PRESENT STATE ABOUT THE MAKING OF THE PIEZOELECTRIC MOTORS

Ilie PRISACARIU
"Stefan cel Mare" University
Universităţii Street, nr.13, RO-720225, Suceava
iliep@eed.usv.ro

Abstract. *The focus of this paper is a presentation of the recent developments of ultrasonic motors (USM) using piezoelectric resonant vibrations. There is a growing interest in the area of microsystems and there is the potential for applying the technology to making micromotors, where the dimensions are in the millimetric range or lower. Piezoelectric motors, which are unconventional by their nature, can be easily implemented at various microsystems. After a brief discussion about USMs in the introduction, there is presented a classification, the advantages and disadvantages of the ultrasonic piezoelectric motors. Then, are described different categories of USMs like rotary USMs, linear USMs and spherical USMs with their applications in various domains such as positioning devices, cameras, robots and many more. The author has been observed, among the study of the piezoelectric literature, that there are many constructive models of USMs and in this paper he presented an actual example from each category. Mention is also made in this article about the applications of the USMs as well as the conclusions of this research.*
Keywords: *ultrasonic motor, piezoelectric motor, active materials.*

Introduction

Since the ultrasonic piezoelectric motor (USM) has features that differ from those of electromagnetic motors, it is hoped that some of them may be fully utilized for supplementary purposes, mainly in areas of general applications where the electromagnetic motor is inadequate.

Piezoelectric motors perform a two-step energy conversion. In the first stage, electrical energy is converted into mechanical vibrations of the stator. In the second stage, high frequency oscillatory vibrations of the stator are transformed into unidirectional macroscopic motion of the rotor.

Due to the gears used with electromagnetic to increase the driving, the existence of backlash makes it difficult to achieve the high level of accuracy.

Piezoelectric motors work by converting small amplitude, high frequency vibration (of 10 kHz and higher) of a stator with piezoelectric elements into unidirectional linear or rotary motion using friction.

Early but rather crude applications were reported by Matsushita, Siemens and IBM in the 1970s.

Researchers from Russia had also contributed to these simple devices in the same decade.

In the 1980s, the invention of the travelling wave ultrasonic motor by Sashida has determinated the search for novel piezoelectric motors even further.

Also, due to the ample advantages that piezoelectric motors offers much research and development have been made in this area (S. Ueha 1989, A. Flynn 1990).

Several university research groups around the world have continued to pursue the development of piezoelectric motors.

Nowadays, linear and rotary piezoelectric motors and appropriate control methods are being developed for various applications in positioning devices.

Classification of ultrasonic piezoelectric motors (USM); advantages and disadvantages of ultrasonic piezoelectric motors [11].

Many types of USM have been proposed since the 1970s. In this large family of USM, we can in essence classify them in this way:

A. Classification of USM by excitation:
-standing wave USM (SWUM);
-travelling wave USM -TWUM-can be used in areas where a very thin motor structure is required or where it is desirable to physically separate the electrical drive from the rotating element. An example of this might be in the handling of flammable liquids where the drive could be on one side of a bulkhead (a fuel tank) and the rotating component on the other. In this category we can mention: mode conversion USM (MCUM); multi-mode (MMUM); mode rotation USM (MRUM); hybrid transducer USM (HTUM).
B. Classification of USM by motor construction:
-disk or ring vibrator USM. In this category we can mention: bending motion perpendicular to horizontal plane USM; flexural motion parallel to horizontal plane USM; radial & flexural motion in horizontal plane USM;
-rod vibrator USM. In this category we can mention: flexural vibration USM; longitudinal & torsional vibration USM;
-thin rectangular plate USM. In this category we can mention: longitudinal &bending vibration USM; flexural vibration USM.
C. Classification by motor function:
-rotary USM. In this category we can mention: continuous USM; stepping USM.
-linear USM.

