

Design Considerations of Piezo Stepping Actuator

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ABSTRACT: Piezo stepping actuator is used to produce a displacement by step mechanism. This step mechanism is used in fine positioning of any object with great precision, low power consumption, less wear and tear, high load carrying capacity and good resolution. As the title suggests the required displacement is obtained in steps. For the displacement of an object in this paper, a piezo stepping actuator is designed. It consists of two sets of lock-release actuators and two sets of push-pull actuators which are used to achieve the required displacement. Suitable mathematical model has been developed using MATLAB-Simulink software for generating the stepping sequence. MATLAB Simulink is used to develop the model and simulations are performed to determine the displacement produced by the piezoelectric actuators with proper sequence of applied voltage. Maxwell's slip model is used for the hysteresis compensation and the different parameters are determined and the displacement corresponding to the applied voltage are obtained.

KEYWORDS: Piezo stepping actuator, Step mechanism, Maxwell's slip model.

I. INTRODUCTION

A piezo actuator converts electrical energy into mechanical energy and vice-versa. A piezoelectric actuator is one device that converts electrical energy into mechanical energy which here is observed in the means of displacement. Actuators are specifically designed which consists of stacked piezoelectric actuators to perform the required action. Chen Sheng Ting et al. [1] has developed a displacement mechanism system using linear stepping motors. In this paper, voltage controlled pulse width modulation (PWM) technique is used for controlling the stepping motor. Yuan-jin Yu et al. [2] developed a positioning system by producing a torque by tilting the shaft of the motor. He proposed a new approach of control by back stepping mechanism. This approach has provided a good stability in positioning of any object. Robert Konowrocki et al.[3] have worked on interaction of the belt transport system and driving stepping motor. The system consist of measuring techniques for obtaining the electrical and mechanical quantities. Electro-Mechanical model is derived for the analytical measurements. Shunming HUA et al. [7] developed a inchworm actuator for fine positioning of work piece. Here three sets of actuators are used to obtain a displacement. However the control mechanism is difficult in the proposed method. Various methods for positioning the object are developed but none of the methods use stepping motion using piezo stepping actuator. In this paper a new design for stepping mechanism using piezo electric actuator has been proposed.

II. PROPOSED PIEZO STEPPING ACTUATOR

Figure 1 shows the mechanical structure which is used to obtain the displacement. The structure consist of four lock-release actuators and four push-pull actuators incorporated with MLA 10*10*20 stacks. Each lock-release actuator and push-pull actuator consists two stacks and one stack respectively. The stepping bar positioned in the centre. The movement of the bar will be guided by the piezo stepping actuator. The actuators and the stepping bar are enclosed by the mechanical casing. When the voltage is applied to the piezostack, piezoelectric actuator produces displacement.

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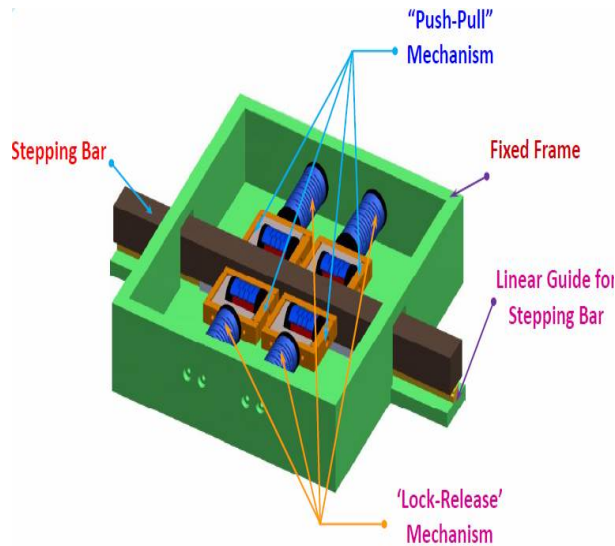


Figure 1. Structure of piezo stepping actuator

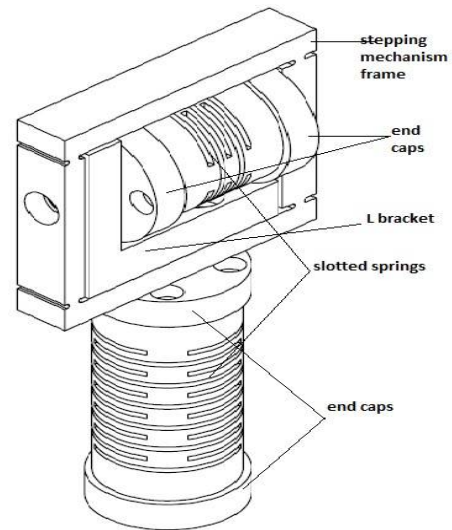


Figure 2. Assembly drawing for single leg of piezo stepping actuator

The displacement produced by the actuators aids in the movement of the stepping bar. The voltage is applied in the following sequence. First the voltage is applied to the lock-release actuator and once it is excited the voltage is applied to push-pull actuator. The push-pull actuator produce the displacement. At the same time the second lock-release is excited by applying the voltage and once the first set is released the second push-pull actuator is excited by giving the voltage and in turn this again produce a displacement. Figure 2 shows the assembly for a single leg of stepping actuator. It has two slotted springs, one for lock-unlock mechanism and the other to attain push-pull mechanism. Both ends of slotted spring is covered using end caps. Piezo electric stacks are accommodated in these slotted springs.

