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PIEZOELECTRIC EFFECT AND ITS APPLICATIONS IN MODERN TECHNOLOGIES

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Abstract
This article examines the piezoelectric effect and its applications in modern technologies. The piezoelectric effect, discovered in 1880 by the Curie brothers, is the ability of certain crystalline materials to generate electrical charge in response to mechanical stress and vice versa. The study explores the fundamental principles of piezoelectricity, analyzes its theoretical foundations, and investigates experimental methods for studying this phenomenon. The article reviews the wide range of modern applications including sensors, actuators, energy harvesting devices, medical equipment, and consumer electronics. Special attention is given to recent innovations in flexible piezoelectric materials, nanostructured devices, and sustainable energy applications. The research demonstrates the growing importance of piezoelectric technologies in advancing smart materials, Internet of Things (IoT) devices, and renewable energy systems.

Keywords: Piezoelectric effect, smart materials, energy harvesting, sensors, actuators, crystalline materials, modern technology, sustainable energy.

Introduction

The piezoelectric effect was discovered in 1880 by the Curie brothers, Jacques and Pierre. The direct effect was predicted in 1881 by Lippmann based on thermodynamic considerations. That same year, it was realized through experiments conducted by the Curie brothers.

The piezoelectric effect (from the Greek piezo (piézo) meaning 'to press' or 'to squeeze') refers to the phenomenon of dielectric polarization occurring under mechanical stress (the direct piezoelectric effect). Additionally, there is the inverse piezoelectric effect, which involves the generation of mechanical deformations under the influence of an electric field.

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Currently, the piezoelectric effect plays a significant role in the development of technologies worldwide. It is widely used in various fields, ranging from sensor sensors in smartphones to medical devices, the automotive industry, aerospace technologies, and energy efficiency sectors.
The aim of the article is to thoroughly explore the fundamental principles of the piezoelectric effect, its applications in modern technologies, and the potential pathways for its future development.

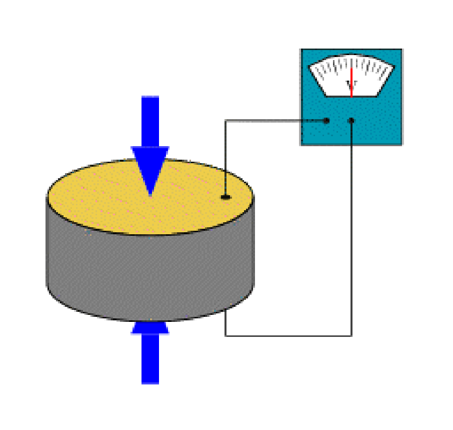

***Figure 1**: Generation of electrical voltage using piezoelectricity. For clarity, the amplitude of the disk vibrations has been increased*

With the direct piezoelectric effect, the deformation of the piezoelectric material leads to the generation of electrical voltage between the surfaces of the deformed solid. In contrast, with the inverse piezoelectric effect, the applied stress causes the material to deform.
Piezoelectric elements always exhibit both direct and inverse piezoelectric effects simultaneously. The material does not necessarily need to be crystalline; the effect can also be observed in polycrystalline elements that are pre-polarized with a strong electric field during crystallization, or in ferroelectrics during the phase transition at the Curie temperature when cooling (for example, lead titanate-based ceramic piezoelectric materials), under an external electric field. When an external mechanical force is applied to the piezoelement, the total energy is equal to the sum of the elastic deformation energy and the charge energy of the piezoelement. Due to the reversibility of the piezoeffect, a piezoelectric reaction occurs: the electrical voltage generated as a result of the direct piezoelectric effect (or the mechanical stress resulting from the inverse piezoelectric effect) also

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induces deformations that oppose the external forces. This is observed as an increase in the rigidity of the piezoelement. If the electrical voltage generated by the piezoelectric effect is removed, for example, by reducing the electrodes of the piezoelectric element, the inverse piezoelectric effect is not observed, and the rigidity of the piezoelectric element decreases. Studies of the piezoelectric effect show that it is defined by the properties of the elementary unit cell of the material structure. Since the elementary unit cell is the smallest symmetric unit of the material, a microscopic crystal can be obtained by repeating this unit multiple times. A necessary condition for the occurrence of the piezoelectric effect is the absence of a center of symmetry in the unit cell. Conductors do not have a piezoelectric coefficient because the applied mechanical stress (direct effect) and electrical (inverse effect) voltage are compensated by the charge-conducting medium.

Methods for Determining Piezoelectric Properties

1. Measuring the piezoelectric modulus using a d_{33} meter:

For the experiment, the following is required:
- PZT-5A ceramic sample (10×10×1 mm)
- d33 meter (Pizotest d33 meter)
- Calibrated force (10 N)
- Measurement results:
- For PZT-5A, d_{33} = 374 pC/N.
- Temperature change: -0.3%/ °C.

