

Ultrasonic Motor

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Abstract- An Ultrasonic Motor (USM) is a special type of electric motor that uses ultrasonic vibrations to produce motion instead of electromagnetic forces. Unlike conventional motors, ultrasonic motors operate through the piezoelectric effect, where certain materials generate mechanical vibrations when subjected to an electric voltage. These vibrations occur at ultrasonic frequencies, typically above 20 kHz, which are beyond the range of human hearing. Ultrasonic motors offer several advantages such as high torque at low speeds, compact size, silent operation, fast response, and the ability to hold position without consuming power. These characteristics make them suitable for precision positioning systems, robotics, medical devices, cameras, aerospace systems, and industrial automation. The technology has gained significant attention due to its ability to overcome limitations of traditional electromagnetic motors. This paper presents the working principle, construction, types, advantages, disadvantages, applications, and future developments of ultrasonic motors. The study highlights the growing importance of ultrasonic motor technology in modern engineering systems requiring high precision and reliability.

Keywords- Ultrasonic Motor (USM), Piezoelectric Effect, Piezoelectric Ceramics, Ultrasonic Vibration, Stator, Rotor, Motion Control, High Torque, Robotics,

I. INTRODUCTION

The demand for compact, efficient, and precise motion control systems has increased significantly in recent years. Conventional electromagnetic motors have been widely used in industrial and commercial applications; however, they face challenges such as electromagnetic interference, limited positioning accuracy, and the need for gear mechanisms to achieve low-speed operation with high torque.

To overcome these limitations, ultrasonic motor technology was developed. The ultrasonic motor is a friction-driven motor that utilizes vibrations generated by piezoelectric materials at ultrasonic frequencies. The concept of ultrasonic motors emerged in the 1960s and has since evolved into a

practical technology for various high-precision applications.

The operating principle of an ultrasonic motor is based on the piezoelectric effect. When alternating voltage is applied to a piezoelectric ceramic element, it expands and contracts rapidly, creating ultrasonic vibrations. These vibrations are transferred to a stator, which drives a rotor through frictional contact. The motor converts high-frequency vibration energy into rotational or linear motion.

One of the most significant advantages of ultrasonic motors is their ability to produce high torque at very low speeds without requiring reduction gears. They also provide excellent positioning accuracy, making them suitable for applications such as camera autofocus systems, robotic actuators, medical

instruments, optical equipment, and aerospace mechanisms.

Because ultrasonic motors do not rely on magnetic fields, they can operate in environments where electromagnetic interference must be minimized. Their compact size, lightweight construction, and silent operation further enhance their suitability for modern technological applications.

As industries continue to demand greater precision and efficiency, ultrasonic motors are becoming an increasingly important alternative to conventional electric motors. Ongoing research aims to improve their performance, durability, efficiency, and cost-effectiveness, ensuring their continued growth in future engineering applications.

History of Ultrasonic Motor

The development of ultrasonic motors began in the 1960s when researchers started investigating the use of piezoelectric materials for motion generation.

- 1965: Initial concepts of ultrasonic vibration-based motion systems were introduced.
- 1970s: Practical ultrasonic motor prototypes were developed.
- 1980s: Japanese researchers significantly improved motor performance.
- 1990s: Ultrasonic motors were commercially used in camera focusing systems.
- 2000s: Applications expanded into robotics, medical devices, and aerospace systems.
- Present Day: Advanced ultrasonic motors are used in precision positioning and micro-electromechanical systems (MEMS).

II. PRINCIPLE OF OPERATION

The operating principle of an Ultrasonic Motor (USM) is based on the inverse piezoelectric effect, in which certain piezoelectric materials produce mechanical vibrations when an alternating electrical voltage is applied. Unlike conventional electric motors that use electromagnetic forces to generate motion, ultrasonic motors utilize high-frequency mechanical vibrations and frictional forces to create rotational or linear movement.

An ultrasonic motor consists mainly of a piezoelectric element, a stator, a rotor (or slider), and a driving circuit. When a high-frequency alternating voltage, typically in the range of 20 kHz to 100 kHz, is applied to the piezoelectric ceramic element, the material rapidly expands and contracts. These rapid expansions and contractions generate ultrasonic vibrations that are transmitted to the stator.

