feasibility of the devices for real-world applications. The energy produced by the PZT was stored in two different ways. The first was in a capacitor that allows for immediate access to the stored energy and the second method charged a nickel metal hydride battery. The power generated by the vibration of the piezoelectric is shown to be a maximum of 2mW, and provide enough energy to charge a 40mAh button cell battery in one hour.

Piezoelectric materials form transducers that are able to interchange electrical energy and mechanical motion or force. These materials, therefore, can be used as mechanisms to transfer ambient motion (usually vibration) into electrical energy that may be stored and used to power other devices. By implementing power harvesting devices we can develop portable systems that do not depend on traditional methods for providing power, such as the battery, which has a limited operating life. Recent studies, experiments and patents, indicate the feasibility of using PZT devices as power sources. Umeda, yet all uses a free-falling ball to impact a plate with a piezo-ceramic wafer attached to its underside and developed an electrical equivalent model of the PZT transforming mechanical impact energy to electrical power. They also investigated the energy storage characteristics of the PZT with a bridge rectifier and a capacitor. Starner examines the energy available from leg motion of a human being and surveys other human motion sources of mechanical energy including blood pressure.

The author claims 8.4 watts of useable power can be achieved from a PZT mounted in a shoe. Kymissis yet all examine using a piezo-film in addition to the ceramic used in, to provide power to light a bulb in a shoe, entirely from walking motion. Kimura's US Patent centers on the vibration of a small plate, harnessed to provide a rectified voltage signal. The effort seems to be motivated by providing enough energy to run a small transmitter fixed to migratory birds for the purpose of transmitting their identification code and location. This result is also compared to using existing battery technology.

Goldfarb yet all presented a linearized model of a PZT stack and analyzed the efficiency of it as a power generation device. It was shown that the maximum efficiency occurs in a low frequency region much lower than the structural resonance of the stack. The efficiency is also related to the amplitude of the input force due to hysteresis of the PZT. In addition to the force applied in the poling direction (d33 mode), Clark and Ramsay have investigated and compared it with the transverse force (d31 mode) for a PZT generator. There work showed that the d31 mode has a mechanical advantage in converting applied pressure to working stress for power generation. They concluded that a 1-cm2 piezo-ceramic wafer can power MEMS device in the microwatt range. Elvin yet all theoretically and experimentally investigates the use of the self-powered strain energy sensors using PVDF. Their half-rectified circuit was then combined with wireless communication device for human bone strain monitoring. Kasyap yet all formulated a lumped element model to represent the dynamic behavior of PZT in multiple energy domains using an equivalent circuit. Their model has been experimentally verified using a 1-d beam structure with the peak power efficiencies of approximately 20%. Gonzalez yet all analyzed the prospect of piezoelectric based energy conversion and suggested several issues to raise the electrical output power of the existing prototypes to the level that can be theoretically obtained.

Nomenclature

PZT	Lead zirconate titanate (Pb[Zr(x)Ti(1-x)]O3), one of the world's most widely used piezoelectric ceramic materials
MEMS	Micro-Electro-Mechanical Systems
PVDF	Polyvinylidene fluoride

2. Piezo electric effect

Piezoelectricity is defined as a change in electric polarization with a change in applied stress (direct piezoelectric effect) shown in Fig. 1(a). The converse piezoelectric effect is the change of strain or stress in a material due to an applied electric field shown in Fig. 1(b). Another interesting property of piezoelectric material is that they change their dimensions (contract or expand) when an electric field is applied to them. The converse piezoelectric effect describes the strain that is developed in a piezoelectric material due to the applied electric field.

Piezoelectricity is the ability of some materials such as crystals and certain ceramics, to generate an electric potential in response to applied mechanical stress or heat. If the piezo crystals are not short-circuited, the applied charge induces a voltage across the material.

