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Letter to the Editor

Modal analysis and control of a bowl parts feeder activated by piezoceramic actuators

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1. Introduction

Vibratory bowl feeders are the most versatile and common feeding and orientating devices for automatic assembly (refer to Fig. 1). Thus, they are being widely used in many industry fields. The electromagnet has been and being commonly used as an exciting actuator in these vibratory bowl feeders. However, because of complexity of its mechanical structure and limited capability, there exist various impending problems such as severe noise, non-linear motion of parts, passive characteristics and so forth. Early work on vibration bowl feeder was reported by Redford and Boothroyd [1]. They presented a theoretical analysis of vibratory parts feeder to figure out the feeding mechanism. Boothroyd et al. [2] studied the automatic feeding and orientation of parts on vibratory feeders and developed various forms of orienting devices to improve feeding efficiency. MacDonald and Stone [3] developed a simple linear vibratory feeder model using the MacPascal language. Lim [4] simulated the conveying velocity of a linear vibratory feeder.

Despite of many research works to improve dynamic performance of the conventional electromagnet actuator-based bowl parts feeder, there still exists some significant problems; noise and passive motion. As one of solutions to resolve these problems is to use piezoactuators as a new exciting technology. The piezoelectric material is one of smart materials that can develop mechanical strain when subjected to an electric field, or, alternatively can develop an electric field subjected to mechanical deformation. Advantages of the piezoelectric material include fast response time, wide frequency bandwidth and accurate control capability [5]. By adopting the piezoelectric material as an exciting actuator, we can devise more effective bowl parts feeder providing accurate and adjustable feeding speed of parts than the conventional one activated by the electromagnet actuator.

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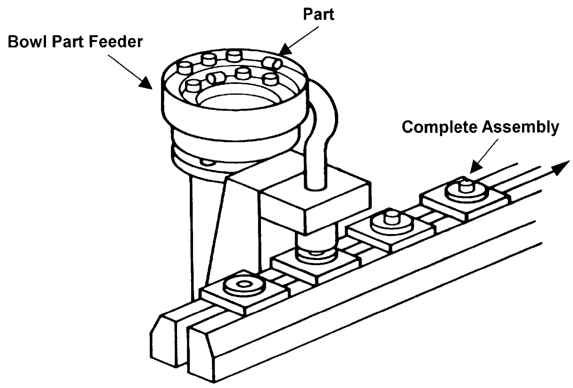


Fig. 1. Assembly line with bowl parts feeder.

In this work, as the first phase to develop highly effective piezoactuator-driven bowl parts feeder, a system model is established using a finite element method (FEM). By adopting commercial software package, modal characteristics of the proposed bowl parts feeder are analyzed and compared with experimentally measured ones. In addition, control aspects of the parts feeder are experimentally investigated by emphasizing the feeding speed of parts with respect to the intensity of the input voltage.

2. Modal analysis

First of all, it is very important to investigate the principle of the motion of the bowl parts feeder. Though many researches have been undertaken to understand this principle, the motion of the bowl parts feeder is not yet clearly demonstrated because of its structural complexity. The modal analysis can provide us relatively exact knowledge of the motion principle of the bowl parts feeder. In other words, the construction of an appropriate FEM model can provide us various potentials for analyzing modal characteristics and hence better understanding of the feeding principle.

In order to undertake modal analysis and experiment, a new type of bowl parts feeder activated by the piezoactuators is manufactured as shown in Fig. 2. As clearly seen from the photograph, the piezoceramic patch has been bonded to the steel plate. The bowl is made of stainless steel, while the leaf spring is made of mild steel. The dimensional specifications of the proposed bowl parts feeder are as follows: inclined angle of the inner track is 3.7°, inclined angle of the leaf spring is 78.7°, diameter of the bowl is 232 mm, thickness of the bowl plate is 2 mm, height of the bowl is 90 mm, length of the piezoactuator is 44 mm, width of the piezoactuator is 44 mm, and thickness of the piezoactuator is 0.75 mm. The finite element analysis for the proposed bowl parts feeder has been performed by using commercial software packages. ANSYS is used as the solver, while PATRAN as the pre-post-processor. Fig. 3 shows the mesh generation of the bowl parts feeder. This FEM model has a total node points of 6188 and element of 4677. This gives a total degree of 32 520 (refer to Ref. [6] for the details).