The stator is specially designed to convert these vibrations into wave motion. Depending on the motor design, either traveling waves or standing waves are produced on the stator surface. These waves cause microscopic points on the stator surface to move in small elliptical trajectories. Although the displacement of these points is extremely small, the vibration frequency is very high, enabling significant mechanical energy transfer.

When the rotor is pressed against the vibrating stator with a suitable contact force, friction is created between the two surfaces. As the particles on the stator surface move along their elliptical paths, they continuously push the rotor in a specific direction. The combined effect of millions of these microscopic movements generates a continuous macroscopic motion of the rotor. Thus, electrical energy is converted into mechanical motion through the sequence of piezoelectric vibration, wave generation, frictional interaction, and rotor movement.

The operation begins when the driving circuit supplies alternating electrical signals to the piezoelectric elements attached to the stator. These signals are carefully controlled to generate vibration modes that create either standing or traveling waves. In a traveling-wave ultrasonic motor, two vibration modes with the same amplitude but a phase difference of 90 degrees are superimposed. This produces a traveling wave that moves around the stator surface. The particles on the stator then follow elliptical motion paths, transferring force to the rotor through friction.

In a standing-wave ultrasonic motor, stationary vibration patterns are generated within the stator. Through proper mechanical design and excitation

techniques, these standing waves are converted into useful directional motion. Although standing-wave motors are simpler in construction, traveling-wave motors generally provide smoother motion and better performance.

One of the most important characteristics of ultrasonic motors is their ability to generate high torque at very low speeds without requiring gear reduction mechanisms. The frictional driving method allows the motor to produce significant holding torque even when power is removed. This self-locking capability enables precise positioning and reduces energy consumption in many applications.

Because ultrasonic motors do not rely on magnetic fields, they do not generate electromagnetic interference. This makes them suitable for environments where electromagnetic compatibility is critical, such as medical equipment, aerospace instruments, and precision optical systems. Additionally, their operation is extremely quiet because the vibration frequencies are above the range of human hearing.

The efficiency of the energy conversion process depends on several factors, including the quality of the piezoelectric material, vibration amplitude, friction conditions, contact pressure, and operating frequency. Engineers carefully optimize these parameters to achieve maximum performance and durability. Advanced control circuits are often used to maintain resonance conditions and improve motor efficiency.

The entire operating process of an ultrasonic motor can be summarized in the following steps:

- High-frequency AC voltage is applied to the piezoelectric element.
- The piezoelectric material expands and contracts rapidly.
- Ultrasonic vibrations are generated in the stator.
- Traveling or standing waves are formed on the stator surface.
- Surface particles move in microscopic elliptical paths.
- Frictional contact transfers force to the rotor.
- The rotor rotates or moves linearly.

- Continuous mechanical motion is produced.

III. CONSTRUCTION OF ULTRASONIC MOTOR

The construction of an Ultrasonic Motor (USM) is significantly different from that of conventional electromagnetic motors. Instead of using magnetic fields, windings, and permanent magnets, an ultrasonic motor utilizes piezoelectric materials, high-frequency vibrations, and frictional contact to produce motion. The motor is designed to convert ultrasonic vibrations into rotational or linear movement with high precision and efficiency.

The basic construction of an ultrasonic motor consists of several important components, including the piezoelectric element, stator, rotor, friction layer, preload mechanism, shaft, bearings, and driving circuit. Each component plays a vital role in the operation and performance of the motor.

1. Piezoelectric Element

The piezoelectric element is the most important part of an ultrasonic motor. It is usually made from piezoelectric ceramic materials such as Lead Zirconate Titanate (PZT). These materials exhibit the inverse piezoelectric effect, meaning they deform mechanically when subjected to an electric voltage. When a high-frequency alternating voltage is applied, the piezoelectric element expands and contracts rapidly, producing ultrasonic vibrations. These vibrations serve as the driving force for the motor. The piezoelectric elements are carefully attached to the stator and are designed to operate at specific resonance frequencies to maximize vibration amplitude and efficiency.

Functions of Piezoelectric Element

- Generates ultrasonic vibrations.
- Converts electrical energy into mechanical energy.
- Excites vibration modes in the stator.
- Provides the primary driving force for motor operation.