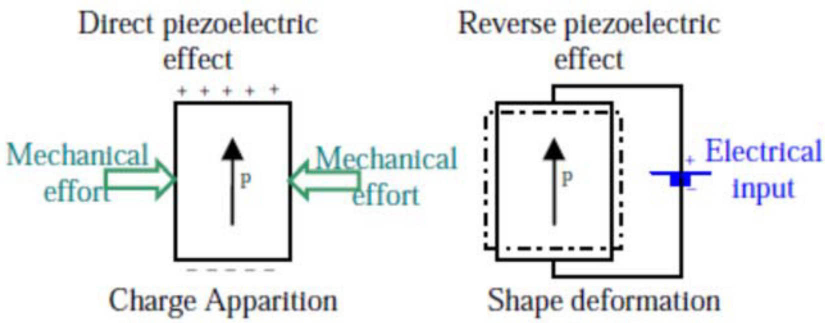


Fig. 1. (a) Piezo Electric Mechanism; (b) Converse Piezo Mechanism.

2.1. Principle of operation

The microscopic origin of the piezoelectric effect is the displacement of ionic charges within a crystal structure. In the absence of external strain, the charge distribution is symmetric and the net electric dipole moment is zero. However, when an external stress is applied the charges will be displaced and the charge distribution will be no longer symmetric and net polarization will be created. In some cases a crystal possesses a unique polar axis even in the unstrained condition. This can result in a change of the electric charge due to a uniform change of temperature. This is called the pyroelectric effect. The direct piezoelectric effect is the basis for force, pressure, vibration and acceleration sensors and the converse effect for actuator and displacement devices.

2.2. Piezo materials

Some examples of practical piezo materials are barium titanate, lithium niobate, polyvinyledenedifluoride (PVDF), and lead zirconate titanate (PZT). There are several different formulations of the PZT compound, each with different electromechanical properties.

3. Mechanism of the proposed system

Mechanical compression or tension on a poled piezoelectric ceramic element changes the dipole moment, creating a voltage. Compression along the direction of polarization or tension perpendicular to the direction of polarization generates voltage of the same polarity as the poling voltage (Fig. 2).

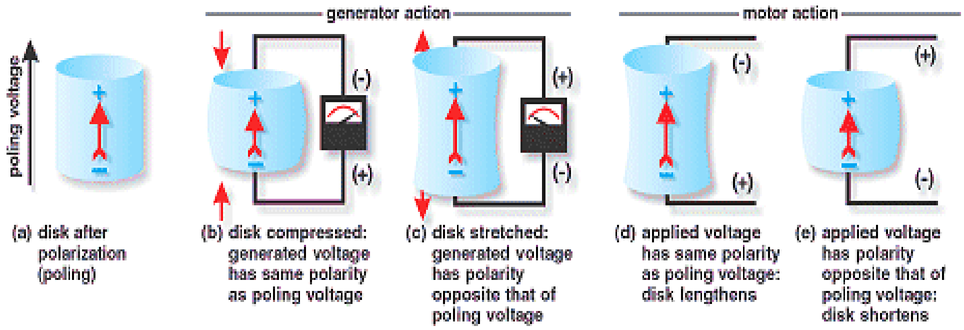


Fig. 2. Working mechanism of simple Piezo Transducer

The principle is adapted to piezoelectric motors, sound or ultrasound generating devices, and many other products. *Generator* action is used in fuel-igniting devices, solid state batteries and other products; *Motor action* is adapted to piezoelectric motors, sound or ultrasound generating devices and many other products.

In addition the superscripts "S, T, E, D" are introduced. They describe an electrical or mechanical boundary condition.

Definition:

S = Strain = constant (mechanically clamped)
T = Stress = constant (not clamped)
E = Field = constant (short circuit)
D = Electrical Displacement = constant (open circuit)

3.1 How it works?

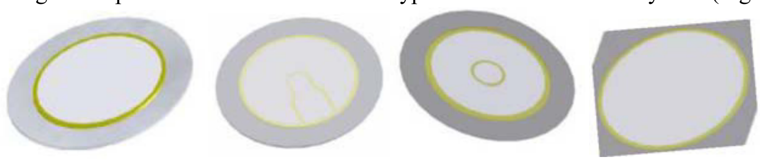
In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed. This makes the crystal electrically neutral. Each of these sides form an electric dipole and dipoles near each other tend to be aligned in regions called "Weiss domains". The domains are usually randomly oriented, but can be aligned during poling, a process by which a strong electric field is applied across the material, usually at elevated temperatures. When a mechanical stress is applied, this symmetry is disturbed and the charge asymmetry generates a voltage across the material. In Converse piezoelectric effect, application of an electrical field creates mechanical deformation in the crystal.