Table 1. Relative property indicators of various piezoelectric materials.

Material	d_{33}(pC/N)	k_{33}	g_{33} (mV m/N)	T_c (°C)
Quartz	2.3	0.1	50	573
$BaTiO_3$	190	0.51	14	120
PZT-5A	374	0.72	25	365
PZT-5H	593	0.75	19.7	193
PVDF	-33	0.12	216	-

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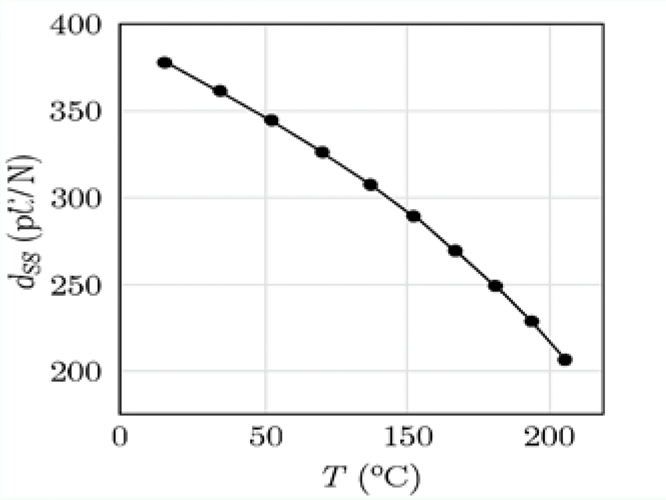

***Figure 2**. Temperature dependence of the d_{33} (piezoelectric coefficient) constant for the PZT-5A material.*

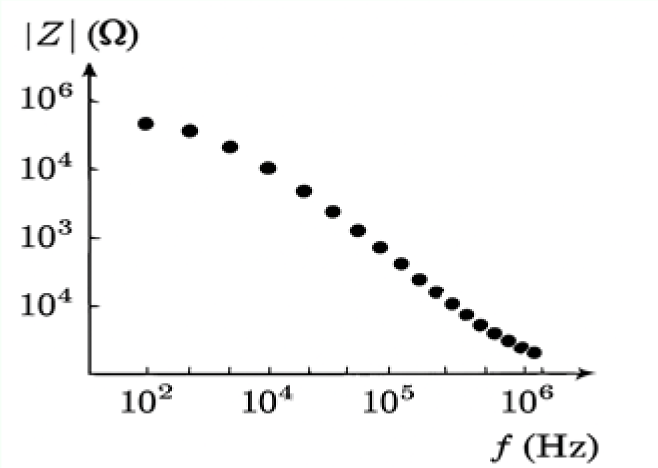

***Figure 3.** Frequency spectrum of PZT ceramics.*

Applications in modern technologies

Applications in the medical field. Ultrasound medical devices:

- Diagnostic ultrasound equipment.
- Ultrasound surgical instruments.
- Physiotherapy devices.
- Implantable devices:
- Piezoelectric pacemaker.

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- Neurostimulator devices.

Pizoelektrik effekt zamanagóy texnologiyalardıń rawajlanıwında úlken áhmiyetke iye. Izertlew nátiyjeleri tómendegi juwmaqlardı shıǵarıwǵa imkan beredi:

1. The piezoelectric effect plays a crucial role in the development of modern technologies. The research results allow the following conclusions to be drawn:

Material appearance: The PZT-5H material, exhibiting the highest piezoelectric coefficient (d_{33} = 593 pC/N), confirms that it is one of the most optimal materials for energy harvesting applications.

2. Temperature invariance: Compared to quartz, PZT ceramics are more significantly affected by temperature variations, but their piezoelectric constants are 10-20 times higher.

3. Application diversity: Piezoelectric technologies are widely used across various fields, from medicine to the automotive industry, which is evidence of their universal properties.

In summary, the piezoelectric effect stands as a cornerstone in the development of various modern technologies. Its ability to convert mechanical energy into electrical energy (and vice versa) has opened up vast applications across diverse industries, from medical diagnostics and treatment devices to advanced automotive systems. The research highlights materials like PZT-5H for their exceptional piezoelectric properties, particularly their high d33 coefficients, making them optimal for energy harvesting and sensor technologies.

While temperature variations significantly affect the performance of PZT ceramics compared to other materials like quartz, their superior piezoelectric constants offer a substantial advantage in many applications. The versatility and efficiency of piezoelectric devices have made them indispensable in fields such as medicine (e.g., ultrasound devices and pacemakers) and industrial applications, showcasing their universal potential.

The ongoing advancements in piezoelectric materials and their integration into modern technologies suggest that their role will continue to expand, driving innovation and improving the efficiency of numerous systems.

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