Hybrid Transducer Type Ultrasonic Linear Motor
Using Flexural Vibrator

Minoru Kurosawa, Kazuhide Nishita, Yoshikazu Koike
and Sadayuki Ueha

Precision and Intelligence Laboratory Tokyo Institute of Technology,
4259 Nagatsuta, Midori-ku, Yokohama 227, Japan

(Received February 12, 1991)

Reduction of the size and weight of a hybrid transducer type ultrasonic motor without increase of the resonance
frequency was accomplished by using a flexural vibrator in place of a driving vibrator. The contact parts of the transducer
were fabricated so that they achieved a line contact condition to a guide rail. The maximum speed and maximum output
force were 47 cm/s and 140 gf.

KEYWORDS: ultrasonic motor, piezoelectric actuator, linear motor, ultrasonic transducer, bending vibration

§1. Introduction

A hybrid transducer type ultrasonic motor has the advantage of being applicable to a number of various
configurations. Basic properties of this type of linear motor composed of a longitudinal vibrator and multilayered
piezoelectric actuators (MPA) have been reported.

With a longitudinal vibrator, it is difficult to reduce the size and weight of the motor, since miniaturization of the
vibrator increases the resonance frequency; therefore, another type of vibrator is more suitable. In the present
paper, we report the fabrication of a new hybrid transducer type ultrasonic linear motor which uses a flexural
vibrator as the driving source to satisfy the miniaturization.

§2. Hybrid Transducer and Motor Configuration

The hybrid transducer with the flexural vibrator to generate the driving force of the motor is shown in Fig.
1. The vibrator is composed of a duralumin bar 30 mm in length, 10 mm in width and 5 mm in thickness and two
PZT elements which are 10 mm square and 1 mm thick. The PZT elements are polarized in the thickness direction.
The flexural vibrator has two holes at its nodal points so that it can be fixed in a holder. This transducer
has 4 MPA which are 5 mm square and 5 mm high, and these are attached to the nodal parts of the flexural
vibrator. A guide rail is attached to the heads of the upper two MPA which are electrically driven to control
the friction force. The two lower MPA are simply counterweights to symmetrize the vibration mode. The

![Fig. 1. Configuration of the hybrid transducer.](image1)

![Fig. 2. Schema of the hybrid transducer type ultrasonic motor using the flexural vibrator.](image2)

![Fig. 3. Vibration mode of the transducer.](image3)

resonance frequency of the flexural mode and the force factor are 16.0 kHz and 0.021 N/V, respectively.

The flexural vibration mode of the transducer was analyzed by finite element method and is shown in Fig. 2.
The peaks of the MPA vibrate in a horizontal direction due to this flexural mode and have no vertical vibration
component. Flat top surfaces of the MPA would cause other parts of the surface center to have a vertical vibra-
tion component, and this vibration component would disturb the operation of the motor. Therefore, the head
parts were shaped as shown in the figure to make linear contact of the surface to the rail.

The pressing force to the rail was provided by four coil springs as shown in Fig. 3 to maintain a stable contact.
condition of the MPA heads to the rail. Separate electrical sources were used to supply the flexural vibrator and the MPA.

§3. No-Load Characteristics

No-load velocity versus the phase difference between the flexural vibrator and the MPA is shown in the Fig. 4. The driving voltages of the flexural vibrator $V_B$ and the MPA $V_M$ were respectively 90 $V_{rms}$ and 10 $V_{rms}$, and the pressing force to the rail $F$ was 580 gf. The maximum velocity was obtained at a $-20$ degree and $170$ degree phase difference. This result shows that the flexural vibrator is working at the resonance frequency and the MPA is working at the non-resonance one.

No-load velocity against the applied voltage $V_M$ curves at various pressing forces is shown in Fig. 5. Voltage applied to the flexural vibrator $V_B$ was 150 $V_{rms}$ during this measurement. It was found that the required pressing force was between 500 gf and 1 kgf both for appropriate velocity and load force, and that the required $V_M$ was about 10 $V_{rms}$. These conditions were due to the MPA cross section areas and the limits were caused by the contact surface. The line contact condition of the MPA head, in particular, was not proper for large contact force control.

The velocity versus the applied voltage $V_B$ in the no-load state is shown in Fig. 6, together with the vibration velocity at the contact points of the MPA without the rail. The applied voltage $V_M$ was 10 $V_{rms}$ and the pressing force was changed as indicated in the figure. In the range of relatively low voltage, for example, below 50 $V_{rms}$, the motor hardly operated. The maximum velocity of 47 cm/s was obtained when the pressing force was 560 gf and the $V_B$ was 150 $V_{rms}$.

§4. Loaded Performance

The loaded velocity characteristics of the motor were measured as shown in Figs. 7 and 8. In these experiments, $V_M$ and pressing force $F$ were maintained at 10 $V_{rms}$ and 770 gf, respectively.

Figure 7 shows the velocity versus the mechanical load force curves, where the flexural vibrator driving voltage $V_B$ is one parameter. The curves show that the maximum force of the motor depends on the driving voltage $V_B$. If,
for example, $V_B$ were 150 $V_{rms}$ and the head parts of the MPA were in contact with the rail during a half period of flexural vibration, the mean output force of the flexural vibrator would be 140 gf. This value was similar to the measured maximum force of the motor.

Figure 8 shows the loaded performance, that is, the velocity of the motor $v$, input power of flexural vibrator $P$ and transform efficiency $\eta$ from the input power of the flexural vibrator to the motor mechanical output power. The maximum output force and the maximum efficiency were 120 gf and 22%.

The specifications of this motor are listed in Table I in comparison with a previously produced motor which employed the longitudinal vibrator as the driving source. The earlier motor was relatively large in size and had greater output force, while the flexural vibrator motor has larger output force for its weight than the longitudinal vibrator motor.

| Table I. Comparison between the longitudinal and the flexural type vibrators. |
|-----------------|-----------------|-----------------|
| Driving         | Longitudinal    | Flexural        |
| vibrator        | vibrator        | vibrator        |
| Size (mm)       | $\phi 22 \times 83$ | $30 \times 10 \times 5$ |
| Weight (gf)     | 90              | 10              |
| Resonance       | 31.3            | 16.0            |
| frequency (kHz) |                 |                 |
| Maximum velocity | 50              | 47              |
| Maximum force   | 500             | 140             |
| Maximum efficiency | 36              | 22              |

§5. Conclusion

To reduce the size and weight of a hybrid transducer type ultrasonic motor, a flexural vibrator was introduced as the source of the motor driving force. Reduction was then achieved without an increase in the resonance frequency of the driving vibrator.

Nevertheless, the contact surface area of the MPA head was too narrow for a large output force of the motor. The shape of these parts was little changed owing to the vibration mode. The contact material should therefore be chosen carefully to increase the output force of the motor.

References