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A new loudspeaker for low frequency radiation by linear motion type ultrasonic motor

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ABSTRACT

This work gives a new loudspeaker construction which is completely different from the conventional electrodynamic loudspeakers. Direct-radiator-loudspeaker is required a large diaphragm displacement and low resonant frequency for satisfactory performance at a low frequency range. The conventional electrodynamic transducer is, however practical, not ideal for this sort of loudspeakers because motion of the voice coil driven through an air gap cannot be controlled perfectly and its resonance peak with high Q-factor may result a long group delay time.

The authors proposed an improved driving construction by using revolution of ultrasonic motors for direct-radiator-loudspeakers. It is suitable for radiate a high sound pressure at a low signal frequency.The piezoelectric ultrasonic motor is characterized by excellent motion controllability and high driving mechanical impedance because its rotor contacts its stator tightly. Therefore, the loudspeaker driven by ultrasonic motors expected to operate with large amplitude and high-fidelity in low frequency region even by a heavy diaphragm.

However, continuous revolution of ultrasonic motor cannot induce reciprocal motion of the diaphragm directly. Authors tested a loudspeaker by using reciprocal revolution of an ultrasonic motor at the first stage. However, it produced a sound with remarkable distortion due to friction characteristics of the motor.

The solution for reduction of distortion by the authors was use of linear motion type motors. The preliminary model included a metal movement, connected directly to a cone radiator and set on a sliding stage, which is driven by two piezoelectric linear actuators fixed opposite to each other. It radiated a satisfactorily large sound. However, its efficiency and distortion characteristics were unsatisfactory.The next model has an improved simple construction. Size and weight of the movement is reduced and the slide stage is removed. Performance of this model will be introduced at the meeting.

1 INTRODUCTION

The authors proposed completely new constructions of loudspeakers driven by piezoelectric ultrasonic motors, which are suitable for a precise very-low frequency reproduction[1]. The piezoelectric ultrasonic motor is characterized by excellent motion controllability and high driving mechanical impedance because its rotor contacts its stator tightly. Therefore, the loudspeaker driven by ultrasonic motors expected to operate with large amplitude as well as a high-fidelity in low frequency region. due to its high driving mechanical impedance. It has a lot of merits comparing to the conventional electrodynamic loudspeakers.

The authors have examined a few constructions by using revolution of ultrasonic motors. Their merits have been clear. However, their construction is more complicated than it of the conventional electrodynamic loudspeakers.

In this paper, other loudspeaker constructions which are driven by a linear motion of the piezoelectric ultrasonic motors are proposed. Rotational and linear ultrasonic motors are compared as driver elements of the loudspeakers, and then, merits of the loudspeaker driven by linear actuators are shown.

2 A LOUDSPEAKER BY ROTATIONAL TYPE ULTRASONIC MOTOR

Driving principle of the rotational and linear ultrasonic motors are similar. However, convenience of them for examination devices were somewhat different. Investigation of the authors' reseach work was started from use of rotational type ultrasonic motors because this sort of ultrasonic motors, driven by a travering wave, were commertialy avairable by a few makers for components of office-automation equipment etc..

2.1 Rotational type ultrasonic motor

Figure.1 shows the cut view photo of a travelling wave type ultrasonic motor, model USR60 by Shinsei kogyo, which is used at the authors' examinations. A piezoelectric actuator, teethed stator and metallic rotor are seen. The stator is laminated by a thin piezoelectric ceramic ring. Two 40-45 kHz sinusoidal waves, with same frequency and with phase difference of 90 degree, are applied to the piezoelectric ceramic to generate a progressive wave[2].

Driving force of the ultrasonic motor is larger than it of the conventional electromagnetic motors because rotor and stator of the ultrasonic motor are contacted each other. Infinite rotation of the motor brings more suitable nature for large amplitude operation than conventional electrodynamic actuator of the loudspeakers.

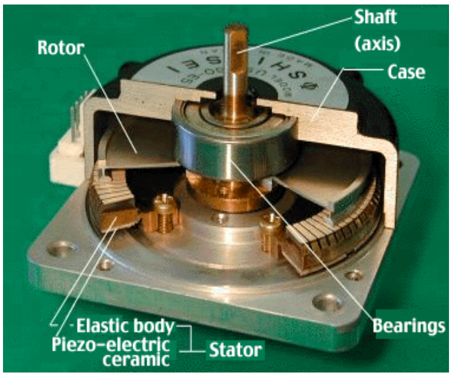

Figure 1. USR60 by Shinsei Kougyo Corp.

