The First International Workshop on Ultrasonic Motors and Actuators
November 14-15, 2005, Yokohama, Japan

Recent Progress of Ultrasonic Motors in Japan

Takashi Maeno*

*Associate Professor, Keio University
3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan
Tel +81-45-566-1516 Fax +81-45-566-1516 maeno@mech.keio.ac.jp

1. Introduction

Ultrasonic motors have been commercialized by numbers of companies especially by precision and mechatronics companies in Japan. In this paper overview of recent progress of ultrasonic motors mostly by companies in Japan is shown. First, market size, share and application products of mass-produced ultrasonic motors are shown. Overview of type and characteristics of motors are followed. Approaches for reducing costs and increasing performance of the motor are shown as well. Examples are shown for ring-type and bar-type traveling wave (mode rotation type) ultrasonic motors mass-produced by Canon, Inc. Then, our approaches for making multi-DOF ultrasonic motors are introduced. Results of non-linear modeling method of traveling wave ultrasonic motors are also shown.

2. Market

As everybody knows, the ultrasonic motor was invented by Sashida in 1980. Twenty five years have passed since then. Now, the ultrasonic motors are produced by numbers of makers in Japan including Canon, Fukoku, Asmo, SII, Canon Precision, Shinsei, Kyocera, Olympus and Mitsuba. The amount of sales in Japan has been about four billion yen per year throughout year 2001 to 2005 according to the survey by Yano research institute(1). Approximately 40 percent is for cameras and 35 percent is for cars. Other mass-produced products are printers, copy machines, medical equipments including MRIs, manufacturing machines, audio equipments, and so on. Share of companies are as follows: Canon: 33 percent, Fukoku: 26 percent, Asmo: 21 percent, SII: 8 percent, Canon precision: 5 percent, Shinsei: 3 percent(1). Growth ratio of sales is not extremely large. However, market size is gradually becoming larger. We can conclude that the ultrasonic motors are not new actuators any more, however, they have potential to be much influential actuators.

3. Types and configurations

The ultrasonic motors are categorized into two types, traveling-wave-type and standing-wave-type.

Figure 1 shows an example of the former one, a ring-type ultrasonic motor that has been produced by Canon since 1986(2). It consists of a stator and a rotor. A traveling wave of seventh bending mode with frequency of about 30kHz is excited by PZT plate bonded at the bottom of the stator ring. The rotor is pressed against the rotor with load of about 15N. Produced maximum torque is about 160mN-m. Maximum rotation speed is about 60 rpm. It was originally used for autofocus of SLR cameras. The cost was several thousand yen when it was unvailed. Canon produced another traveling-wave-type micro USM (ultrasonic motor) also for autofocus lenses in 1990 (see Fig. 2) (3). It applied Langevin type configuration to reduce the cost. As shown in Fig. 2, first bending mode of the bar-shaped stator is excited by PZT rings screwed between metal parts. By adding two

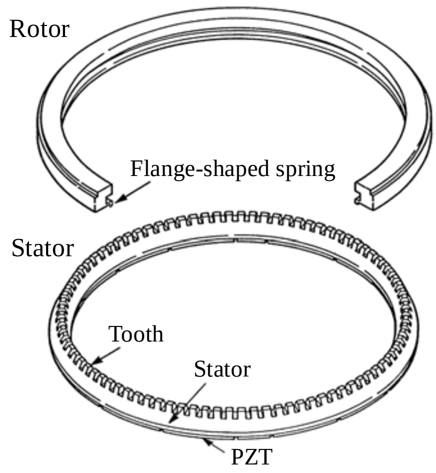

Fig. 1 Ring-type ultrasonic motor
(70 mm in diameter)

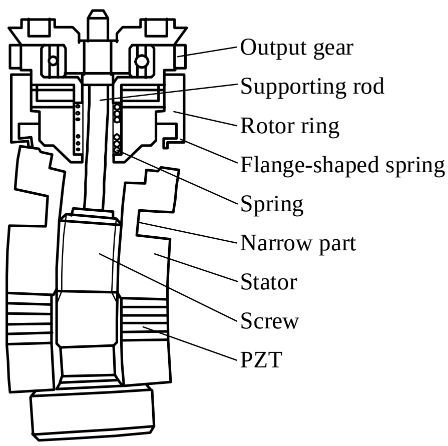

Fig. 2 Sectional view of configuration and natural mode of Canon micro USM
(10 mm in diameter and 25 mm in length)

