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Thin Rotary and Linear Ultrasonic Motors Using a Double-Mode Piezoelectric Vibrator of the First Longitudinal and Second Bending Modes

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This paper deals with thin rotary and linear ultrasonic motors using a double-mode piezoelectric ceramic vibrator; a rectangular plate vibrator of the first longitudinal and second bending modes is utilized. A specific merit of the motors is that their thickness can meet the restriction of 10 mm, which is one of the practical requirements of a light load gearless motor. The rotary motor is intended for application in card forwarding, and the linear motor, in magnetic-head traveling and so on. Construction and characteristics of the motors are described herein.

KEYWORDS: rotary motor, linear motor, piezoelectric vibrator, piezoelectric ceramics, double-mode vibrator

§1. Introduction

Various types of ultrasonic motors using piezoelectric vibrators have been investigated up to now.[1)]

Research and development of ultrasonic motors seem to now be in the stage of practical applications,[2)] depending upon fundamental considerations of the motors up to the present.[3)] In such a background, we have investigated rotary and linear motors using a double-mode piezoelectric ceramic rectangular plate vibrator in which the first longitudinal and second bending modes are utilized.[4)] That is, the rotary motor is intended for application in card forwarding and the linear motor, in magnetic-head traveling, for example.

In these cases, thin motors are desired, especially in practical office-automation use, but thickness is restricted to less than 10.0 mm. We believe that such thin motors might be difficult to construct without using a longitudinal and bending-double mode vibrator, even if various types of motors have been proposed. This is one reason why have applied the double-mode vibrator, dealt with herein, to achieve the rotary and linear motors.

In the first part of this paper is described the principle of the ultrasonic motors, the second part pertains to the rotary motors and the third deals with the linear motors.

§2. The Principle of Motors

The principle of the motors dealt with herein is as follows: Longitudinal and bending mode resonance frequencies of relatively low orders in a rectangular vibrator (length: L and width: d) are as shown in Fig. 1,[5)] although they are differently obtained by vibrator material constants. In Fig. 1, the thickness of the vibrator gives little effect to the resonance frequencies.

Therefore, some double-mode vibrators can be constructed because two modes of longitudinal and bending vibrations degenerate at the proper dimensional ratio d/L for coincidence of two resonance frequencies.

When such a double-mode vibrator is constructed by piezoelectric ceramics of lateral effect use, the electrodes, whose one is divided, for example, as shown in Fig. 2, are positioned to act as two channel terminals for 2-phase driving of the vibrator; that is, in this case, the first longitudinal and second bending double-mode vibrator can be constructed, and the elliptic motions of displacements of two resonance modes are achieved at both ends, as shown in Fig. 2. Therefore, by pressing the rotors on both ends, for example, a rotary motor can be constructed. Obviously as mentioned above, the double-mode vibrator of this type is of such a construction that two resonance modes in a rectangular plate of piezoceramics are utilized independently. Of course, the double-mode vibrator can also be constructed utilizing the coupling between two modes, for example, of the