2.2 Rotation to linear conversion mechanism

Figure 2 shows a preliminary model which is driven by a reciprocal motion of a rotational type ultrasonic motor. As is described in Figure.3, this driving construction includes a conversion mechanism of rotation to linear motion.

This experimental model induced too much wave distortion. It might be caused by friction characteristics of the rotation to linear motion conversion mechanism. In addition, combination of a spring and a sliding rail was less suitable to transfer driving force completely.

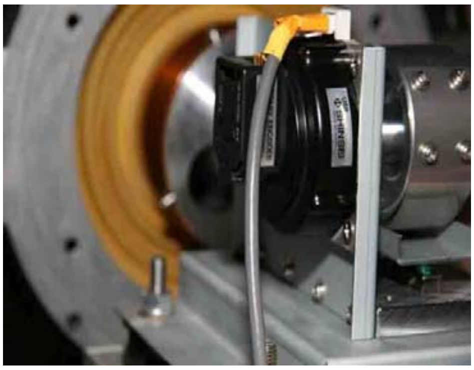

Figure 2. The loudspeaker by rotation to linear conversion

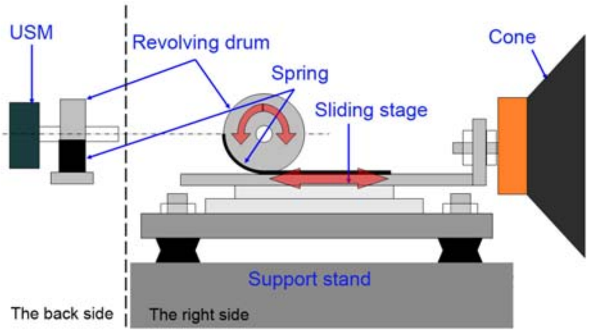

Figure 3. Driving principle of the loudspeaker by rotation to linear conversion mechanism

3 A LOUDSPEAKER BY LINEAR MOTION TYPE ULTRASONIC MOTOR

The solution for reduction of distortion was use of motors designed for linear motion only. The authors examined a prototype linear motion model by composite vibration type linear ultrasonic motors[3].

3.1 Composite vibration type ultrasonic motor

Figure 4 shows external view of HR8 linear ultrasonic motor by Nanomotion Ltd. in Israel.

Driving principle of this motor is explained by Figure.5. Small rotational motion of the finger tip is induced by a composite of longitudinal and bending vibration at the same resonant frequency, of the piezoelectric ceramic rod having four divided electrodes. Trajectory of the motion of tip top due to this vibration, which is due to deformation of piezoelectric ceramic by an electric input, is on a small elliptical orbit, because the. ceramic pearforms as a dual mode standing wave motor. Its resonant frequencies of longitudinal extension vibration and transverse bending vibration of the ceramic are designed to be close frequency proximity.

Figure.6 describes the relationship between applied voltage and revolution velocity. It is quoted as a long life of 20000 hours, but its maximum velocity is rather limited to 270 mm/s.This motor is suitable for use with our loudspeaker by linear motion type, because the rotation stands up even when the applied voltage is low.