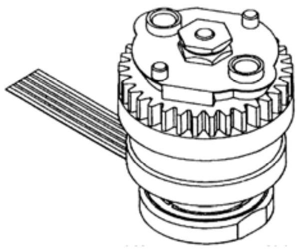

Fig. 3 Traveling-wave type ultrasonic motor, Canon micro USM II
(10 mm in diameter and 11 mm in length)

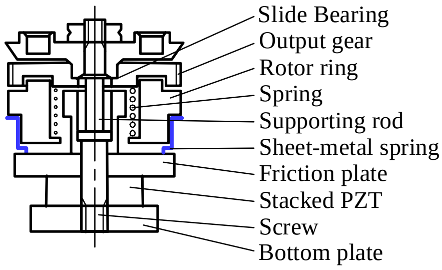

Fig. 4 Sectional view of Canon micro USM II
(10 mm in diameter and 11 mm in length)

perpendicular bending modes, mode rotation is obtained. The rotor pressed against the stator rotates around the longitudinal axis. Since a part of the rotor in contact with the top surface of the stator rotates along with the mode rotation, it is one of the traveling-wave-type ultrasonic motors. The cost was about a thousand yen. Another traveling-wave-type ultrasonic motor, micro USM II (see Fig. 3 and Fig. 4) was produced in 2003 as well. The size of the motor is about the half compared with the previous micro USM. Although the weight of the stator is about one fifth of the previous micro USM, output power is about the same. The cost is said to be about several hundred yen. Stacked PZT in a body is used to reduce the voltage and cost, and to increase the efficiency.

Figure 5 shows the fundamental principle of a typical standing-wave-type linear ultrasonic motor. This example shows a usage of a first longitudinal mode and a second bending mode. Points at the surface of two projections rotate clockwise when the two modes are excited. A slider that is pressed against the two projection moves to the right. Not many standing-wave-type ultrasonic motors have been mass-produced. Reasons are as follows; they have to make the natural frequencies of two different modes whereas traveling-wave-type motors utilize similar two modes, sine and cosine modes. Wear problem exists as well. Wear is centralized at the top of the two projections of the stator that is intermittently in contact with the slider in the standing-wave-type motor, whereas, the wear is distributed in the traveling-wave type motor because the contact points rotate along with the mode rotation. Since the needs of linear actuation are not small, development of high performance linear ultrasonic motors are expected.

4. Our approaches

The author has been engaged in the research for suggesting new types of ultrasonic motors and for analyzing the performance of the ultrasonic motors. In this chapter, a couple of examples are shown.

First one is the development of multi-DOF (Degree of freedom) ultrasonic motors[4]. Figure 6 shows the