Fig. 4 presents the mode shapes of the proposed bowl parts feeder obtained from the FEM analysis. The first mode indicates reciprocating rotational motion with respect to the vertical axis,

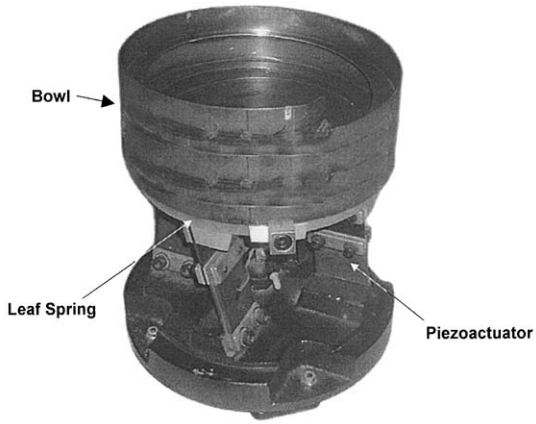


Fig. 2. The proposed bowl parts feeder with the piezoactuators.

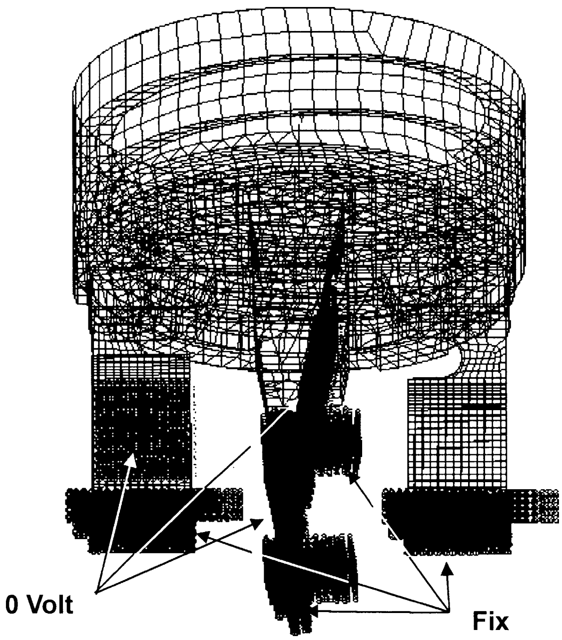


Fig. 3. Mesh generation for the finite element model.

while the fourth and fifth modes show seasaw motion and expansion motion, respectively. These three modes are principal modes to cause the movement of parts inside the bowl along the inner tracks. On the other hand, the second and third modes represent the bending motions with respect to the x- and y-axis, respectively. Furthermore, the sixth mode indicates expansion motion of the upper plate of the bowl. The measured mode shapes of the three principal modes are also presented in Fig. 5. The experimental results are obtained by using 3-axis accelerometers associated with STAR Software, which is one of commercial softwares to achieve mode shapes from the measured values. The bowl parts feeder is randomly excited ranging from 0 to 3200 Hz,

