

Design and Control of Piezoactuator Based Workpiece Feeding System for Micro Milling

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ABSTRACT: In late years, there has been plenty of advancement in the domain of piezo-actuated systems which find substantial application in Nano/micro positioning. The fortunate or preferable features of Piezoactuator involve higher positioning precision, low wear and tear, high dynamic reaction, high stiffness and compact design. In this work an attempt is made to design, fabrication and testing of a Piezoactuator based workpiece feeding system for tool based Micromilling machine. Micromilling exhibit unbalance in workpiece. To overcome this problem, we propose a vertical slider (vertical guideways) in a design which support the workpiece to move in vertical direction. The mathematical model is evolved incorporating Prandtl-Ishlinskii model of hysteresis to balance out for the hysteresis of Piezoactuator. Simulation and experiment are done to study the displacement response of the Flexural Amplified Piezoactuator (FAP1000).

KEYWORDS: Piezoactuator, Prandtl-Ishlinskii model,

I. INTRODUCTION

Piezoelectricity is a phenomenon by which some materials convert electrical energy into mechanical energy, reverse is also true. A piezoelectricity is a word which means electricity in which it exhibits through applied pressure. Piezoelectricity is developed in helpful applications like in production and identification of sound, making of large voltages, microbalances, electronic frequency creation. [1]

The piezo-actuator device which has large movement accuracy, which also has large comeback speed and high impulse generation. Piezoactuator is basically tested with means of industrial machines which require proper position controlling. The piezo actuator gains displacement by applying direct deformation of solid and finally features large displacement accuracy, high response speed and large generation force than other type of actuators.

Piezo actuators are classified into two groups, stripe and stack actuators. The name express stripe actuator is in the design of thin strips. Stack actuators are compound structures done by stacking individually finished piezoelectric materials. Stacked Piezoactuator has an operating voltage of 0 to 1000V with long lifetime without power derating and also has some higher movements, less electrical capacitance with working temperature ranges from -20°C to 85°C. [2]

Linear guideways which moves in linear motion which utilize circulating balls. Also using rolling balls for linear guideways in between block and rail, where it can gain a high precision linear. and by comparing the linear guideways with traditional slide, which has co-efficient of friction is 1/50 for linear movement guideways. Which is of restraint effects on block and rail, and also the linear movement guideways can have loads on up/down and left/right in both directions. By all these benefits of linear guideways, linear guideways can highly enhance accurate movement, and it is also true when it has accompanied with precision ball screws. Some of the advantages of linear guideways are large accuracy in position, high accuracy in motion with period of long life, which is easy to install and also interchangeability, easy for lubrication, in all direction it has equivalent loading capacity etc. [8]

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II. PROPOSED DESIGN OF PIEZOACTUATOR BASED WORKPIECE FEEDING SYSTEM

In this project work a piezo actuator based workpiece feeding system is developed for Micromilling machine. Figure 2.1(a) shows the sectional view of Piezoactuator based workpiece feeding system. The Piezoactuator used is APA 1000L which can produce maximum displacement of 1000µm. Design which consist of block, actuator, workpiece feeding block, guideways. One end of the actuator is fixed to supporting block at the top and other end at the bottom is connected to workpiece feeding block, the rail of guideways is fixed to block and the carriage of guideways are connected to workpiece feeding block

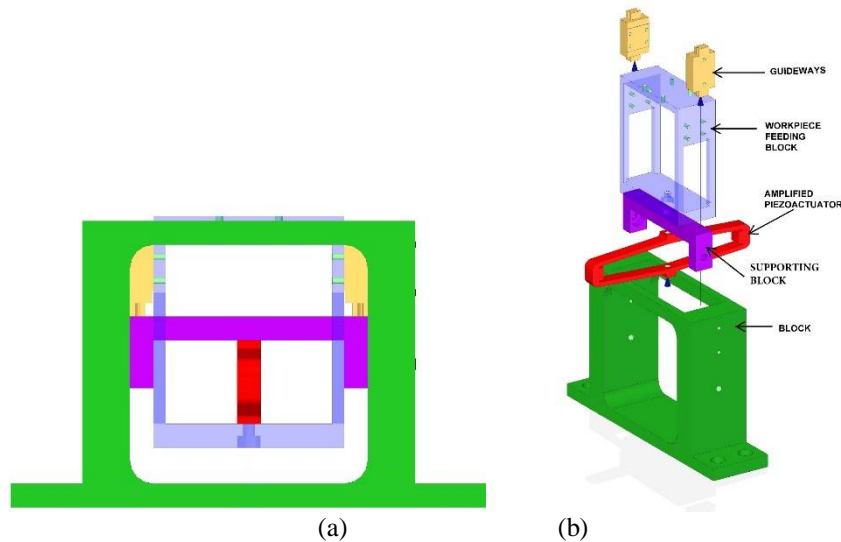


Figure. 2.1:(a) Sectional view of Piezoactuator based workpiece feeding system (b) Exploded view of Piezoactuator based workpiece feeding system