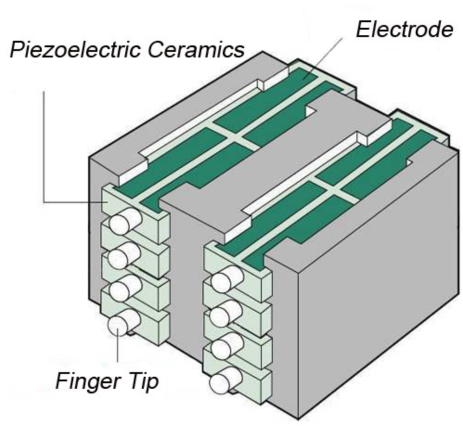

Figure 4. Structure of composite vibration type ultrasonic motor

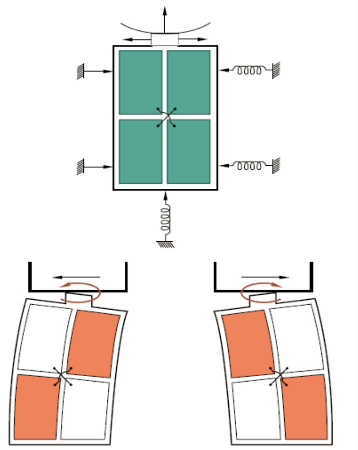

Figure5. Driving principle of composite vibration type ultrasonic motor

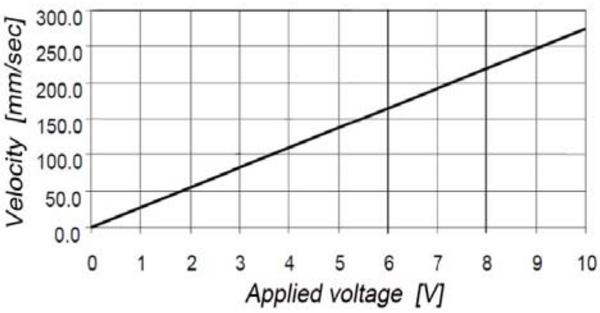

Figure 6. Characteristics of HR8

3.2 Loudspeaker by linear motion type ultrasonic motors

A loudspeaker by using the linear motion type ultrasonic motors is expected to be suitable for low frequency sound signal reproduction. Its driving mechanism can be simpler than that the driving mechanism by rotational type motors, because no parts for the mechanism of rotation to linear motion are necessary. Moving part of the motor is connected directly to the cone radiator.

An ordinaly equipment including the linear ultrasonic motors is a driver for linear slider for a conveyer in, for example, IC manufacturing plants. The authors examined loudspeakers with a cone radiator connected a linear slider which is driven by two ultrasonic motor blocks at opposite sides.

3.3 The 2009 model

Figura 7 and Figure 8 show the first experimental models by using linear ultrasonic motors. The slider and its rail for the models were ready-made components for a conveyer system. Weight of the solid steel slider was 430 gram.

A model shown in Figure 7 is called as 2009 Model 1. The cone radiator and the slider were connected by a brass rod and a star-shaped spider. Silicon rubber dampers were inserted at the connedting point.

The other model shown in Figure 8 is called as 2009 Model 2. The cone and the slider were connected by tight metal components.

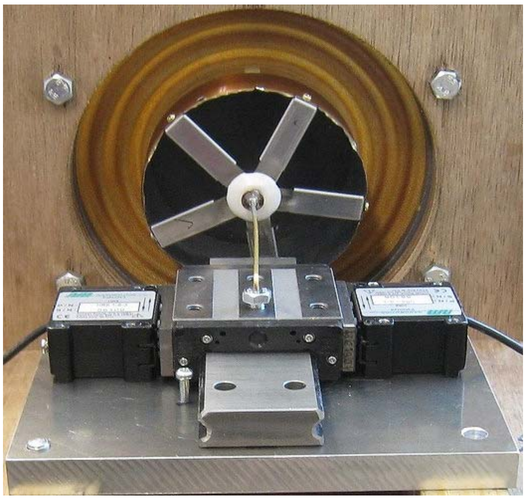

Figure7. The 2009 Model-1

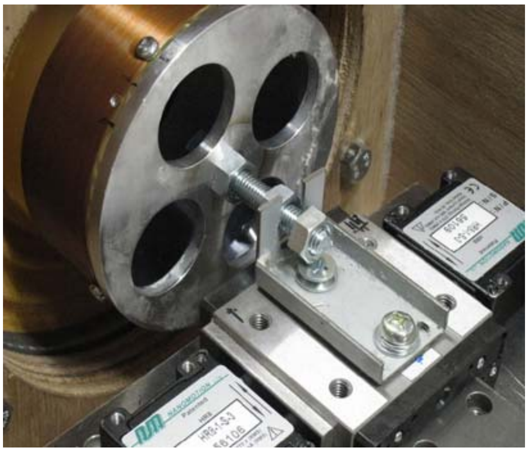

Figure8. The 2009 Model-2

3.4 Experimental procedure

Frequency response curves of the experimental models were measured in an anechoic room. Distance between the microphone and the loudspeaker was 1000 mm, and the applied voltage was 8 volt.

3.5 Experimental results of the 2009 model

Figure 9 compares frequency responses of two models.

The response of the Model 1 includes a peak at 56 Hz. This peak seems to be a resonance by silicon rubber damper. The frequency response of the Model 2 does not include this remarkable peak.and performance t higher frequency is better.