The most common application of piezo crystals to generate a potential is the electric cigarette lighter. Pressing the button of the lighter causes a spring-loaded hammer to hit a piezoelectric crystal, producing a sufficiently high voltage that electric current flows across a small spark gap, thus heating and igniting the gas. Some substances like quartz can generate potential differences of thousands of volts through direct piezo electric effect.

Flexible Piezoelectric Materials are attractive for power harvesting applications because of their ability to withstand large amounts of strain. Larger strains provide more mechanical energy available for conversion into electrical energy. A second method of increasing the amount of energy harvested from a piezoelectric is to utilize a more efficient coupling mode.

3.2 Types of piezo- sensors

The below figures depicts the various models and types of Piezo transducer system (Fig. 3):



(a) (b) (c) (d)

Fig. 3.(a) Two-terminal circle type, the metal is Stainless Steel, Brass and Nickel Alloy;
(b) Three-terminal circle with brim feedback, the metal is Brass and Stainless Steel;

(c) Three-terminal circle with centre feedback, the metal is Brass and Stainless Steel;
(d) Two-terminal square type, the metal is Nickel Alloy.

All the types of above products can be attached a connector with two or three wires accordingly, also can produce come other dimensions piezo plate (Fig. 4).

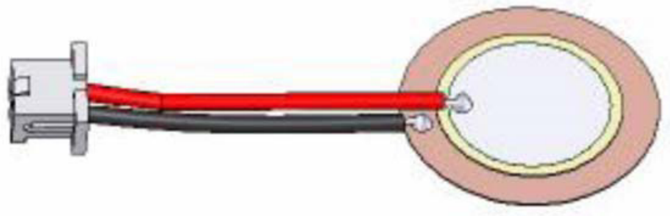


Fig. 4. Connection setup of Piezo-Transducer

4. Construction of the piezo generator

Battery powered mobile devices have recently been rapidly gaining widespread popularity. However, they must always be charged before use. If they are equipped with a generator which transforms mechanical impact energy during travel to electric energy, the batteries can be charged without electrical power sources. For this purpose we have proposed a piezo-generator which transforms mechanical impact energy to electric energy and have discussed its fundamental characteristics. The generator consists of a steel ball and a piezoelectric vibrator. The impact of the ball against the generator produces electrical energy via the piezoelectric effect. By introducing a bridge-rectifier and a capacitor, we have been able to study the energy storage characteristics both theoretically and experimentally. The efficiency and the stored charge are discussed with respect to the initial voltage and the capacity of the capacitor.

Piezoelectric generators (PEGs) are simple, inexpensive and very compact devices. Unlike other explosive power sources, such as magneto-cumulative or ferromagnetic generators, PEGs do not require the use of explosives to produce the required mechanical forces to generate electrical power. However, they are inherently low-energy devices with a maximum energy density of only about 1 J/cm3, which limits their utility to certain specific applications.

To the best of the author’s knowledge, work on explosive driven PEGs can be traced back to the early 1960s in the United States, Former Soviet Union and France. All of these early studies had two central themes: using ferroelectric or piezoelectric materials as the working body and using shock waves to depolarize these materials.

Most of the early studies focused on either single crystals or ferro-ceramic materials such as barium titanate, Tibalit, lithium niobate, and lead zirconate titanate (PZT). These materials are still investigated today, but there is also interest in ferroelectric polymers such as PVDF.

One of the early papers that investigated the feasibility of using PEGs as pulsed power supplies was by J.E. Beasancon, J. David, and J. Vedel. Since then, others have investigated their utility as pulsed power devices including A.B. Prishchepenko , B.M. Novac , S. Shkuratov , and Ya. Tkach.

