PIEZOELECTRIC SENSORS

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Abstract- **The basic theory behind piezoelectricity is based on the electrical dipole. At the molecular level, the structure of a piezoelectric material is typically an ionic bonded crystal. At rest, the dipoles formed by the positive and negative ions cancel each other due to the symmetry of the crystal structure, and an electric field is not observed. When stressed, the crystal deforms, symmetry is lost, and a net dipole moment is created. This dipole moment forms an electric field across the crystal**

I.   INTRODUCTION

Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for "push".

One of the unique characteristics of the piezoelectric effect is that it is reversible, meaning that materials exhibiting the direct piezoelectric effect (the generation of electricity when stress is applied) also exhibit the converse piezoelectric effect (the generation of stress when an electric field is applied).

When piezoelectric material is placed under mechanical stress, a shifting of the positive and negative charge centers in the material takes place, which then results in an external electrical field. When reversed, an outer electrical field either stretches or compresses the piezoelectric material.

The piezoelectric effect is very useful within many applications that involve 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, such as scanning probe microscopes (STM, AFM, etc). The piezoelectric effect also has its use in more mundane applications as well, such as acting as the ignition source for cigarette lighters.

II.   SENSORS

The principle of operation of a piezoelectric sensor is that a physical dimension, transformed into a force, acts on two opposing faces of the sensing element. The detection of pressure variations in the form of sound is the most common sensor application, which is seen in piezoelectric microphones and piezoelectric pickups for electrically amplified guitars. Piezoelectric sensors in particular are used with high frequency sound in ultrasonic transducers for medical imaging and industrial nondestructive testing. Based on piezoelectric technology various physical quantities can be measured; the most common are pressure and acceleration. For pressure sensors, a thin membrane and a massive base is used, ensuring that an applied pressure specifically loads the elements in one direction. For accelerometers, a seismic mass is attached to the crystal elements. When the accelerometer experiences a motion, the invariant seismic mass loads the elements according to Newton's second law of motion $F = ma$.

The main difference in the working principle between these two cases is the way forces are applied to the sensing elements. In a pressure sensor a thin membrane is used to transfer the force to the elements, while in accelerometers the forces are applied by an attached seismic mass.

Sensors often tend to be sensitive to more than one physical quantity. Pressure sensors show false signal when they are exposed to vibrations. Sophisticated pressure sensors therefore use acceleration compensation elements in addition to the pressure sensing elements. By carefully matching those elements, the acceleration signal (released from the compensation element) is subtracted from the combined signal of pressure and acceleration to derive the true pressure information.

Vibration sensors can also be used to harvest otherwise wasted energy from mechanical vibrations. This is accomplished by using piezoelectric materials

to convert mechanical strain into usable electrical energy.
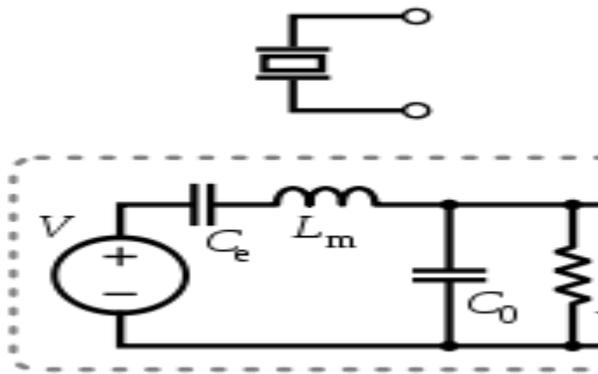
III. PROPERTIES

The generated voltage from a piezoelectric material can be calculated from the followingequation.

$$V = Sv * P * D$$

Where V = Piezoelectric generated voltage (Volts)

Sv = Voltage sensitivity of the material (Volt *meters / Newton)

P = Pressure (N/m2)

D = thickness of material (meters)

Voltage sensitivity values are provided with the material when received from the manufacturer. Different materials and different geometry cuts give different sensitivities. A detailed model includes the effects of the sensor's mechanical construction and other non-idealities. The inductance L_m is due to the seismic mass and inertia of the sensor itself. C_e is inversely proportional to the mechanical elasticity of the sensor. C_0 represents the static capacitance of the transducer, resulting from an inertial mass of infinite size.R_i is the insulation leakage resistance of the transducer element. If the sensor is connected to a load resistance, this also acts in parallel with the insulation resistance, both increasing the high-pass cutoff frequency. In the flat region, the sensor can be modeled as a voltage source in series with the sensor's capacitance or a charge source in parallel with the capacitance.
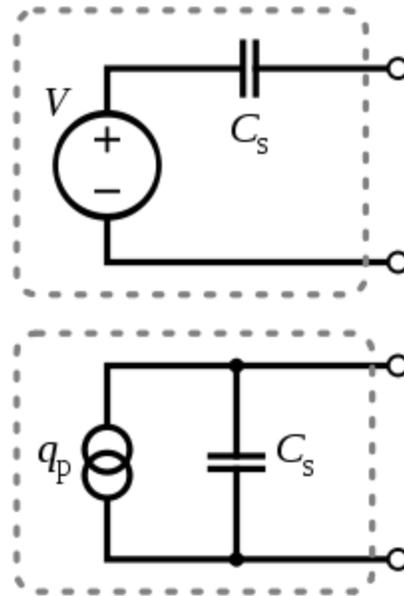
IV. APPLICATIONS