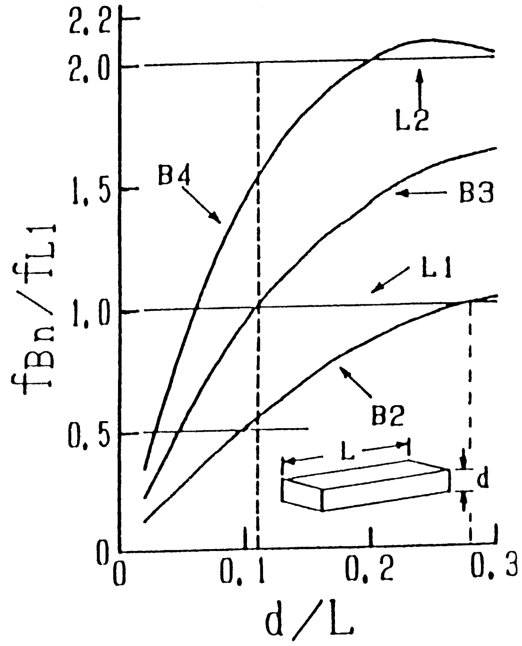

Fig. 1. f_{Bn}/f_{L1} vs d/L characteristics

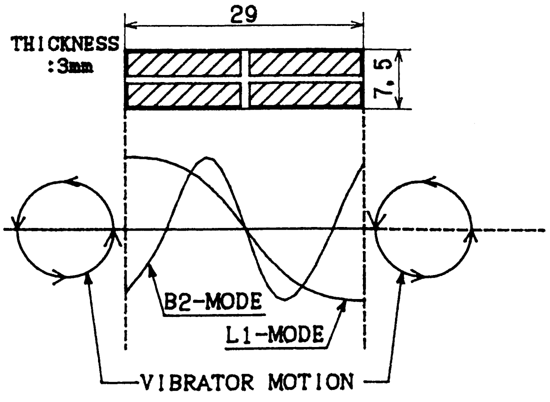

Fig. 2. Vibration modes.

first longitudinal and second bending vibration.

The ultrasonic motors using such a vibrator have also been reported.[6)]

§3. The Rotary Motor

Construction of the rotary motor using the double-mode vibrators mentioned above is shown in Fig. 3, where two vibrators of a piezoelectric ceramic rectangular plate are set between two rollers of slender rod type, and the clamping force of rollers onto both ends of the vibrator is adjusted by the coil springs shown in Fig. 3. It goes without saying that frictional material chips of PPS (poly phenylen sulfide: Sumitomo Bakelite Co., Ltd.) are bonded on both vibrator ends in contact with the rollers.

An important point of the motor is that it is constructed as flat as possible by using the double-mode vibrator within its width of 10.0 mm. The motor shown in Fig. 3 has such a function as forwarding the card inserted between the rollers and a base plate, effectively by a proper motor modification of belting between two rollers, and moreover it can be applied as a usual rotary motor with flat dimensions if the rollers are constructed to be shorter than those shown in Fig. 3.

Measured characteristics of the prototype motor shown in Fig. 3, where two stator vibrators in Fig. 2 were used, are shown in Figs. 4 and 5;[4)] that is, the optimum torque and efficiency are obtained as 10.8 gf·cm and 2.07%, respectively, from only one roller, under the conditions of roller clamping force 125 gf and electrical input power 1.8 W, and in this case, the revolution of rollers was 300 rpm.

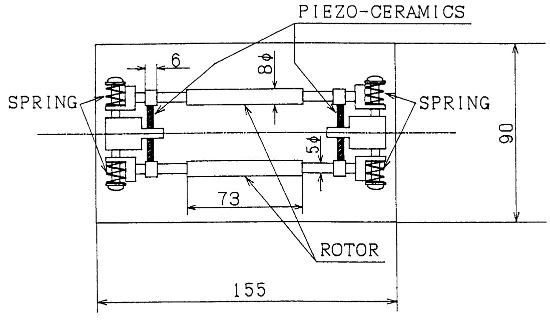

Fig. 3. Rotary motor construction.

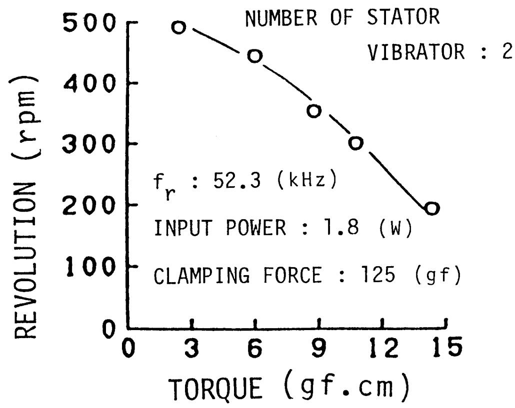

Fig. 4. Revolution characteristic.

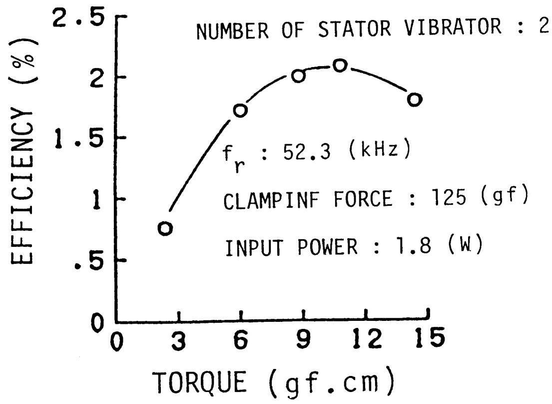

Fig. 5. Efficiency characteristic.

