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AUTOMATION COMPONENTS BASED ON THE INVERSE PIEZOELECTRIC EFFECT. (Further Development of Innovative Applications Based on the Inverse Piezoelectric Effect)

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Abstract

The article examines the application of piezoelectric motors operating on the principle of the inverse piezoelectric effect in advanced automation and precision engineering systems, with particular emphasis on their use as precision miniature stepper motors. As requirements for higher accuracy, lower motor weight, and reduced overall dimensions become increasingly stringent, the integrated use of specialized composite materials as the primary materials for motor components and structures is becoming an important direction in the development of such motors. Testing of these types of piezoelectric motors and attempts to use them as stepper motors have raised a number of technical issues. These are largely related to the incompatibility between modern control processors and their software functions and the design limitations resulting from the use of conventional structural materials that performed well with earlier generations of components. The mechanical transmission chain extends from the plain bearing to the piezoceramic ring, then through the spring-steel fingers soldered to the ring, to the friction ring and, finally, to the motor rotor. Design limitations in this chain have shown that the principal cause of the wide variation in motor output parameters is the insensitivity of its components to changes and fluctuations in control and monitoring pulses. Analytical studies have shown that the main problem is the system's inability to distribute or dissipate the pulses applied to the piezoelectric ring virtually instantaneously. As the first step in optimization, it was decided to replace the conventional piezoceramic material of the piezoelectric ring with a piezoceramic composite containing components that do not respond to the pulses applied to the ring. Previous practical experience has shown that this can be achieved by uniformly incorporating synthetic diamond microspheres into the piezoceramic material.

Keywords: *Automation; automation components; direct piezoelectric effect; inverse piezoelectric effect; innovative applications; piezoelectric motors; piezoelectric motors operating on the principles of the inverse piezoelectric effect; a foundation for advanced automation and precision engineering systems; systems and configurations for precision*

miniature stepper motors; virtually instantaneous distribution or dissipation of pulses applied to the piezoelectric ring; the insensitivity of the components in the mechanical transmission chain to changes and even fluctuations in control and monitoring pulses as the principal cause of the wide variation in motor output parameters

Introduction

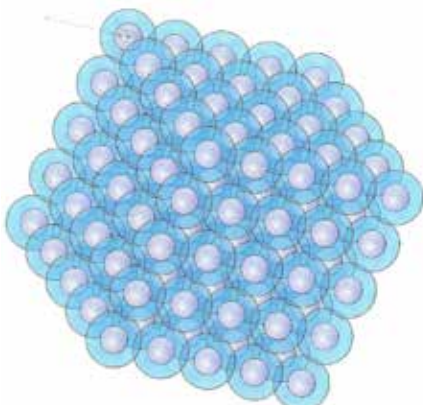
Practical experience has shown that piezoelectric motors operating on the principles of the inverse piezoelectric effect can provide a foundation for advanced automation and precision engineering systems incorporating elements of artificial intelligence and artificial neural networks.

Developers and designers are particularly interested in the potential to use the inverse piezoelectric effect to develop systems and configurations for precision miniature stepper motors.

Figure 1. *Piezoelectric motor*



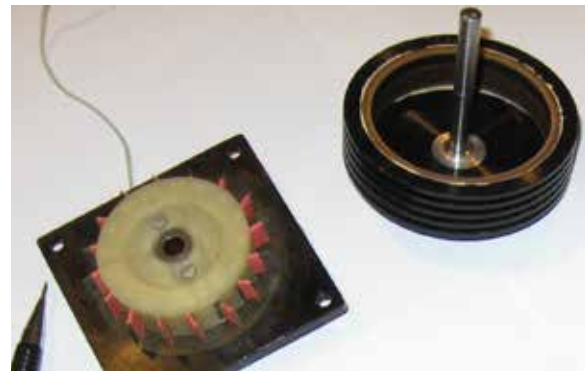
Figure 2. *Three-dimensional model of spherical capsules*



As requirements for greater accuracy and lower motor weight become more stringent, including through reductions in overall dimensions, an increasing number of designs and engineering solutions propose the inte-

grated use of specialized composite materials as the primary materials for motor components and structures.

Figure 3. *Piezoelectric motor with the rotor removed*



Optimization Process

The accuracy required of piezoelectric stepper motors, together with software-based monitoring and control, requires a consistent relationship between motor output parameters and the characteristics of the signal pulses applied to the piezoceramic ring.

The mechanical transmission chain extends from the plain bearing to the piezoceramic ring, then through the spring-steel fingers soldered to the ring, to the friction ring and, finally, to the motor rotor. Design limitations in this chain have shown that the principal cause of the wide variation in motor output parameters is the insensitivity of its components to changes and even fluctuations in control and monitoring pulses.

Analytical studies have shown that the main problem is the system's inability to distribute or dissipate the pulses applied to the piezoelectric ring virtually instantaneously.

As the first step in optimization, it was decided to replace the conventional piezoceramic material of the piezoelectric ring with a piezoceramic composite containing components that do not respond to the pulses applied to the ring.

Previous practical experience has shown that this can be achieved by uniformly incorporating synthetic diamond microspheres into the piezoceramic material.

Figure 4. *Piezoelectric motor beside a mechanical pencil for scale*



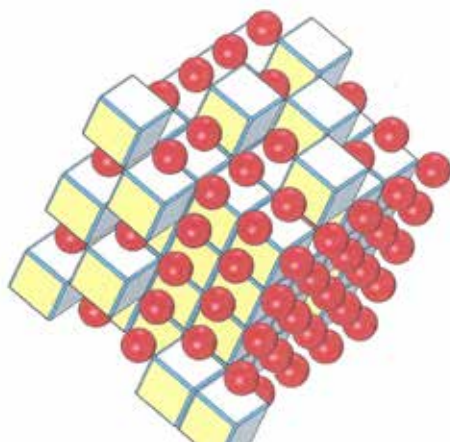
Pseudoporous Structure

The model of this material shows its three-dimensional structure, comprising numerous spherical capsules with at least two constituent levels.