Functions in figure2.1(b) of different components are as follows:

- **Block:** which holds the entire setup, where bottom side of it is fixed.
- **APA 1000L:** piezoelectric actuator which converts applied voltage into mechanical displacement.
- **Workpiece feeding block:** which is used to hold the workpiece with movement given by actuator
- **Guideways:** which gives linear movement in Z-direction
- **Supporting block:** which holds the piezo actuator fixed on one side to give movement in vertical direction on other side

III. HYSTERESIS MODELLING

Hysteresis in piezoelectric actuator is unasked effect which continuously limits performance of it and which need to be compensated. Output of structure depends on present and past input values. Which effects the execution of actuator where exact displacement is required. Various types of hysteresis models are present for piezoelectric actuators like Maxwell slip model, Bouc-wen model, Prandtl-Ishlinskii model, Preisach model etc. In present work forward and inverse model of Prandtl-Ishlinskii model based on Piezoactuator is used to control the hysteresis of the piezoactuator.

Forward Prandtl-Ishlinskii Hysteresis Model

Prandtl-Ishlinskii Hysteresis model which takes advantage of backlash operator, to distinguish the relativity between input and output function. Backlash operator which is also defined as play operator. The preciseness of hysteresis model increase with the iteration of backlash operators. The forward Prandtl-Ishlinskii model is shown in equation (3.1).

$$y(t) = p u(t) + \sum_{i=1}^n w_i F_r[u](t) \quad (3.1)$$

u - input applied voltage

y - output displacement

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p - positive constant

w_i – weighting function

n - total number of backlash operator

The backlash operator is perpetual and rate-independent where the output value of operator is determined by present input and last input but not through rate of input. The play operator analytically represented for $t_o = 0, t_o < t_1 < \dots < t_N = t_E$ as shown in equation (3.2).

$$F_r[u](0) = f_r(u(0), 0) = v(0)$$

$$F_r[u](t) = f_r(u(t), F_r[u](t_i)) \dots \dots \dots (3.2)$$

for $t_i < t < t_{i+1}$ and $0 \leq i \leq N-1$

where,

$$f_r(u, v) = \max(u - r, \min(u + r, v)) \dots \dots \dots (3.3)$$

u - input voltage

v - output displacement

r - threshold of backlash operator

$$r = \beta j \dots \dots \dots (3.4)$$

the threshold of backlash operator is explained in equation (4.4). ‘ β ’ is constant, ‘ j ’ is number of backlash operator. ‘ r ’ is threshold of backlash operator which also determines the width of the curve, where curve width increase with value of r . The w_i weighting function is constant which is larger than zero. Later which effects curve shape and size of backlash operator as described in equation (3.5). where τ and ρ are constants which can be obtained through estimation.

$$w_i = \rho e^{-\tau r} \dots \dots \dots (3.5)$$

By addition in backlash operator the hysteresis curve is obtained, and by increase in number of backlash operator the curve goes smoother.

Inverse Prandtl-Ishlinskii Hysteresis Model

In application with Piezoactuator it is mandatory to learn the voltage which has to be applied for Piezoactuator to get deserved output displacement. In inverse model displacement is taken as input value and voltage is an output required. The inverse Prandtl-Ishlinskii model is developed for MLA10x10x20 as shown in equation 3.9

$$y(t) = p u(t) + \sum_{i=1}^n w_i F_r[u](t) \dots \dots \dots (3.6)$$

Equation 3.6 is an equation for forward single stack model. The inverse Prandtl-Ishlinskii model can mathematically derived as shown in equation 3.7. with components mass ‘ m ’, stiffness ‘ k ’ and ‘ b ’ is the damping co-efficient, which has derived from equation 3.6. From equation 3.7 ‘ w ’ is the waiting function and ‘ T ’ is the transformation ratio. Which is further derived for inverse single stack equation as shown in equation 3.8. Later it is further derived for 6 stacks to obtain inverse P-I model as shown in equation 3.9.

$$m\ddot{x} + b\dot{x} + kx = [Pu(t) + w]T \dots \dots \dots (3.7)$$

$$\frac{m\ddot{x}}{TP} + \frac{b\dot{x}}{TP} + \frac{kx}{TP} - \frac{w}{P} = u(t) \dots \dots \dots (3.8)$$

$$\frac{m\ddot{x}}{TP} + \frac{b\dot{x}}{TP} + \frac{(k+3k_s)}{TP} - \frac{w}{P} = u(t) \dots \dots \dots (3.9)$$