Stator

The stator is the stationary part of the ultrasonic motor and acts as the vibration generator. It is generally constructed from high-strength metallic materials such as aluminum, stainless steel, or titanium. The piezoelectric elements are bonded to the stator surface.

The shape of the stator depends on the motor type. In rotary ultrasonic motors, the stator is often ring-shaped, while in linear ultrasonic motors, it may be rectangular or bar-shaped.

When the piezoelectric elements vibrate, the stator produces traveling waves or standing waves on its surface. These waves create microscopic elliptical motion of surface particles, which is transferred to the rotor through friction.

Functions of Stator

- Supports piezoelectric elements.
- Generates traveling or standing waves.
- Transfers vibration energy to the rotor.
- Maintains structural stability.

Rotor

The rotor is the moving part of the ultrasonic motor. It is placed in contact with the stator and receives motion through frictional interaction. Unlike conventional motors, the rotor does not contain windings, magnets, or electrical connections.

The rotor is usually made from lightweight and wear-resistant materials. It is carefully designed to maintain proper contact pressure with the stator. The rotor converts microscopic vibration-induced forces into useful rotational motion.

Functions of Rotor

- Receives force from the vibrating stator.
- Produces rotational output motion.
- Delivers mechanical power to the load.
- Maintains frictional contact with the stator.

Friction Layer

A friction layer is placed between the stator and rotor surfaces to improve energy transfer. Since ultrasonic motors operate based on frictional drive

mechanisms, the quality of the friction layer significantly affects motor performance.

The friction material must possess:

- High wear resistance.
- Stable friction coefficient.
- Good durability.
- Heat resistance.

Common friction materials include special polymers, ceramics, and composite materials.

Functions of Friction Layer:

- Enhances force transmission.
- Reduces surface wear.
- Improves motor efficiency.
- Provides smooth motion.

Preload Mechanism

The preload mechanism is responsible for maintaining the required contact force between the stator and rotor. Proper preload is essential because insufficient pressure reduces torque transmission, while excessive pressure increases wear and energy loss.

Springs, elastic rings, or mechanical clamping systems are commonly used to provide preload force.

Functions of Preload Mechanism:

- Maintains constant contact pressure.
- Ensures efficient frictional drive.
- Improves torque output.
- Enhances operational stability.

Shaft

The shaft is connected to the rotor and transmits the mechanical output to external loads. It is generally made from hardened steel or other high-strength materials capable of handling rotational forces.

The shaft design must ensure minimal vibration and accurate alignment to achieve smooth operation.

Functions of Shaft:

- Transfers mechanical power.
- Supports external loads.
- Provides rotational output.

Bearings

Bearings support the rotor and shaft assembly while minimizing friction during operation. High-precision bearings are commonly used to ensure smooth rotation and accurate positioning.

The bearing system must withstand:

- Radial loads.
- Axial loads.
- Continuous operation.

Functions of Bearings:

- Reduce mechanical friction.
- Support rotating components.
- Improve positioning accuracy.
- Increase motor lifespan.

Types of Ultrasonic Motors

Traveling Wave Ultrasonic Motor

- Uses traveling waves in the stator.
- Provides smooth continuous rotation.
- Most commonly used type.

Advantages

- High efficiency
- Smooth operation
- High torque

Standing Wave Ultrasonic Motor

- Utilizes standing wave vibrations.
- Simpler construction.
- Lower manufacturing cost.

Advantages

- Easy design
- Reliable operation

Rotary Ultrasonic Motor

- Produces rotational motion.
- Commonly used in cameras and robotics.

Linear Ultrasonic Motor

- Produces straight-line motion.
- Used in precision positioning systems.