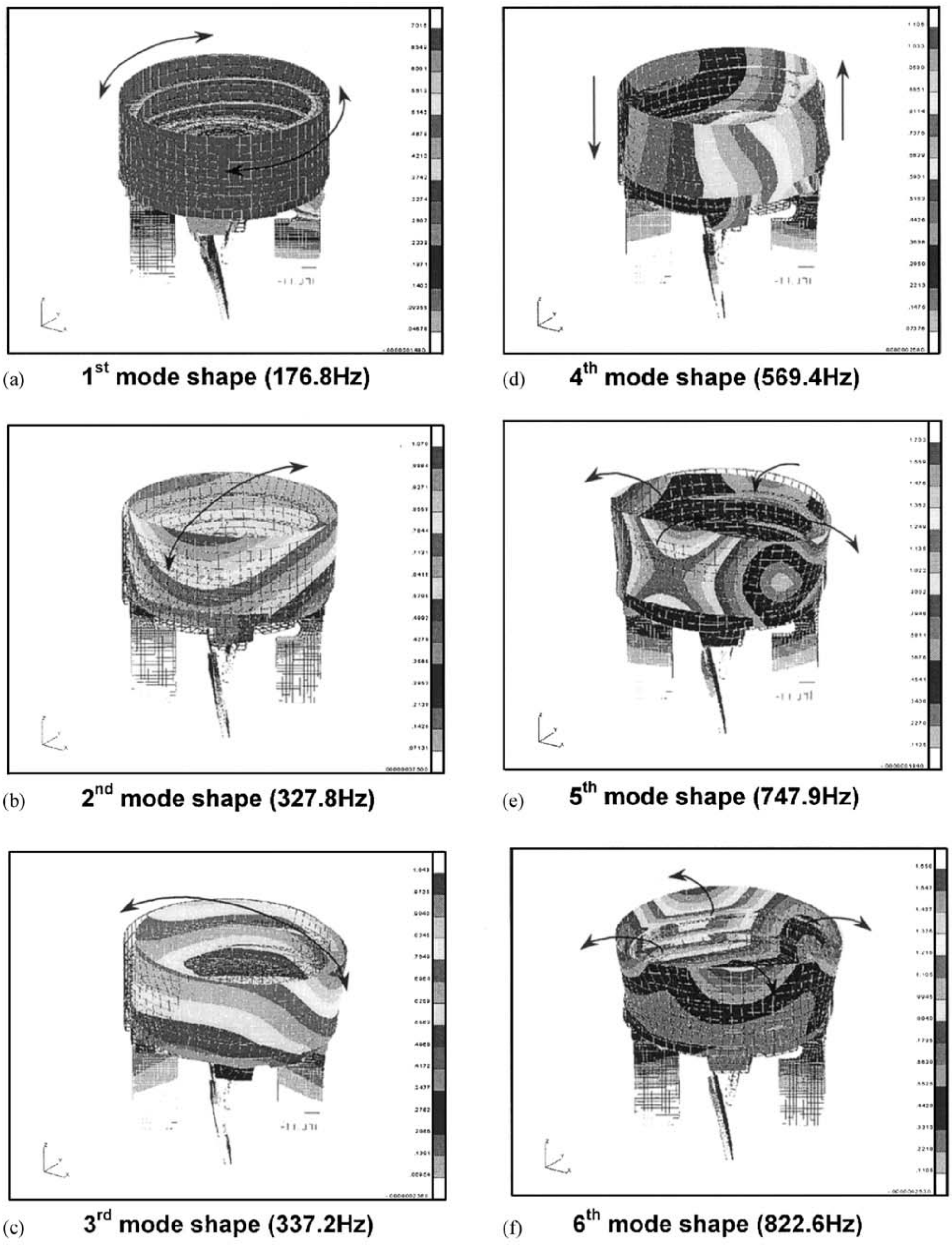


Fig. 4. Simulated mode shapes of the bowl parts feeder.

and the signals from the accelerometers are stored and analyzed in a dynamic signal analyzer. The number of data points is 134. It is clearly observed that the agreement between the finite element analysis and the measured results is excellent. This advocates the efficacy of the proposed finite element model for the bowl parts feeder activated by the piezoactuators.