ELECTROMECHANICAL MODEL OF PIEZO STEPPING ACTUATOR

Electro mechanical modelling is used to model and simulate an electro mechanical system to study the voltage excitation sequence and to determine the displacement with respect to the applied voltage.

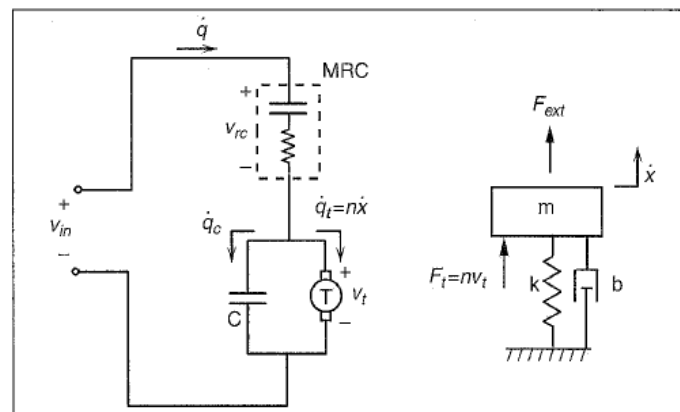


Figure 3. Electrical and mechanical equivalent of single stack

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Figure 3 shows the electrical and mechanical equivalent of the single actuator. This gives the necessary quantities that are used to convert mechanical to electrical equivalent and vice versa. In this paper the equations are used to convert mechanical equivalent to electrical equivalent.

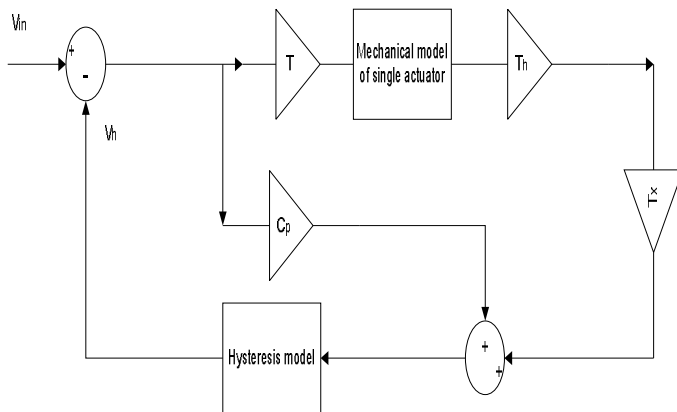


Figure 4. Electromechanical model for single actuator

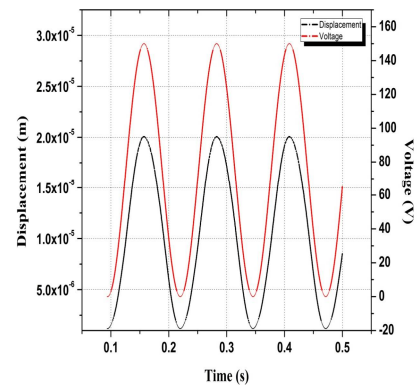


Figure 5. Simulation results for MLA 10*10*20

Figure 4 shows the electromechanical model for single piezo actuator. This model accommodates Maxwell's slip model to reduce the hysteresis effect. When the voltage is applied to the piezo electric actuator the displacement is observed. Fig 5 shows when the sinusoidal voltage is given to the single stack of MLA 10*10*20 the displacement of 20µm is attained. Simulation is carried out for a 50Hz frequency.