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Forward and Inverse Piezoactuator Models

The Piezoactuator model depends on forward and inverse Prandtl-Ishlinskii hysteresis model. Figure 3.1(a) shows block diagram for forward Piezoactuator model which is defined with input voltage u , transformation ratio T , output from P-I hysteresis model y and constant parameters m is a mass, b is a damping constant and k is stiffness of Piezoactuator, output displacement is defined by x . Figure 3.1(b) shows block diagram for inverse Piezoactuator model which is defined with input displacement x , transformation ratio T' and u is output voltage and remaining constant are same as forward model.

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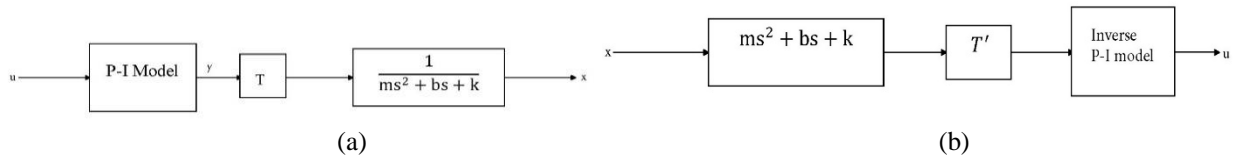


Figure 3.1: (a) Block diagram for Forward Piezoactuator model (b)Block diagram for Inverse Piezoactuator model

Parameter Estimation

The parameters required for verification of piezoelectric actuator for forward and inverse model were obtained through parameter estimation in MATLAB-Simulink software. In present work the developed piezoelectric actuator model is implemented in Flexural Amplified Piezoactuator FAP1000. The parameters like mass (m), damping constant (b), and stiffness (k) of FAP1000 are taken from Cedrat Technologies data sheet which is shown in Table 3.1

Table 3.1 Parameters of FAP1000 piezoactuator

Parameters	Values
m	0.019 kg
b	86.96 Ns/m
k	60000 N/m

Parameter estimation for Prandtl-Ishlinskii model, as a reference values the displacement characteristics of FAP1000 Piezoactuator can be taken. Also implemented the method of nonlinear least square for parameter estimation in MATLAB-Simulink software. The estimated values are then substituted back in to model to check for the final displacement required.

Parameter Estimation for Forward Piezoactuator Model

Through parameter estimation the unknown parameters like β , w_i and p can be obtained for forward Piezoactuator. The block diagram in Simulink file for forward Piezoactuator design is shown in Figure 3.2. the obtained estimation values for forward Piezoactuator model are given in Table 3.2

Table 3.2 Estimated parameters for Piezoactuator model

Parameters	Values
p	14.9650
T	1.3832
β	9.0210
τ	-0.02
ρ	1.0324

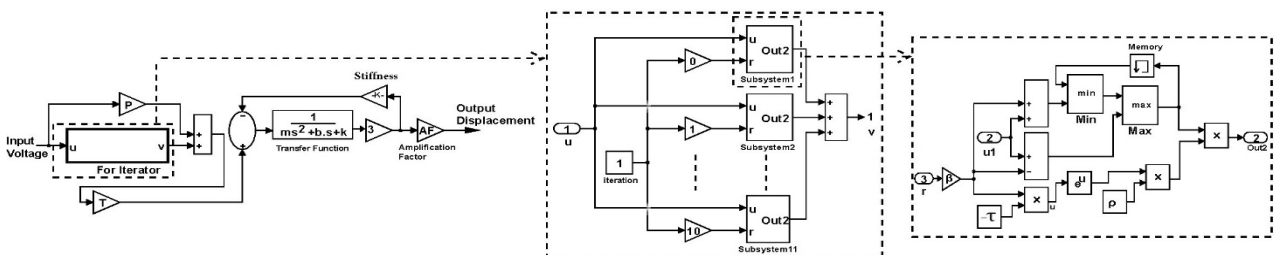


Figure 3.2 Simulink block diagram of forward Piezoactuator model

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To obtain the displacement in simulation the input sinusoidal voltage of 0-150V and 1Hz frequency is applied. Comparison is done between the simulated displacement and applied voltage as shown in Figure 3.3, from figure we can observe that output displacement is in synchronous with applied input voltage.