The first level consists of synthetic diamond microspheres, which can now be produced with very high precision at minimal manufacturing cost and with minimal raw-material costs.

Unlike gem-quality crystals, these synthetic diamonds do not need to meet transparency or purity requirements.

Figure 5. *Schematic model of a composite with spherical inclusions*



The illustration shows the structure of this composite material.

After manufacture, the diamond spheres are coated with a moist ceramic mixture and placed in a mold. Under pressure, the ceramic surrounding the diamond spheres under-

goes bulk deformation, forming numerous cubic microstructures, each with a diamond sphere at its geometric center.

This structure is pseudoporous: the diamond spheres, which are virtually unresponsive to the pulses, cause signals or pulses to be distributed almost uniformly throughout the volume of the ceramic cubes. This provides exceptional stability and uniformity of signal propagation within the pseudoporous piezoceramic ring.

Figure 6. *Three-dimensional model of the capsule structure*

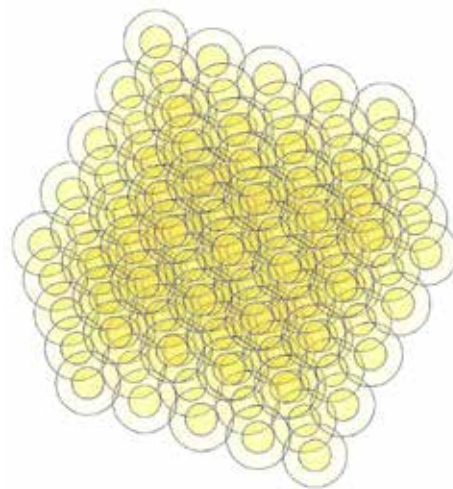
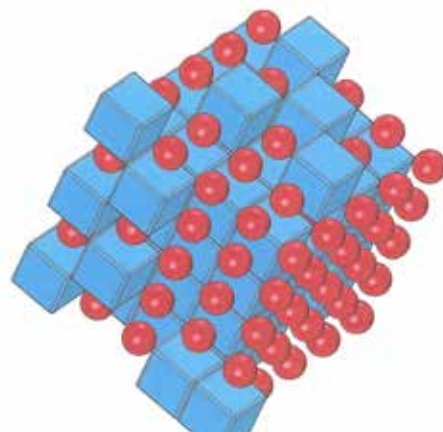


Figure 7. *Schematic model with cubic regions and spherical inclusions*



Because spring fingers are soldered to the ring's outer cylindrical surface, a signal pulse distributed uniformly within the piezoelectric ring can satisfy all the principal requirements for the stability and uniformity of the driving vibratory pulses transmitted from the fingers to the rotor in contact with them.

It is now necessary to return to the question of rotor wear resistance.

The tips of the spring fingers remain in continuous dynamic contact with the rotor's inner surface. If pulses are distributed unevenly throughout the three-dimensional volume of a rotor made of conventional piezoceramic material, it can be assumed that the force transmitted by the finger tips to the rotor's inner surface is nonuniform. This would cause uneven wear of that surface and, consequently, radial runout of the motor's output shaft.

Replacing the piezoelectric ring material with a pseudoporous piezoceramic composite will significantly reduce the dependence of rotor wear on the uneven distribution of pulses in the piezoceramic material. This should have a positive effect on the piezoelectric motor's output parameters and operating characteristics.

The relevant parameters and improvements include:

- Radial runout of the motor shaft;
- Synchronization of all mechanical contacts between the motor's structural components;
- Longer motor service life;
- Easier simultaneous synchronization of the operating output parameters of multiple motors in systems that convert motor rotation into linear carriage motion;
- Uniform and consistent rotor speed.

In the existing motor design, all motor systems are also affected by vibrations arising from the uneven and cyclic transmission of mechanical forces from the piezoceramic material to the rotor and, ultimately, to the output shaft.

Systems analysis and computer modeling have shown that it is also reasonable to replace the rotor material with a material analogous to the pseudoporous composite used for the piezoceramic ring.

In this case, the structural arrangement of the composite remains unchanged; only its constituent materials change.

For example, to improve the durability of the motor's structural components, the diamond core could be replaced with beryllium, with aluminum forming the surrounding shell.

Aluminum is sufficiently ductile to provide the cold flow required when sizing the geometry of motor parts and components by bulk plastic deformation.

Many material options and combinations can be selected for the capsules, providing maximum flexibility in the design of monitoring and control systems that use piezoelectric motor drives.

The spring fingers also warrant discussion in this article.

Soldering the fingers to the piezoceramic ring introduces a further set of problems: the required levels of accuracy, strength, and durability cannot be assured. The reasons are well known and arise from dependence on the specific properties of materials conventionally used for soldering.

Preparing the outer surface of the piezoceramic ring for soldering is particularly difficult, as is applying a metallic or equivalent layer to which the spring fingers can be soldered.

The author proposes solving this problem by eliminating soldering and optimizing the spring-finger assembly as a spring strip with the fingers stamped into it.

The strip is clamped around the outer circumference of the piezoceramic ring, providing several additional benefits for the optimization of the motor's systems:

- Uniform spacing of the fingers around the piezoceramic ring;
- Adjustment of the force pressing the spring strip against the surface of the piezoceramic ring;
- Easy, reliable, and rapid replacement of the strip when the fingers wear out;
- A substantial reduction in motor cost, together with improved efficiency and quality.

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