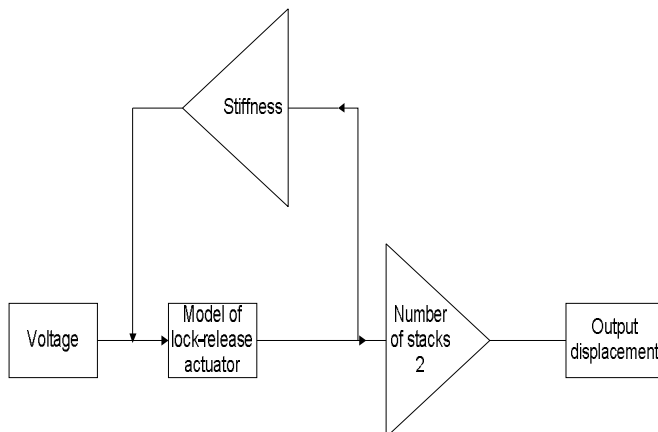


Figure 6. Block diagram for lock-release actuator

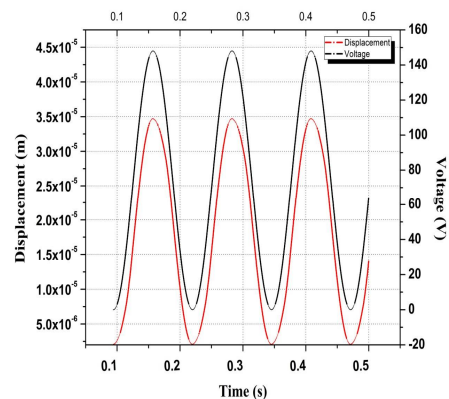


Figure 7. Simulation results for lock-release actuator

Figure 6 shows the block diagram of lock-release actuator. The lock-release actuator consists of two MLA 10*10*20 stacks. The stiffness of lock-release actuator is found to be 1.617N/µm. The input sinusoidal voltage with a frequency of 50Hz is applied to the lock-release actuator. Figure 7 shows when voltage rises from 0-150V there is a displacement of 34.5µm for two MLA 10*10*20 stacks considering the stiffness of the actuator.

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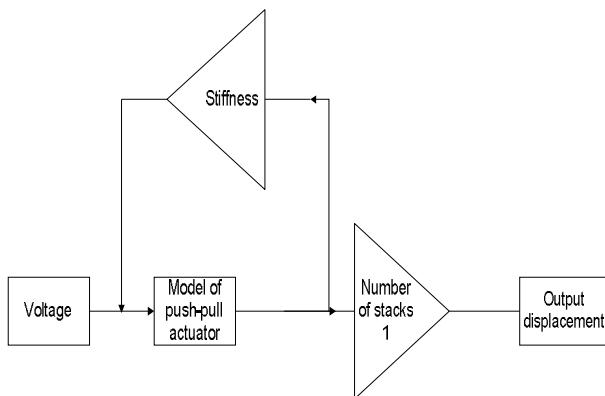


Figure 8. Block diagram for push-pull actuator

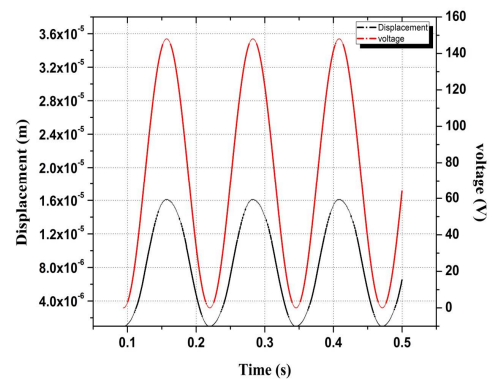


Figure9. Simulation results for push-pull actuator

Figure 8 shows the block diagram of push-pull actuator. The push-pull actuator consist of one MLA 10*10*20 stack. The stiffness of push-pull actuator is 1.735 N/ μ m and that of the frame used is 3.227 N/ μ m. Figure 9 shows that when voltage rises from 0-150V there is a displacement of 16 μ m for single MLA 10*10*20 stack. The stiffness of the push-pull actuator and the stiffness of the frame is included.