A.B. Prishchepenko and his team probably have the most experience with PEGs with work beginning in 1983 and continuing through the late 1990s. They have used their PEGs to drive capacitive loads and in conjunction with ferromagnetic generators.

It was first observed by B.M. Novac et al that these generators work best when the shock pressures are dampened. They investigated the influence of pressure loading on PZT and found that when the pressure exceeded 50 kbar, the output current dramatically decreased. They theorized that this is caused by internal short circuiting of the generator due to massive generation of electrical charges. Two types of attenuators were used in their experiments: copper-Plexiglas and steel. In this study, it was decided to determine the optimal pressures for PEG operation and it was found that shock pressures are detrimental since they cause the ceramics to fracture and can induce electrical breakdown. Therefore, one of the results of this study was to determine if propellants, rather than explosives, could be efficiently used to generate high voltages from these generators.

The construction of the generation and storage system is shown in Fig. 5. Initially, a steel ball rests at a height 1/1 above a piezoelectric vibrator. The electric output of the vibrator is connected to a capacitor C through a bridge-rectifier.

4.1 Operation

The operation of the system is summarized as follows:

a. The steel ball falls freely toward the center of the vibrator under the effect of gravity.
b. After the collision, a bending vibration is produced in the vibrator and the steel ball bounces up.
c. An alternating current I_g generated by the piezo¬electric effect is supplied to the bridge-rectifier.
d. The rectified current I_c flows into the capacitor C.
e. The voltage across the capacitor increases to V.
f. The steel ball falls again and steps (2)—(5) repeat until the steel ball stops.

4.2 Analysis by an equivalent circuit model

To simulate the generation and storage mechanism, we employ an electrical equivalent circuit model shown in Fig. 6 which was introduced by the authors in the previous study. The load resistance in ref. 1 is substituted by a bridge-rectifier and a capacitor. The input mechanical energy of a falling ball is translated into an initial electrical energy by the equivalent mass in the circuit. The separation of the vibrator and the ball is simulated by changing the parameters in the circuit as described in ref. 1. Only the first bending mode is considered for simplicity of analysis. Hence C denotes the capacity of the capacitor connected to the rectifier. The value of the Cd is the clamped capacitance and Rd is the dielectric loss of the piezo-ceramics. Lm, Cm and Rm express equivalent mass, the equivalent stiffness and the equivalent mechanical loss of the first mode of the vibrator, respectively. v0 is the input voltage to the bridge-rectifier, and Vc is the voltage across the capacitor. The values of im and Ic indicate the currents in each branch.

4.3 Piezo-electric effects

- *Direct Effect* called by the Curies the "primary" effect.-Electric polarization produced by mechanical strain, changing its sign with reversal of the strain.
- *Converse Effect* (sometimes called the "reciprocal" effect)-Mechanical stress produced by the application of an electric field, changing its sign with reversal of field. *All piezo-electric crystals necessarily exhibit both the direct and the converse effect.*
- *Longitudinal Effect*-This term is commonly applied only to those cases where a dilatation in a given direction is -accompanied by an electric polarization in the same direction.
- *Transverse Effect*-As commonly employed this term refers to a dilatation at right angles to the associated electric field