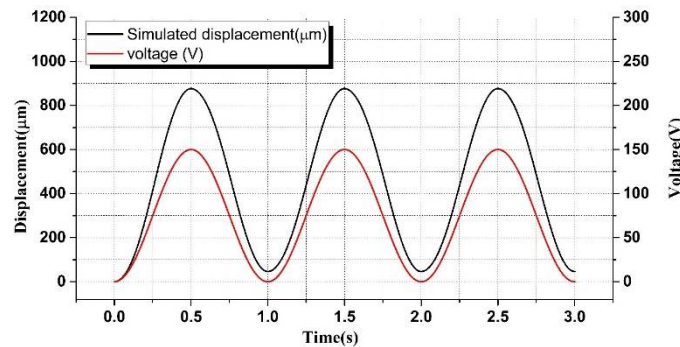


Figure 3.3 Plot of output displacement and input voltage with respect to time

From the graph when voltage starts from 0 V, displacement also starts from zero and reaches 875μm when the voltage reaches 150V, during the second half as the voltage comes back to 0 V, the displacement seen is 45.6μm not zero which is due to hysteresis obtained by Piezoactuator. So in order to reduce the hysteresis we need to apply negative voltage.

Parameter Estimation for Inverse Piezoactuator Model

Through parameter estimation the unknown parameters like β , w_i and p can be obtained for inverse Piezoactuator. The block diagram in Simulink file for inverse Piezoactuator design is shown in Figure 3.4. The obtained estimation values for inverse Piezoactuator model are given in Table 3.2

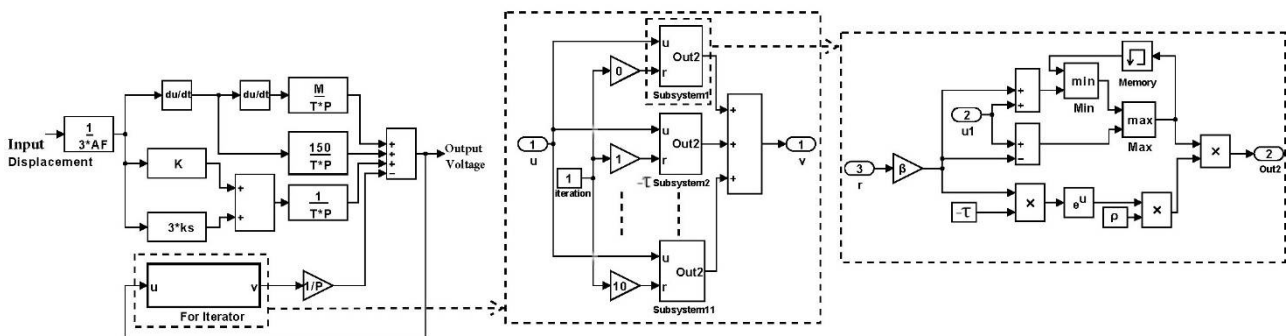


Figure 3.4 Simulink block diagram of inverse Piezoactuator model

To obtain the simulated voltage value in inverse Piezoactuator model the input given is the simulated displacement obtained from forward Piezoactuator model. We can observe 12.5% error at the peak and 4.5% error at the trough. Comparison is made between simulated voltage and input displacement as shown in Figure 3.5. From figure can also be observed that simulated voltage is in synchronous with applied input displacement.

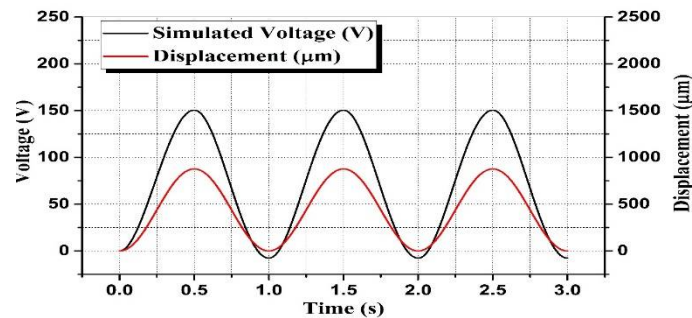


Figure 3.5 Plot of output voltage and input displacement with respect to time

IV. CONCLUSION

In this paper design of Piezoactuator based workpiece feeding system for Micromilling machine is carried out. The Piezoactuator used is FAP1000 that consist of six piezoelectric stack actuators each having a dimension of 10*10*20mm. Inorder to reduce the hysteresis effect in the Piezoactuator, Prandtl-Ishlinskii model is built, and also parameter estimation is done for both forward and inverse Prandtl-Ishlinskii model. Later which the simulation for FAP1000 is done using Prandtl-Ishlinskii model in MATLAB software, where it has maximum displacement of 875µm. later by simulation we can observe 12.5% error at the peak and 4.5% error at the trough.

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