It was found that with the prototype motor, a postcard could be forwarded sufficiently, and the key point to achieving a good motor was to prevent the lack of uniformity of the vibrator characteristics.

We believe that a more powerful motor of this form can be made by parallel use of the vibrators, for example, by bonding two vibrators back to back.

§4. The Linear Motor

With the application of the same piezoelectric vibrator as in Fig. 2 to the construction shown in Fig. 6, a linear motor can be achieved. In the construction, the elliptic motions of displacements on the side-ends of a vibrator are used to yield the driving force of the motor; that is, as shown in Fig. 7, frictional material chips of PPS are bonded on both side-ends of a vibrator, and at these two portions, the vibrator is brought into contact with the guide-rail by means of the clamping force, given by bolting through the jig, shown in Fig. 6.

The guide-rail is made of stainless steel, and on both of its lateral sides, two thin plates of resin are attached to form grooves on the upper and bottom sides of the guide so that the vibrator can travel smoothly on the upper side and the bearing roller set at the jig revolves to move on the bottom side. The construction of the linear motor shown in Fig. 6 is merely fundamental in order to obtain its basic characteristics; that is, the construction can be

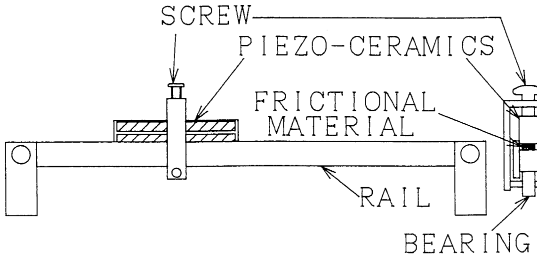

Fig. 6. Linear motor construction.

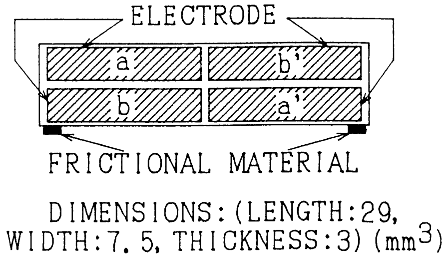

Fig. 7. Piezoelectric ceramics.

transformed. For example, the following linear motors are effectively constructed: one has one stator vibrator clamped between two guide-rails and the other has one guide-rail clamped by two stator vibrators. Moreover, in the latter case, two vibrators can also be connected in the I form at the common node point for two vibration modes used.

Measured characteristics of the prototype motor are presented in Figs. 8, 9 and 10; at the electrical input of 1.0 W, the optimum efficiency was 11.25%, and in this case, the thrust force was 15 gf and the traveling speed was 78 mm/s. Linear traveling of the motor was smooth and change in direction toward the right or left was easily accomplished by switching the phase between input currents to the L_1 and B_2 modes for two-phase-driving of the stator vibrator in order to form the elliptic motion of displacements shown in Fig. 2. It was found from the results that the method using the vibrator as a linear motor was better in motor efficiency than that using it as a rotary motor.

In this construction, an encoder is necessary in order to achieve the precise positioning of the motor.

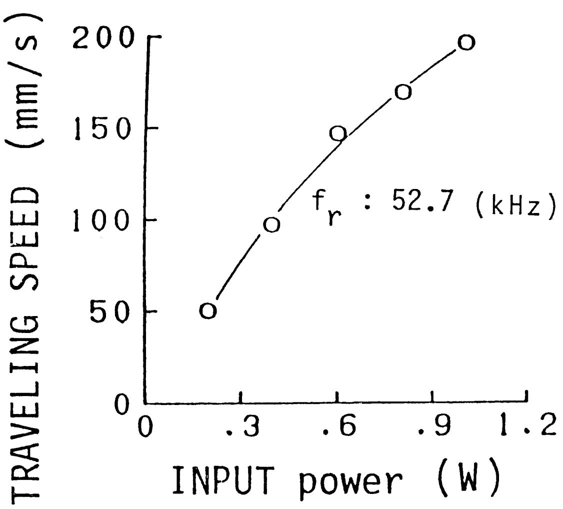

Fig. 8. Traveling speed characteristic (no load).