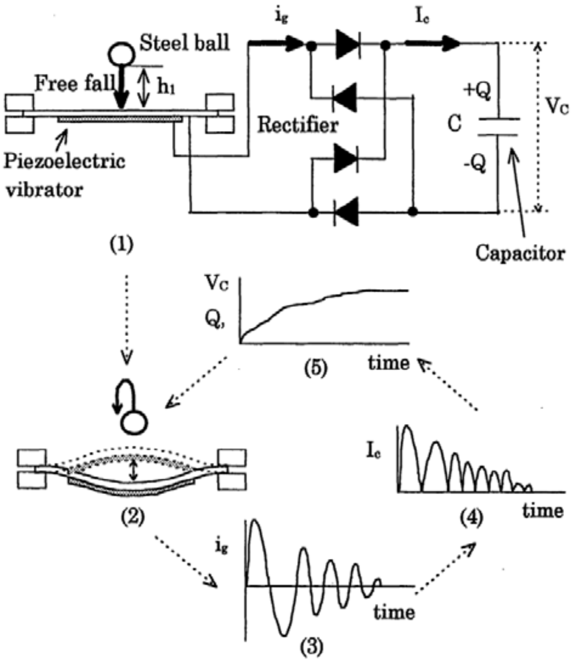


Fig. 5. Principle of generation and storage

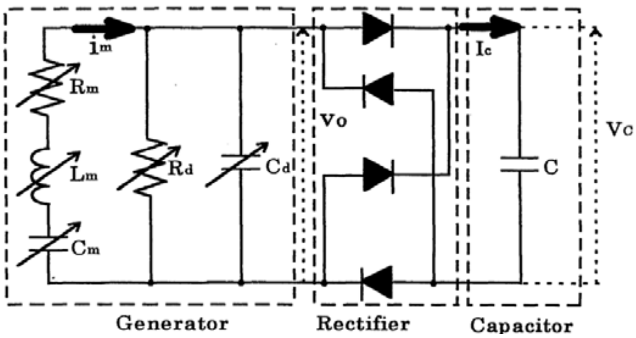


Fig. 6. Equivalent circuit of an generator

5. Types of mechanical vibrations

- *Longitudinal Vibrations* - This term may be applied either to rods or to more extended masses in which the motion of the vibrating particles is parallel to the direction of propagation of the wave, that is, normal to the wave-front. This use of the word "longitudinal" has nothing to do with the longitudinal effect. Vibrations of this type are also called "compressional" and "extensional." Longitudinal vibrations may be produced in either fluids or solids.
- *Transverse Vibrations* - This term is properly related to transverse (distortional) waves in the same manner in which the term "longitudinal vibrations" is related to longitudinal waves. The vibrating particles move in a direction parallel to the wave-front and normal to the direction of propagation. Familiar examples are electromagnetic radiations, vibrating strings, membranes and thin plates. With piezo-electric crystals transverse vibrations may occur when the direction of the electric field is such that the field produces a shearing stress about some axis. If this axis is parallel to one of the principal dimensions of the parallelepiped, the wave propagation may be expected to take place in a direction parallel to another of the dimensions. Such vibrations may also be called "shear vibrations."
- *Flexural Vibrations*- These usually occur in elongated plates or bars and are frequently called "transverse" or "lateral" vibrations. In order to distinguish them from the transverse vibrations described above, it would seem better to use the word "flexural." They are associated with a bending of

the specimen in a certain plane, hence it is best to refer, for example, to "flexural vibrations in the YZ plane."

- *Torsional Vibrations* are those in which a relative angular displacement (shearing strain) about the axis of figure, usually a cylinder or prism, takes place between adjacent cross-sections. For example, we speak of torsional vibrations "about the X-axis."

From what has been said it is evident that it is ambiguous to refer to the "direction of vibration in a crystal," unless the type of vibration is also made clear.

6. Applications

The best-known application of piezo crystals are:

