ABSTRACT
This study presents a design of the linear ultrasonic motor. The major components consist of a slider and a vibrator with a piezoceramic piece. The input signal on the piezoceramic piece causes vibration of the vibrator. The development of the vibrator is based on vibratory analysis of a beam with both ends clamped. The resonant frequencies and the vibratory mode shapes of the vibrator are calculated and compared with those obtained by using the finite element method. By only changing two frequencies of the input signal on the piezoceramic piece, the vibrator is excited and the slider can achieve forward and backward bi-directional movement due to friction between the vibrator and the slider. The calculated results are compared with results obtained by Grant and using software ANSYS.

1. INTRODUCTION
An ultrasonic motor is an actuator which utilizes mechanical vibration with ultrasonic frequency as driving source. Ultrasonic motors are attractive with good potential since they can overcome drawbacks of electromagnetic motors. The major components consist of a slider and a vibrator. The vibrator composes of a piezoelectric driving component and an elastic vibratory part. When alternating current and voltage are applied to the piezoelectric driver, the input signal on the piezoceramic piece causes vibration of the vibrator and motion of the slider. Various ultrasonic motors were designed and studied [1].

The purpose of this study is to present the design of a linear ultrasonic motor that can achieve forward and backward bi-directional movement.

2. METHOD OF APPROACH
The vibrator dimension of the ultrasonic motor designed is shown in Fig. 1. It is assumed that the vibrator is a uniform cross-sectional beam with the mass of the projector concentrated at a point and connected to the beam by a massless rigid link with an equivalent rotary inertia. One dimensional Timoshenko beam theory is utilized to derive vibration equations of the beam with both ends clamped. The coupled differential equations for the total deflection and the bending slope of the beam are derived with the harmonic motion.

3. RESULTS AND DISCUSSION
In order to compare with the existing data, the vibrator without the piezoceramic is analyzed first. The natural frequencies of the bending mode 1 and mode 2 of the vibrator without the piezoceramic are calculated for various projector locations by using software MATLAB. The results are compared with that obtained by Grant and software ANSYS as shown in Figs. 1 and 2, respectively. The results of ANSYS 1D and ANSYS 3D are obtained by using the one-dimensional element and the three-dimensional element, respectively.

It is shown that the present result is closer to that obtained by Grant who considered only the transverse effect of a concentrated mass. Therefore, the calculated results are better than that obtained by Grant.

Effects of various values of design parameters and shapes as shown in Fig. 3 on the performance are studied. The displacements for various shapes of the projector are shown in Table 1. Based on calculated results, the projector semicircle radius to be 5 mm is selected. The displacements, \( u_x \) and \( u_y \), of the vibrator in the \( x \) and \( y \) directions for two frequency
responses varied with the projector position $x_1$ are shown in Figs. 4 and 5, respectively. The position $x_1$ of the projector is selected to be 7.4 mm ($x_1/L=0.37$) because the displacement responses $u_x$ of both mode 1 and mode 2 are equal as shown in Fig. 4. The results show that the vibrator of this design can achieve the bi-directional movement.

4. CONCLUSION

The calculated results are better than that obtained by Grant [2]. The projector shape is semicircle with the radius equal to 5 mm and the position $x_1$ of the projector equal to 7.4 mm ($x_1/L=0.37$) are selected. The vibrator of this design can achieve the bi-directional movement.

ACKNOWLEDGEMENTS

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Table 1 Displacements of various projector shapes

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</table>

Figure 3. Various shapes of projector.

Figure 4. Displacement versus projector position $x_1$.

Figure 5. Displacement versus projector radius.