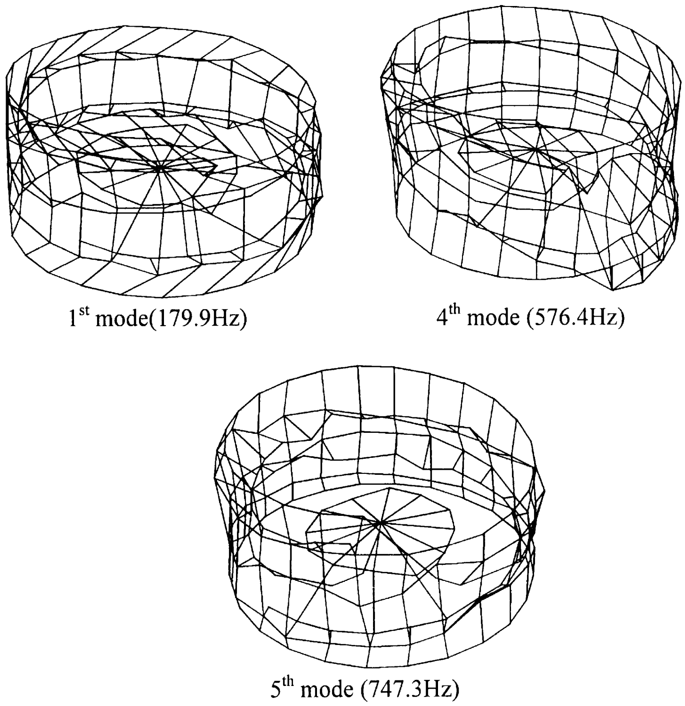
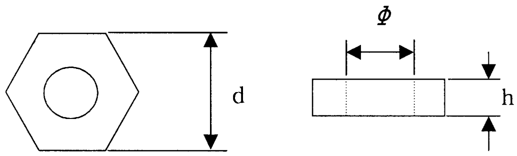


Fig. 5. Measured mode shapes of the bowl parts feeder.

3. Moving speed of parts

In order to demonstrate the controllability of the proposed bowl parts feeder, a mean conveying velocity (MCV) of parts is experimentally measured. Two different steel bolts shown in Fig. 6 are used as the moving parts. The time taken from the initial position in the bowl to the end position on the track is measured five times and the MCV is determined. Fig. 7 presents the measured MCV with respect to the input voltage applied to the piezoactuator. The excitation frequency of the input voltage is 180 Hz, which is the first mode of the bowl parts feeder. As expected, the MCV is increased as the input voltage increases. In addition, we see that part 1 (lighter) moves faster than part 2. The moving velocity of part inside the bowl depends upon several factors: the mass of part, the magnitude of the input voltage, and the exciting frequency of the voltage. For example, very light part will normally not be able to move fast with relatively low exciting frequency of the input voltage.

Now, we consider the controllability of the moving speed of parts. In order to achieve this, the conventional PID controller is adopted and experimentally implemented. The control voltage $V(t)$ is then determined by $V(t) = k_p e(t) + k_i \int e(t)\,\mathrm{d}t + k_d \dot{e}(t)$. Here, k_p, k_i and k_d are control gains, and $e(t)$ is the error signal between the desired velocity (set value in the microprocessor) and the actual velocity. By considering maximum applicable voltage to the piezoactuators, the feedback gains are chosen by $k_p = 2.8$, $k_i = 0.0001$ and $k_d = 0.01$. Fig. 8 presents the mean control velocity for part 1 . We clearly see that favorable control results have been achieved for both slow and fast



	d (mm)	Φ (mm)	h (mm)	Volume (mm^3)	Weight (g)
Part 1	5.4	2.4	2.25	46.6411	0.32
Part 2	9.85	5.05	5	319.972	2.16

Fig. 6. Specifications of parts used in experiment.