The advantages of piezoelectric motor over the conventional electromagnetic motor are: silent drive due to the ultrasonic, no gear mechanism (suitable to video cameras with microphones), thin motor design leading to space saving. Also other advantages of piezoelectric motors can be mentioned: low speed and high torque, quick response, hard brake and no backlash, excellent controllability, fine position resolution, light weight, simple structure and easy production process, negligible effect from external magnetic or radioactive fields and also no generation of these fields.
The disadvantages of piezoelectric motors are: necessity for a high frequency power supply, less durability due to frictional drive, drooping torque-speed characteristics and the costs of piezoelectric elements.

Ultrasonic piezoelectric motors. Overview

This paragraph presents an overview of ultrasonic piezoelectric motors design.
In the 1990s, the needs for miniaturization of consumer products, medical devices and office equipment increased rapidly. Also, it is possible that many wireless communications products with mass data storage requirements and medical catheters for driving imaging elements and surgical tools also needs micromotors.
Most early prototypes of ultrasonic motors did not exhibit the anticipated advantage of high torque at low speed. This is due to a less than optimal design of the energy conversion mechanism and insufficient knowledge of the mechanics of the stator-rotor contact during operation.

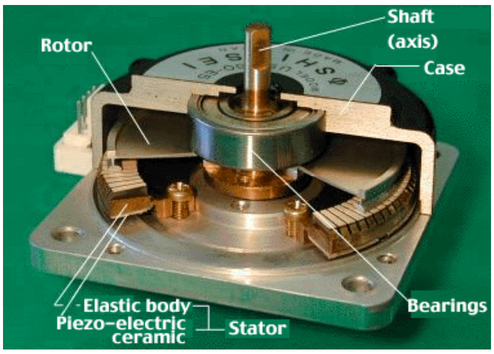

Figure 1. Cutaway view of Shinsei ultrasonic motor (USR 60), reproduced from [1].

One of the categories of USMs is the **rotary USMs**.

The Shinsei Corporation manufactures rotary ultrasonic motors and since they developed and commercialized the world's first ultrasonic motor (USR-4-100) also have been continued their research and development to improve its performance, reliability and to achieve cost reduction.

Figure 1 shows an example of a rotary piezoelectric motor made by the Shinsei Corporation. It is known that current piezoelectric motors are fragile, complex and expensive to manufacture, and require relatively high voltage. An example of a piezoelectric motor supplied with low voltage (1-24 V) is shown in figure 2.

This triangular piezoelectric motor was made by Miniswys Company and it has a simple construction (only three components).

These motors can be manufactured effectively in mass quantities and are using standard piezoelectric materials.

Figure 2. Triangular USM manufactured by Miniswys (Switzerland), reproduced from [2].

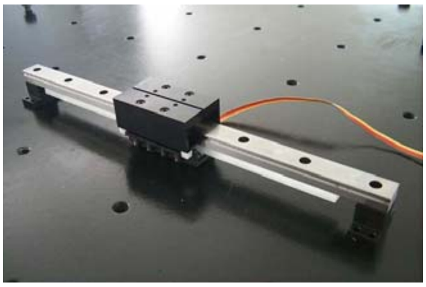

Figure 3. Linear ultrasonic motor made by the, reproduced from [3].

Another category of USMs are linear ultrasonic motors which are used for the construction of many types of high precision positioning stages (X-Y positioning stages, X-Y-Z positioning stages).

An example of a linear piezoelectric motor which has very simple structure and can be easily mounted on to any commercially available linear guide is presented in figure 3.

Also, efficient miniature piezoelectric motors that are compact and consume low power are needed to meet the N.A.S.A. needs of future missions.

Figure 4 shows an example of a robot used in planetary exploration environments which uses in his construction piezoelectric motors.

Figure 4. The robot Rocky 7 with USMs, used in planetary exploration environments, reproduced from [4].

The examples of spherical ultrasonic motors in the scientific literature are very few.

However, by searching the scientific literature and the patent literature it is clear that there is a growing interest in constructing such devices. Figure 5 shows a picture of a spherical piezoelectric motor (SUM 45-S3) used at an artificial arm for a robot made in Toyama Laboratory, Japan.

The artificial arm uses a spherical ultrasonic motor for the wrist joint and the advantages of the arm are small size, lightweight and high torque at low velocity compared with conventional ones.