Piezoelectric sensors have proven to be versatile tools for the measurement of various processes. They are used for quality assurance,process control and for research and development in many industries. Although the piezoelectric effect was discovered by Pierre Curie in 1880, it was only in the 1950s that the piezoelectric effect started to be used for industrial sensing applications. Since then, this measuring principle has been increasingly used and can be regarded as a mature technology with an outstanding inherent reliability. It has been successfully used in various applications, such as in medical, aerospace, nuclear instrumentation, and as a tilt sensor in consumer electronics[1] or a pressure sensor in the touch pads of mobile phones. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. The sensors are either directly mounted into additional holes into the cylinder head or the spark/glow plug is equipped with a built-in miniature piezoelectric sensor. The rise of piezoelectric technology is directly related to a set of inherent advantages. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 10^6 N/m². Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection.

This gives piezoelectric sensors ruggedness, an extremely high natural frequency and an excellent linearity over a wide amplitude range. Additionally, piezoelectric technology is insensitive to electromagnetic fields and radiation, enabling measurements under harsh conditions. Some materials used (especially gallium phosphate ortourmaline) are extremely stable at high temperatures, enabling sensors to have a working range of up to 1000 °C. Tourmaline shows pyroelectricity in addition to the piezoelectric effect; this is the ability to generate an electrical signal when the temperature of the crystal changes.

V. LIMITATIONS

The impedance of the crystal is very high. Therefore we need to measure thevoltage with a higher impedance device to avoid draining the tiny store of energy that isthere. The typical resistance and capacitance values of an 8 mm crystal are about 1015 Watts and 10-15 Farads. These are extremely high impedances. This means that when weamplify the signal we must consider the capacitance of the lead wires and the inputimpedance of the amplifier. Normally in instrumentation design we ignore these factorsbecause sensors generally have impedances in the range of 103 W rather than 1015 W. Inpractice this means that we have a limited amount of time available to take a fixedmeasurement before the charge drains away. If the measurement changes rapidly thenthere is much less of a problem. IE the sensor has a very poor DC response but good ACresponse.Piezoelectric sensors also react to temperature as well as pressure. They must beoperated in their design range to maintain accuracy. Out of their design range they reactso strongly to temperature that they can be used as temperature sensors. The followingfigure illustrates this. As can be seen if the crystal is operated around 20°C then thetemperature can vary a few degrees with minimal effect on the frequency. In this rangewe could use the crystal as a frequency reference. Around 50°C the response totemperature is strong and somewhat linear. In this operating range we could use thecrystal as a temperature sensor. The sensitivity is a function of temperature.

VI. CONCLUSIONS

A piezoelectric transducer is a device that transforms one type of energy to another by taking advantage of the piezoelectric properties of certain crystals or other materials. When a piezoelectric material is subjected to stress or force, it generates an electrical potential or voltage proportional to the magnitude of the force. This makes this type of transducer ideal as a converter of mechanical energy or force into electric potential.The high sensitivity of piezoelectric transducers makes them useful in microphones, where they convert sound pressure into electric voltage, in precision balances, in accelerometers and motion detectors, and as generators and detectors of ultrasound. They are also used in non-destructive testing, in the generation of high voltages, and in many other applications requiring the precise sensing of motion or force.

The piezoelectric effect also works in reverse, in that a voltage applied to a piezoelectric material will cause that material to bend, stretch, or otherwise deform. This deformation is usually very slight and proportional to the voltage applied, and so the reverse effect offers a method of precision movement on the micro scale. A transducer may, therefore, be used as an actuator for the exact adjustment of fine optical instruments, lasers, and atomic force microscopes. These devices can be used both as sensors and actuators, so they're referred to as transducers, a term applied to any device that can convert one form of energy to another. As a result, both piezoelectric sensors and piezoelectric actuators come under this heading. The sensor turns mechanical energy into electric potential, and the actuator converts electrical energy into mechanical force or motion.

The voltage generated by piezoelectric transducers can be quite high, often in the thousands of volts, but is brief, occurring only when the material is initially deformed. This makes them useful in electronic cigarette lighters and push-button igniters for gas ranges and grills. In these applications, pushing a button activates a small, spring-loaded hammer, which strikes a piezoelectric material and generates a voltage sufficient to cause an electric arc to jump between the exposed electrodes of the igniter.

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