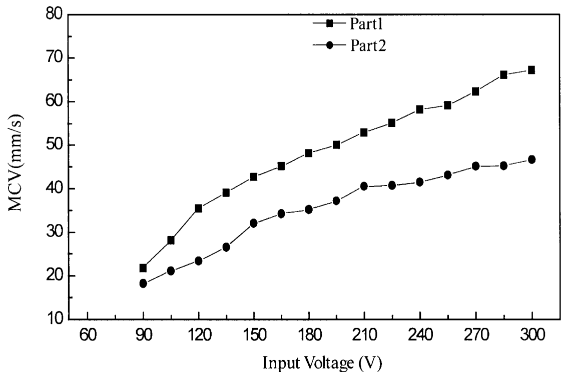
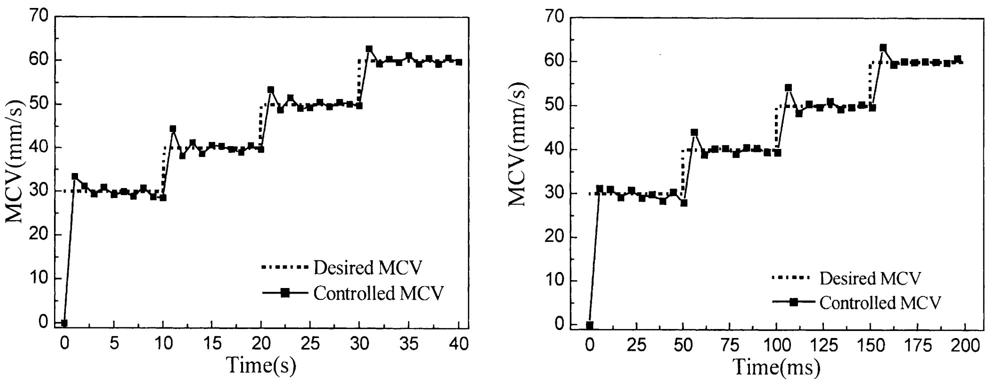


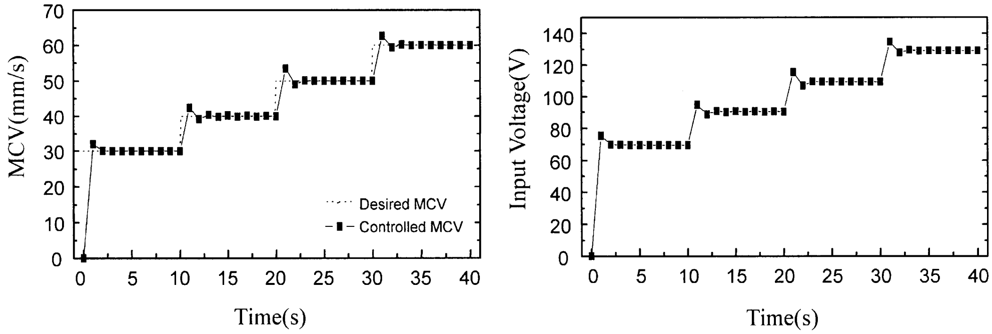
Fig. 7. Mean conveying velocity at various input voltages.



(a) slow motion

(b) fast motion

Fig. 8. Mean control velocity for Part 1.



(a) velocity (b) control voltage

Fig. 9. Mean control velocity for Part 2.

motions of part. The mean control velocity for part 2 is presented in Fig. 9. It is also observed that an excellent control performance has been achieved by activating the piezoactuator. It is noted that control input voltages have been applied to the piezoactuators in the form of sinusoidal time history at each measured point.

4. Concluding remarks

A new type of bowl part feeder activated by the piezoactuators has been proposed and its modal characteristics were analyzed through both the finite element method and experiment. In addition, controllability of the moving velocity of parts has been experimentally demonstrated by implementing simple PID controller. The results presented in this research work are quite self-explanatory justifying that the bowl parts feeder activated by the piezoceramic actuators can be effectively used in the automatic assembly line. It is finally remarked that optimal adaptability of the proposed parts feeder to various types of parts and noise reduction during excitation have to be further investigated in the future.

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