Figure 5. Spherical piezoelectric motor, made inToyama Laboratory, Japan. reproduced from [5].

The artificial arm has enough space that can be used to include sensors or controllers and with a few further assignments of output characteristics, it is possible to fulfil the demands for using the arm for a handicapped person.

Seiko Epson Corporation has developed the world's smallest flying prototype microrobot which uses an ultrasonic piezoelectric motor, case presented in figure 6.

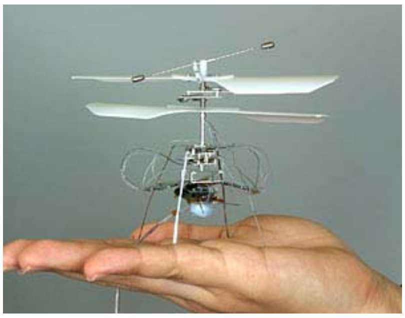

Figure 6. Micro flying robot which uses an piezoelectric motor (by Seiko Epson Corporation), reproduced from [6].

Further on, there is presented in figure 7 an flextensional motor (flexmotor), used in cheap unidirectional motors for toys, disposable camera winding, gas or fluid valves, watch motors or microfluidics and other small size servo motors.

The first prototype was 25 mm in diameter. At this piezoelectric motor the flextensional caps are pressed from circular discs.

Figure 7. Flextensional ultrasonic motor (Flexmotor), reproduced from [7].

The speed of this motor is up to 1200 rpm and the torque is 2 mNm. The miniaturisation to 2 mm diameter has been achieved for this type of motor.

Constructed in one single solid body with four movable legs (made of ceramic "muscles") the "Piezo Legs" micromotor (shown in figure 8) operates without gears or a mechanical transmission.

By taking up to 10,000 steps per second this motor can reach travelling speeds of several centimetres per second.

The simple design makes the motor easy to produce in large quantities with a high degree of precision.

Figure 8. "Piezo Legs", developed by Piezomotor Upsala AB, Sweden, reproduced from [8].

It is a cost-effective alternative to conventional electromagnetic linear motion systems.

In figure 9 is presented an ultrasonic cutter made using a piezoelectric motor.

Applications of the ultrasonic cutter are: cutting and melting of fabrics (textile), clothes, label, vinyl.
The ultrasonic cutter has also the following possible applications: possible to cut special fabrics (as a built in iron core), neat cutting plane meting and adhesion (as a vinyl).
The advantages of the ultrasonic cutter are: simple operating system and easy handling compact design, light weight.
The motor has also other advantages as an exceptionally long and maintenance free service life.

Figure 9. Ultrasonic cutter made by the Piezo Electric Technology (Korea) reproduced from [9].

There is no current draw in hold position and as the drive principle is friction based the motor will not be harmed if the rotation is blocked. The drive electronics for the motor can be made exceptionally simple and cost effective.
Finally there is presented the smallest ultrasonic motor in the world (figure 10) which has been developed by the professor Kenji Uchino and his team from Pennsylvania State University in U.S.A. (1,5 mm stator diameter).
These motors can be revolutionary for the medical applications.
These motors could be used in endoscopes and catheters to rotate imaging instruments or to attack kidney stones. In addition to watches, a hefty existing market is in scanners and printers.

Piezoelectric motors also are used in auto-focus camera lenses.

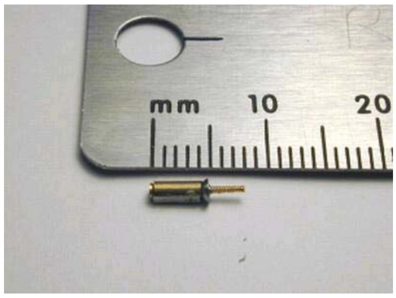

Figure 10. Smallest USM in the world developed by the prof. K. Uchino (Pennsylvania University, USA), reproduced from [10].

Applications of piezoelectric motors.