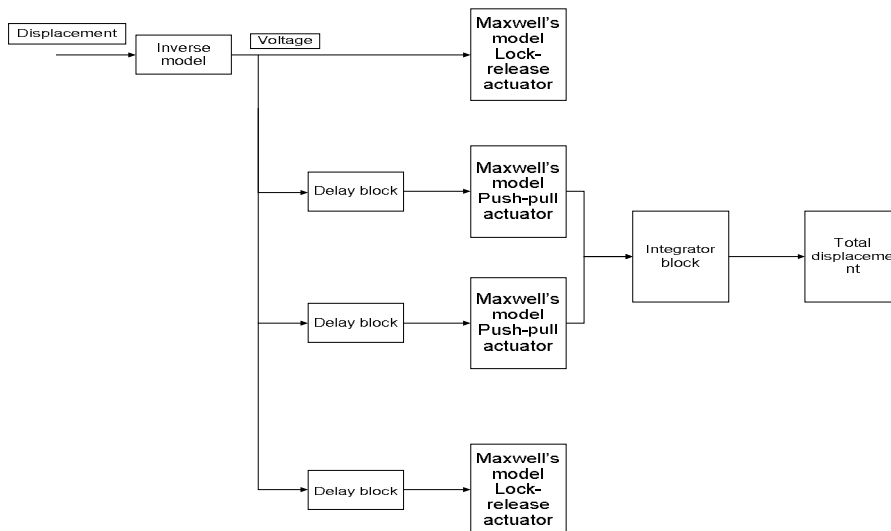


Figure10. Block diagram of the proposed piezo stepping actuator

Figure 10 shows the block diagram of the proposed piezo stepping actuator to attain the total step displacement. Maxwell's slip model is used to compensate the hysteresis effect induced. In this paper, inverse Bouc-Wen model is used to estimate the required voltage for the given displacement. This voltage is applied to the Maxwell's slip model. Maxwell's slip model receive input which is delayed by the time delay block as per the voltage excitation sequence studied. For time delayed voltage, Maxwell's slip model gives output displacement. The output from push-pull actuators are used to determine the total output by step mechanism.

III. RESULTS AND DISCUSSION

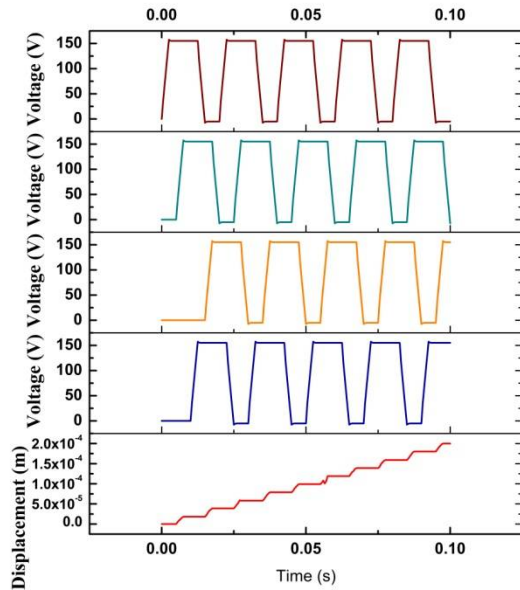


Figure11. Results for voltage synchronisation and displacement

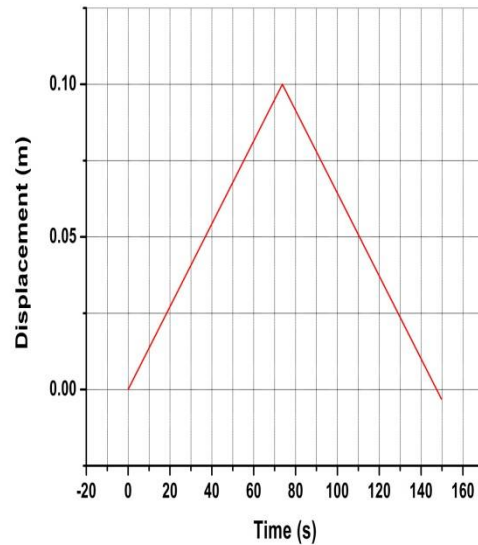


Figure12. Plot of step displacement vs time

Figure 11 shows the voltage excitation sequence for each of the actuators as per the time sequence and the corresponding step displacement obtained. Figure 12 shows the total displacement obtained. For a single stack the mathematical model is built and the displacement of 20µm is obtained when the voltage of 0-150V is applied. The displacement reduces when the stiffness of the actuator is considered. The result shows that for the given stiffness of 1.617N/µm the lock-release actuator gives a displacement 34.5 µm when two stacks of MLA 10*10*20 are used. Similarly for that of push-pull actuator considering the stiffness to be 1.735 N/µm and the stiffness of frame to be 3.227 N/µm the displacement obtained is 16 µm for a single stack. This shows that there is reduction in the displacement when the mechanical stiffness of the material is considered in the simulation. From the simulation, When voltage rises from 0-150V there is a step displacement of 20µm. One full cycle of lock-push-lock-release-push takes place in .03s and total movement of 40µm is realised in one cycle. The displacement of 100mm is obtained in 73 seconds when all the four pairs of lock-release and push-pull actuators are considered.

IV. CONCLUSION

Electro-mechanical system is used to determine the voltage excitation sequence and to determine the displacement with the voltage applied to the model. Voltage to both lock-release actuator and push-pull actuator are applied in the sequence and the corresponding displacement is obtained. From the graph it is clear about the timing at which the voltage is to be applied to the actuators. The voltage generated by the inverse model is fed to the Maxwell's slip model and this produces the displacement. Also simulation is done for determining the total displacement taking place. The displacement of the actuator is obtained by applying voltage to the piezoelectric stack. The total displacement observed in this case is 100mm and this displacement is obtained in seventy three seconds.

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