a. Direct piezoelectricity of some substances like quartz, as mentioned above, can generate potential differences of thousands of volts.
b. As sensing elements, Detection of pressure variations in the form of sound is the most common sensor application, e.g. piezoelectric microphones. Sound waves bend the piezoelectric material, creating a changing voltage
c. Ultrasound imaging, Piezoelectric sensors are used with high frequency sound in ultrasonic transducers for medical imaging .For many sensing techniques, the sensor can act as both a sensor and an actuator. Ultrasonic transducers, for example, can inject ultrasound waves into the body, receive the returned wave and convert it to an electrical signal (a voltage).
d. Sonar sensors, Piezoelectric elements are also used in the detection and generation of sonar waves. Applications include power monitoring in high power applications such as medical treatment, sono chemistry and industrial processing etc.
e. As chemical and biological sensors, Piezoelectric microbalances are used as very sensitive chemical and biological sensors. Piezo are also used as strain gauges.
f. Automotive application, automotive engine management systems use a piezoelectric transducer to detect detonation by sampling the vibrations of the engine block. Ultrasonic piezo sensors are used in the detection of acoustic emissions in acoustic emission testing.
g. Piezo-resistive silicon devices, the piezo-resistive effect of semiconductors have been used for sensor devices employing all kinds of semiconductor materials such as germanium, polycrystalline silicon, amorphous silicon and single crystal silicon. Since silicon is today the material of choice for integrated digital and analog circuits the use of piezo-resistive silicon devices has been of great interest. It enables the easy integration of stress sensors with Bipolar and CMOS circuits.
h. Piezo-resistors, Piezo-resistors are resistors made from a piezo-resistive material and are usually used for measurement of mechanical stress. They are the simplest form of piezo-resistive device.
i. In Music instruments, Piezoelectric transducers are used in electronic drum pads to detect the impact of the drummer's sticks.

6.1. The piezo-resistive effect

It is the changing electrical resistance of a material due to applied mechanical stress. The piezo-resistive effect differs from the piezoelectric effect. In contrast to the piezoelectric effect, the piezo-resistive effect only causes a change in resistance; it does not produce an electric potential

6.2. Some other applications in practice

6.2.1. Tokyo Railway Will Have Piezoelectric Power Generators

The tests are concluded in February 2009

The East Japan Railway Company (JR East) has announced that it will outfit the floor of its Tokyo railway station with piezoelectric devices that have the capacity to draw electricity from the steps of those passing in front of ticket booths. For now, the experiment will be fairly limited, covering a small area but, if successful, the system will be implemented at a large scale, probably in all railway or subway stations in Japan, or even worldwide.

According to company officials, the piezoelectric system will be able to supply 1,400 kW/sec under normal traffic condition, which means that it could power up all displays in the station by itself. Of course, the amount of electricity it puts out is directly dependent on the number of people walking over it, to trigger the electric potential of thousands of tiny devices.

Piezoelectric materials, usually crystals or ceramics, have the capability to generate a small amount of current, when they are subjected to mechanical pressure, such as pushing, bending, twisting and turning. Such multiple materials, placed near each other in densely-trafficked areas, could power up even larger structures, provided that the stream of passengers are large enough.

The limitations that these materials have, are the same as for nearly all renewable energy sources – once the "trigger" (the Sun, the wind, human steps etc.) is gone – the power-generating capacity decreases drastically.

The test portion of the railway in Tokyo will only have about 25 sq meters (82 square feet), and it will still be capable of producing sufficient amounts of current.

The piezoelectric materials started testing on December 10th and functioned non-stop until February 2009.

6.2.2. Piezoelectric Crystals Turn Roads into Power Plants

The system is tested in Israel starting January 2009

A new design, devised by HaimAbramovich, a developer at the Technion-Israel Institute of Technology in Haifa, Israel, may hold the key to harnessing the power of moving vehicles to create electricity, he says. Piezoelectric crystals could be used to absorb heavy traffic and convert a 1 kilometer stretch of highway into a 400 kilowatt power plant, much like Japan's railway project.

Innowattech, Abramovich's Haifa-based spin-off company, already announced its intentions of testing the new system as early as January 2009, on a short stretch of highway, about 100 meters long, in Northern Israel. The researcher says that, if successful, the new concept could be implemented in many highways and freeways, through basic maintenance work, without the need for further digs in the pavement.

Piezoelectric materials, crystals and ceramics have the ability to generate a small electric potential when they are subjected to mechanical stress, which makes them suitable for a variety of applications, from harnessing sounds to producing electricity. Piezoelectric concepts include the use of these small devices to capture sound waves from cell phones and convert them into current to feed the battery. This would basically create a self-powering device that would never need re-fuelling.

Critics to the Israeli system say that inserting this type of materials in the surface of the road would basically increase the traction force cars would have to exert on the road, as the surface of the street would resemble that of a mud-covered area. This would mean that fuel consumption would increase, though even opponents admit that powering roadside structures would be very beneficial to everyone.