Due to their advantages mentioned above, piezoelectric motors have begun to be used in many various domains.
An important application of these motors is at micropositioning stage.
These micropositioning stages can be used in: life science, medicine, biology semiconductors, microelectronics data storage, optics, photonics, fiber optics metrology and measuring technology precision mechanics and mechanical engineering.
We can also mention the following applications for piezoelectric motors: manufacturing process control, fiber optic positioning pick-and-place assembly camera autofocus medical catheter placement, microsurgery, semiconductor test equipment computer disk drives robotic positioning pharmaceuticals handling.
There are well-known commercial applications of piezoelectric motors such as the mobile phones security equipment, automotive applications toys.
On the other hand, piezoelectric motors are a good candidate for aforementioned applications and have already been used in horological applications [12].

Conclusions

In this paper, the author presented some examples of each category of ultrasonic piezoelectric motors in order to present an overview of them. Some conclusions are necessary to be mentioned:
-there is a growing interest for the study of the piezoelectric motors;
-because of the advantages of the piezoelectric motor, it can be used in many areas where the classic electromagnetic motor is inadequate;
-probably, in the next years, the piezoelectric motors will be a serious alternative for the standard electromagnetic motors;
-the most significant deficiency lies in the working life of the USMs because of the friction of the stator and the rotor;
-piezoelectric motors can be easily made just from three parts.
Future work will include an investigation of the drive systems for ultrasonic piezoelectric motors.

References

[1]. SHINSEI CORPORATION INC. [on-line] *Shinsei ultrasonic motor*. [quoted March 2005]. Available on World Wide Web: <http://www.tky.3web.ne.jp/~usrmotor/English/html/index.html>
[2]. MINISWYS CO. [on-line]. *Small triangle Motor: 6 Trapez 4V1*. [quoted March 2005]. Available on World Wide Web: <http:// www.miniswys.ch/portofolio_e.htm>
[3]. PHYSIKINSTRUMENTE CO. [on-line]. *Micropositioners*. [quoted March 2005]. Available on World Wide Web: <http://www.physikinstrumente.de/products.htm>
[4]. DAS, H.; BAO, X.; BAR-COHEN, Y.; BONITZ, R.; LINDEMANN, R.; MAIMONE, M.; NESNAS, I.; VOORHEES, C. *Robot manipulator technologies for planetary exploration.* 1999: Proceedings of the 6th Annual International Symposium on Smart Structures and Materials. Newport Beach.
[5]. TOYAMA LABORATORIES [on-line]. *SUM45-S3-Spherical ultrasonic motor*. [quoted March 2005]. Available on World Wide Web: <http://www.tuat.ac.jp/~toyama/sum/susm3.htm>
[6]. SEIKO EPSON CO. [on-line]. *Flying microrobot prototype.* [quoted March 2005]. Available on World Wide Web: <http://www.deviceforge.com/news/NS3491398424.html>
[7]. FLEXMOTOR CO. [on-line]. *Flexmotor*. [quoted March 2005]. Available on World Wide Web: <http://www.flexmotor.com/page2.htm>
[8]. PIEZOMOTOR UPSALA AB [online]. *Piezo Legs* [quoted March 2005]. Available on World Wide Web: <http://www.piezomotor.com/pages/information.html>
[9]. PIEZO ELECTRIC TECHNOLOGY CO., LTD. [on-line] *Ultrasonic cutter*. [quoted March 2005]. Available on World Wide Web: <http://piezotech.en.ec21.com/GC00370947/CA00371229/Ultrasonic_Cutter_Welder.html>
[10]. PIEZOWORLD [on-line]. *Ultrasonic motors.* [quoted March 2005]. Available on World Wide Web: <http://www14.brinkster.com/piezoworld/articles/news/3.asp>
[11]. KIAN, L. C. *Systematic Design of a disc-typed travelling wave ultrasonic motor.* Master's thesis. 2001: Nanyang Technological University, p. 4-14.
[12]. IINO, A.; SUZUKI, K.; KASUGA, M.; SUZUKI M.; YAMANAKA T. *Development of a self-oscillating ultrasonic micromotor and its application to a watc*h. Ultrasonics, 2000, vol. 38, p. 54-59.