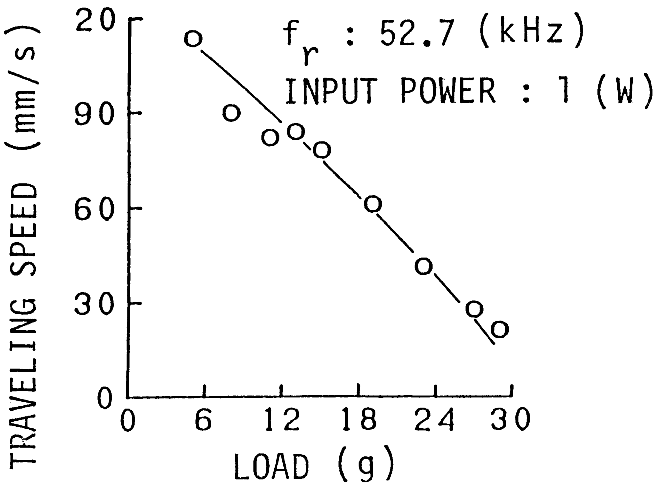

Fig. 9. Traveling speed vs load characteristic.

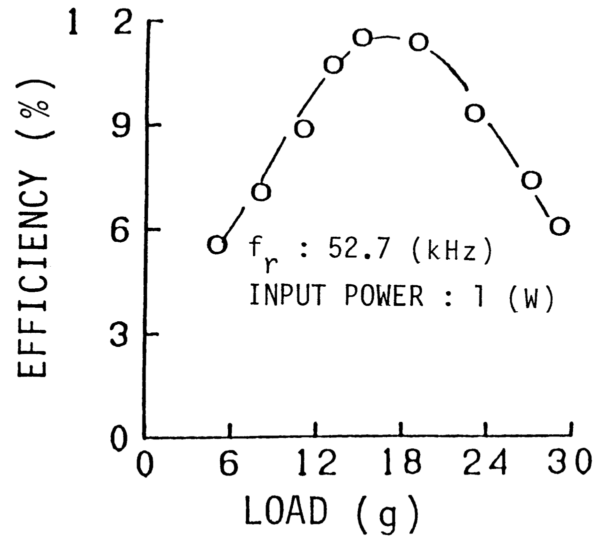

Fig. 10. Efficiency characteristic.

§5. Conclusions

We investigated flat rotary and linear motors within the thickness of 10 mm, using the double-mode piezoelectric ceramic rectangular plate of the first longitudinal and second bending vibration.

It is encouraging to the authors that the rotary motor will be practically applied to a paper- or card-forwarding device and the linear motor will also be applied, for example, to an opto-pick-up element in the compact disk.

Acknowledgement

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References

1) S. Ueha and T. Tomikawa: *Shinpan Choonpa Motor* (Advanced Ultrasonic Motors) (Trecepps, Tokyo, 1991) [in Japanese].
2) T. Maeno, T. Tsukimoto and A. Miyake: *1990 IEEE 7th Int. Symp. Application of Ferroelectrics (Piezodevices)* (IEEE, New York, 1990) p. 535.
3) S. Ueha: *IEEE 1989 Ultrasonic Symp. Proc.* (IEEE, New York, 1989) Vol. 2-2, No. TJ-4, p. 749.
4) Y. Tomikawa, Y. Ohshima, T. Takano and H. Umeda: *1992 Spring Natl. Conv. Rec.* (IECE Jpn., Tokyo, 1992), No. A-378, p. 1-379 [in Japanese].
5) H. Jumonji and M. Onoe: Trans. IECE Jpn. **51-A** (1968) 110 [in Japanese].
6) Y. Tomikawa, M. Aoyagi and T. Takano: *Report of 1992 Spring Meeting* (Acoustical Society of Japan, Tokyo, 1992) No. 1-7-10, p. 801 [in Japanese].