Regardless of this project, the future of piezoelectric materials looks bright, with studies focusing on their properties and applications even in nanotechnology. If a compromise between the hardness of the road and the make-up of the small devices is reached, then undoubtedly the system will benefit both drivers and the Israeli national power grid.

7. Summarization

With reference to quartz crystals, the terms "X-cut" and "Y-cut" are recommended in place of "Curie cut" and "thirty-degree cut" for plates perpendicular to the X and Y axes respectively. It is suggested that the terms "X-waves”, " Y-waves", or "Z-waves " be applied to waves of mechanical vibration the direction of propagation of which is parallel to the X, Y or Z axis respectively, whatever the mode of vibration. For the quantity "meters per millimeter," the name wave-constant, to be designated by the symbol h, is recommended.

It is in general importance for the proper understanding of any paper on piezo-electricity or its applications that the various dimensions of the preparation be clearly specified with respect to the crystal axes, and that the values of the dimensions to be stated. Exceptions may, of course, be made when one of the universally recognized cuts is used and the dimensions of the plates are not essential.

In the first case, we have the cut variously referred to in the literature as "Curie cut," "zero-angle cut," "perpendicular," or "normal" cut. Owing to the evident ambiguity in the use of any of the last three, the term "Curie cut" is preferable. However, a still more concise term would be the "X-cut," denoting a plate the normal to whose face, and hence for which the applied electric field, is parallel to an X-axis.

Similarly, the term "Y-cut" would apply to the second type of quartz plate, which has hitherto been referred to as the "30-deg. cut" or "parallel cut." The author ventures to urge that the general adoption of the terms "X-cut" and Y-cut" would at once meet the need for definiteness, brevity and consistency.

Fig. 7 illustrates the X-cut (at the right) and the Y-cut (above) with reference to the crystal axes. The thickness dimensions are parallel to the X- and Y-axes, respectively, while in each case the breadth of the plate is perpendicular to the diagram (parallel to the optic axis).

As is well known, it is exceedingly difficult to cut quartz plates with such precision as to avoid very complex types of vibrations, so that in any given case, owing partly to the effects of elastic reaction and lack of uniformity of the electric field, a wild medley of both longitudinal and transverse waves may be present. Fortunately, the frequencies commonly employed in practice are usually found to have values in fair agreement with those calculated for one or other of the simple vibration modes. In what follows only these simple modes, need be considered.

X-Cut-The chief mode of vibration is longitudinal, in the direction of the X-axis, employing the longitudinal piezo-electric effect; the Y-axis, employing the transverse piezo-electric effect; or the Z-axis, in which case, the vibrations are produced by elastic reaction. The use of the term "transverse vibrations" of quartz plates as applied to longitudinal vibrations which are "transverse" with respect to an electric axis is inconsistent and likely to lead to serious confusion. The characteristic elongation of the plate through the transverse effect is illustrated below in Fig. 7.

One of the most important characteristics of a piezo-electric resonator is that quantity known as the "meters per millimeter," that is, the number of meters of electromagnetic wavelength for the fundamental mode of vibration along any dimension, divided by that dimension expressed in millimeters. For this quantity the term wave-constant is recommended. The term is of course applicable to resonators formed from any kind of crystal. It is suggested that for the wave-constant the symbol has be adopted.

In order to avoid the confusion that arises from attempts at specifying modes of vibration, it is recommended that the term "X-waves", "Y-waves," or "Z-waves" be applied to waves of whatever type whose direction of propagation is parallel to the X, Y or Z axis respectively. For example, instead of the phrase "longitudinal vibrations of a Curie cut plate in the direction of the Y-axis" we would now write "Y-waves in an X-cut plate."