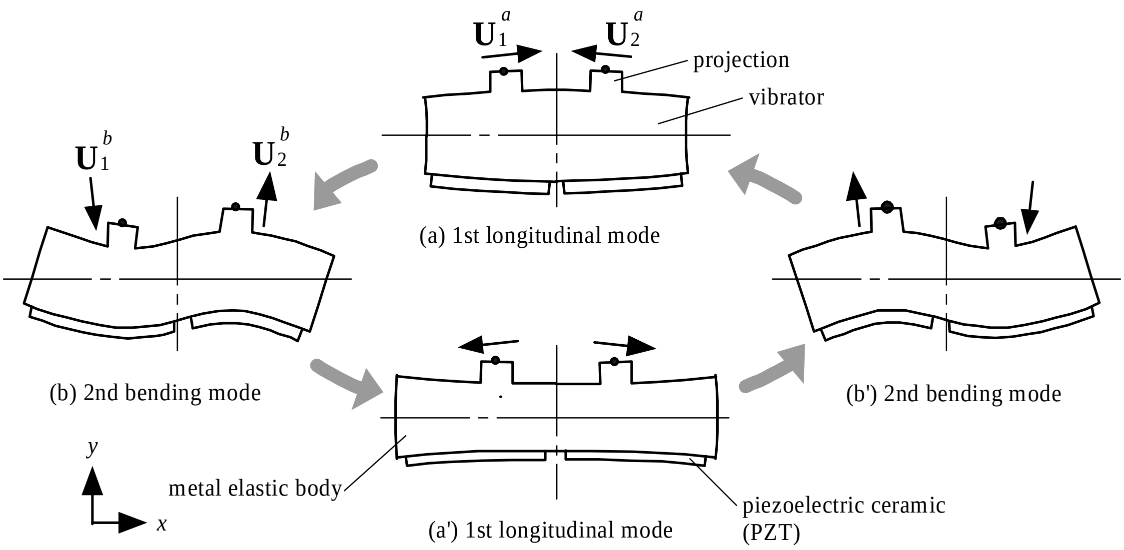

Fig. 5 Driving principle of a linear ultrasonic motor

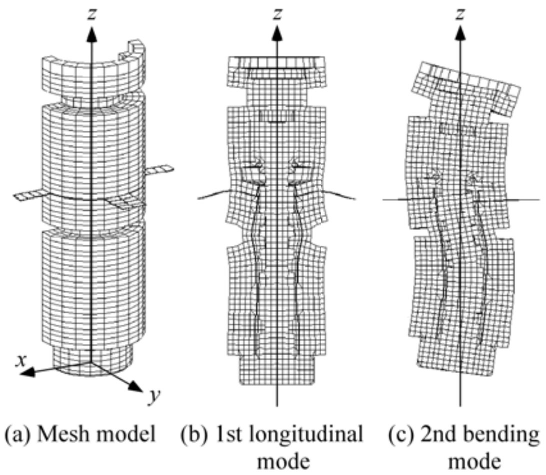

Fig. 6 Natural modes of a bar-shaped vibrator of multi-DOF ultrasonic motor

Fig. 7 Multi-DOF forceps by use of multi-DOF ultrasonic motor

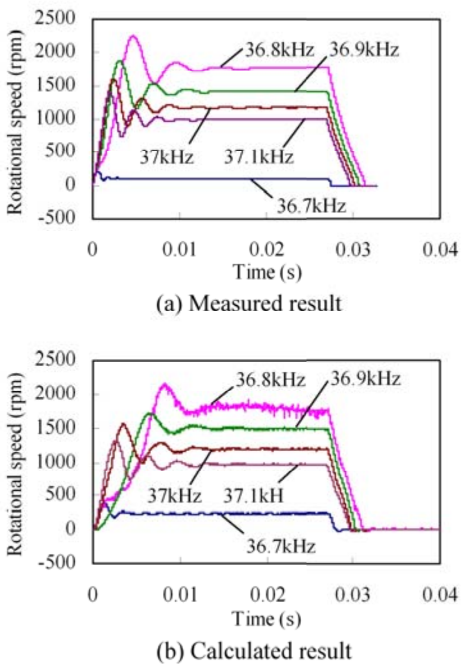

Fig. 8 History of transient response of a micro USM

developed multi-DOF ultrasonic motor. Figure 6 (a) is a mesh model of a finite element analysis. Figure 6 (b) and (c) show first longitudinal and second bending natural modes having the same natural frequencies. A spherical rotor is placed at the top of the stator. By adding a first longitudinal mode and two second bending modes, we can obtain a rotation of the spherical rotor around arbitrary axes. Fig. 7 shows an example of application. The multi-DOF ultrasonic motor is used for an actuation of a multi-DOF forceps used for surgery[5].

Figure 8 shows results of modeling traveling-wave type ultrasonic motors[5]. Figure 8 (a) is a measured transient response of the rotor. AC voltage is applied at the time zero and is stopped at time 0.028s. Figure (b) shows a calculated result by use of the driving model of the ultrasonic motor we developed. It is shown that the measured and calculated results agree well by taking the non-linearity of the stator's vibration into account. It can be used to optimize the control method of the ultrasonic motors.

5. Conclusions

First, recent market of the ultrasonic motor is described. Then types and configurations of recent ultrasonic motors are shown. Finally, our approaches for designing new ultrasonic motors and for analyzing ultrasonic motors are shown.

References

(1) The Latest Market Trend and Middle-Term Survey of Motors Watched with Keen Interest, Yano Research Institute Ltd, 2003 (in Japanese)

(2) Takashi Maeno, Takayuki Tsukimoto and Akira Miyake, Finite Element Analysis of the Rotor/Stator Contact in a Ring-Type Ultrasonic Motor, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 39, No. 6, 1992, pp. 668-674

(3) Takashi Maeno, Ichiro Okumura, Takayuki Tsukimoto and Takao Mori, How to Make High-Efficiency Ultrasonic Motors, Proc. Intl. Conf. Acoustics, 2004, pp. I409-I412

(4) Kenjiro Takemura and Takashi Maeno, Method for Controlling Multi-DOF Ultrasonic Motor Using Neural Network, Journal of Robotics and Mechatronics, Vol. 15, No. 2, 2003, pp. 534-540

(5) Kenjiro Takemura, Dai Harada and Takashi Maeno, Development of a Master-Slave System for Active Endoscope Using a Multi-DOF Ultrasonic Motor, Transactions on Control, Automation and Systems Engineering, Vol. 4, No. 1, 2002, pp. 17-22

(6) Yosuke Nakagawa, Akira Saito and Takashi Maeno, Non-linear Dynamics of Traveling-Wave-Type Ultrasonic Motors, JSME Journal (in Japanese, in preparation)