IV. WORKING MECHANISM

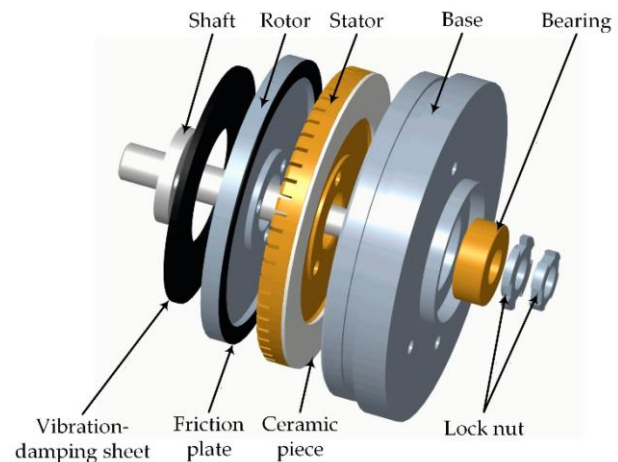


Figure 1: Rotating Of Ultrasonic Motor

The working mechanism of an Ultrasonic Motor (USM) is fundamentally different from that of conventional electric motors. Traditional motors operate using electromagnetic forces generated between magnetic fields and current-carrying conductors, whereas ultrasonic motors utilize high-frequency mechanical vibrations produced by piezoelectric materials. These vibrations are converted into rotational or linear motion through frictional contact between the stator and the rotor. This unique operating mechanism enables ultrasonic motors to provide high torque, precise positioning, silent operation, and compact size.

The operation of an ultrasonic motor is based on the inverse piezoelectric effect. When an alternating electrical voltage is applied to a piezoelectric material, the material undergoes rapid expansion and contraction. These dimensional changes occur at ultrasonic frequencies, generally above 20 kHz, which are beyond the range of human hearing. The resulting vibrations are transmitted to the stator, where they generate mechanical waves that drive the rotor.

The operation can be explained as follows:

- AC voltage is supplied.
- Piezoelectric elements vibrate at ultrasonic frequency.
- Vibrations create traveling waves.
- Surface particles move in elliptical paths.

- Friction force drives the rotor.
- Mechanical motion is produced.

This process allows direct conversion of electrical energy into motion without magnetic interaction.

Characteristics of Ultrasonic Motor

Parameter	Value
Frequency Range	20–100 kHz
Speed Range	Low to Medium
Torque	High
Noise	Very Low
Efficiency	Moderate
Positioning Accuracy	Excellent
Electromagnetic Interference	None

Advantages of Ultrasonic Motor

- High torque at low speed.
- Compact and lightweight design.
- Silent operation.
- Excellent positioning accuracy.
- No electromagnetic interference.
- Quick response time.
- Self-locking capability.
- No need for reduction gears.
- Suitable for vacuum environments.
- High reliability.

Disadvantages of Ultrasonic Motor

- Lower efficiency compared to some conventional motors.
- Wear due to frictional contact.
- Complex control circuitry.
- Heat generation during operation.
- Limited lifetime of friction materials.
- Higher manufacturing cost.

Applications of Ultrasonic Motor

Camera Systems

- Autofocus mechanisms
- Zoom lens control

Robotics

- Precision robotic joints
- Micro-robots

Medical Equipment

- Surgical instruments
- Medical imaging systems

Aerospace Industry

- Satellite positioning
- Space telescope adjustment

Industrial Automation

- CNC machines
- Precision positioning stages

Optical Systems

- Laser alignment
- Optical fiber adjustment

Semiconductor Manufacturing

- Wafer positioning
- Microfabrication systems

Future Scope

The future of ultrasonic motors is promising due to increasing demand for precision motion control.

Future developments may include:

- Nano-scale motors.
- Medical implant devices.
- Advanced robotic systems.
- Space exploration mechanisms.
- High-performance industrial automation.
- Smart manufacturing equipment.
- Artificial intelligence integrated motion control.

With continuous advancements in materials science and electronics, ultrasonic motors are expected to become more efficient, durable, and affordable.

V. CONCLUSION

Ultrasonic motors represent an innovative advancement in motion control technology. By utilizing piezoelectric vibrations instead of electromagnetic forces, they provide unique advantages such as high torque at low speed, silent operation, compact size, and exceptional positioning accuracy. These characteristics make them highly suitable for applications in robotics, medical devices, aerospace systems, industrial automation, and optical instruments.

Although challenges such as friction wear and moderate efficiency remain, ongoing research continues to improve motor performance and reliability. As technology advances, ultrasonic motors are expected to play a significant role in future precision engineering applications, offering an effective alternative to conventional electric motors.

4. Journal of Intelligent Material Systems and Structures.
5. International Journal of Advanced Manufacturing Technology.
6. Piezoelectric Motor Technology Research Publications.
7. Modern Motion Control Engineering Journals.

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