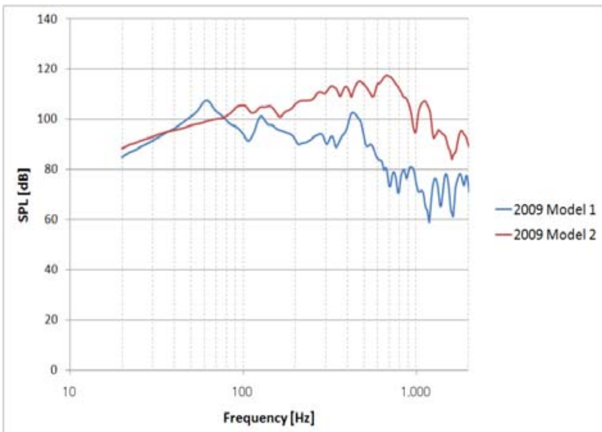

Figure 9. Frequency response of the 2009 models

3.6 The 2010 model

Figure 10 shows a viw of improved model called as 2010 Model. Figure 11 describes its configuration:

The 2009 model included a steel slider, connected directly to a cone radiator and set on a sliding rail. It radiated a satisfactorily large sound. However, its efficiency and distortion characteristics were unsatisfactory.

The 2010 model has an improved simple construction. Size and weight of the movement was reduced and the slide rail was removed.

Figure10. The 2010 Model

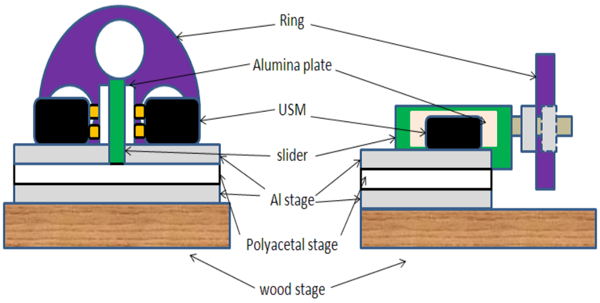

Figure11. Configuration of the 2010 Model

3.7 Experimental procedure

The 2009 Model 2 and the 2010 model were measured by a similar procedure to it for the 2009 models, for conparison. The applied voltage was reduced to be 5.6 volt. A vented box of 125 litter was used. An air damper, a bundle of small tubes, was inserted in the duct.

3.8 Experimental results

Frequency response of the 2009 model-2 and the 2010 model are compared by Figure.12 and Figure.13.

The 2010 model's output sound is available up to 1300 Hz. Therefore, the direct linear drive seems suitable for a wide frequency band operation, not only for lower frequency signals.

Signal distortion level is not so low, similar to the 2009 model-2.

4 CONCLUSION

New loudspeaker models suitable for a low frequency reproduction were proposed. They utilize linear motion of composite vibration type ultrasonic motors. Their performance was improved by a simpler driving mechanism.

The next step will be improvement of the mechanical alignment.

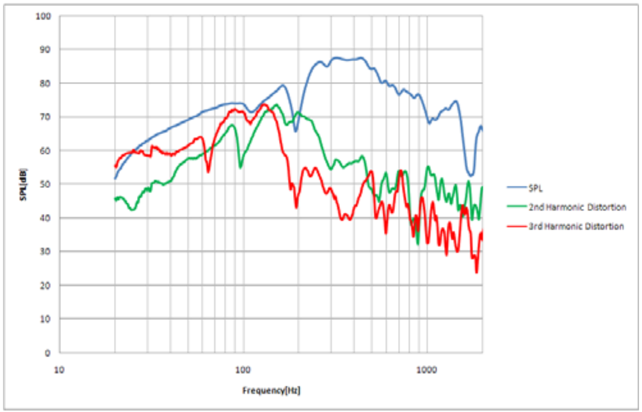

Figure12. Frequency response of the 2009 model-2

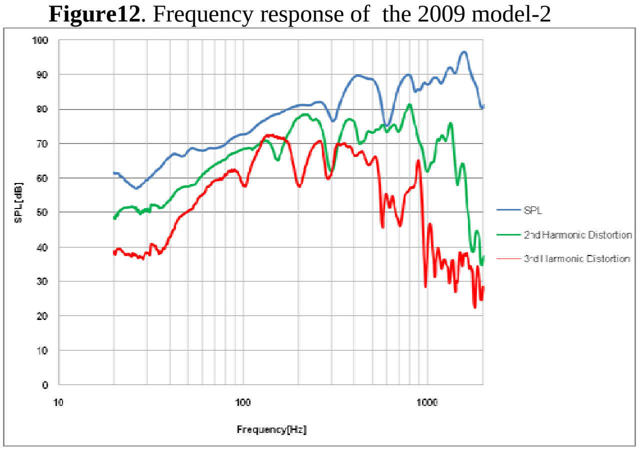

Figure13. Frequency response of the 2010model

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