Y-Cut-The only mode of vibration that has received much attention hitherto appears to be a shear vibration, the shearing strain taking place about the Z-axis and the direction of wave propagation being parallel to the Y-axis. The wave velocity, and hence the wave constant for-the fundamental frequency, calculated on the assumption of shear vibrations from the accepted values of the elastic constants of quartz, are in fair agreement with observation. In Fig. 7 the nature of the shearing strain produced in a Y-cut plate is indicated.

8. Rochelle salt

This crystal, when in an electric field is subjected primarily only to a shearing stress, hence in the case of plates cut with all edges parallel to the axes, shear vibrations are the type to be expected in an alternating field, although, through elastic reactions, the possibility of longitudinal vibrations is not excluded. As is well known, plates may also be cut from a Rochelle salt crystal in such a manner as to exhibit resultant extensions and contractions in directions perpendicular to the electric field, so that in this sense one may speak of longitudinal vibrations produced by the transverse effect in Rochelle salt. No longitudinal effect exists with this crystal.

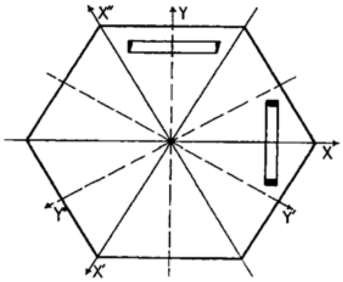


Fig. 7.Rochelle Salt crystalline structure

Strictly, all piezo-electric preparations commonly used in radio are resonators. Nevertheless, in order to avoid the confusion which has already begun to appear in various publications, it is suggested that the term "resonator" be used, as a rule, in a more restricted sense, and that the following definitions be adopted.

Piezo-Electric Resonator- Any device that may be excited piezo-electrical into resonant vibrations at one or more frequencies. In a more restricted sense the term is also applied to such a device when so connected as to exert no appreciable controlling effect upon the applied frequency through its reaction.

Piezo-Electric Oscillator- A circuit containing a resonator and possessing too little regeneration to oscillate of it, but which oscillates through the reaction of the resonator when the latter is vibrating near one of its normal frequencies with energy derived from the circuit. Such a circuit is often called a "crystal-controlled" or "quartz-controlled" circuit, also a "piezo-oscillator." *Piezo-Electric Stabilizer-*A stabilized circuit is one which oscillates without the resonator, but the frequency of which is, usually over a rather narrow range, stabilized when the resonator is connected to the circuit. The resonator itself may, in this case be referred to as a "piezoelectric stabilizer."

Since the distinction between a stabilizer and an oscillator lies largely in the amount of regeneration, it follows that the transition from one to the other may be gradual.

A Crystal Monitor or Piezo-Electric Monitor consists of a resonator in an independent circuit of low power (resonator, stabilizer, or oscillator) serving as a frequency standard to which a generator may be tuned.

A Piezo-Electric Calibrator is a resonator, or set of resonators, so connected as to serve as a frequency standard for the calibration of frequency meters, etc.

9. Conclusions

Experiments on the frequency of piezo-electric elements are described with special reference to the effect due to supersonic sound waves generated in the air gap of the holder and due to its capacity. It is shown that a mechanical load on the crystal increases its thickness frequency and that an air gap has a similar effect. The velocity of the supersonic sound waves is about the same as for ordinary sound waves. The value found is 338.68 meters per second at 24.5C deg.

An appropriate air gap gives even more high frequency output than a mechanically-loaded crystal and procures a steady frequency operation. Two sputtered piezo-electric elements can produce a beat frequency which is correct within a few parts in 100,000. A method is shown by means of which a low-frequency standard can be obtained by harmonic division of a high frequency due to piezo-electric element.

It is possible to generate Electrical Energy by the use of unwanted ground vibrations or simply sound pollution causing vibrations by the use of PIEZO GENERATION. Further, it is also possible to generate Electrical Energy by usual vibration causing works like Message typing in Mobiles, Bike rides, listening music from Audio decks, travelling in conventional trains, etc.,

Hence all the usual and useless works can be effectively turned into most powerful ELECTRICITY (ELECTRICAL ENERGY) GENERATION by the use of Piezo Sensors.

Fig. 8. Piezo-Gen

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