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Resonant drive of a linear motor based on piezoelectric actuator

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Abstract. Based on the large amplitude of piezoelectric actuators at low frequency, a new type of piezoelectric linear motor based was presented. Piezoelectric actuators combine a high position resolution with a high passive stiffness and a highly dynamic performance, making them appropriate for the application in the proposed positioning system. Through analyzing the working principle of the presented motor, a drive circuit was presented for the motor. The experimental results show that the presented circuit could drive the linear motor over the frequency range of 1.5KHz to 2.5KHz with low power loss.

Key words. Piezoelectric linear motor; resonant circuit; offset voltage; high efficient.

1. INTRODUCTION

Piezoelectric actuators offer high stiffness, low drive voltage, high power to volume ratio and fast response times [1],[2], which makes them well suited for such fields as miniature, specialized and precision. Especially in recent years it's being widely used in piezoelectric motors and ultrasonic motors [3]-[5].

In reference [6] a new type of linear motor was introduced based on piezoelectric actuators. The piezoelectric actuator is composed of multilayer piezoelectric ceramics in series in the mechanical structure, so at low input voltage it can output a large force and displacement. But from the view of electrical characteristics the multilayer piezoelectric ceramics are parallel and this lead to a larger capacitance, which bring the high power requirements during driving. Therefore, high efficiency power amplifiers for piezoelectric actuators determine the performance of piezoelectric actuators to some extent [7],[8].

Currently two drive method for piezoelectric actuator used: (1) Linear analog voltage driver [9],[10], driving the piezoelectric actuator with a linear ampli?er, which

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is generally used for low frequencies, about several hundred hertz or less. Because driving frequency increases will make the system power consumption increases due to the large capacitance characteristics of the actuator, and the driver will generate a lot of heat. (2) Switching driver [11],[12], driving the piezoelectric actuator with a pulse width modulation ampli?er, which has a higher efficiency, but needs a complex control logic. As the driving frequency increases a higher speed control system is needed, and the drive waveform will become worse. An optimum choice of architecture depends on the requirements in the application. Main parameters are complexity, ef?ciency and signal quality.

2. STRUCTURE OF THE MOTOR

The structure of a new type of linear motor based on two piezoelectric actuators is shown as Fig.1. The motor consists of two actuators, actuator A and actuator B, which are located orthogonally. Actuator A generates the vertical vibration, and actuator B generates the horizontal vibration. The piezoelectric actuator elongates 2.2μm under the input voltage of 100V without load.

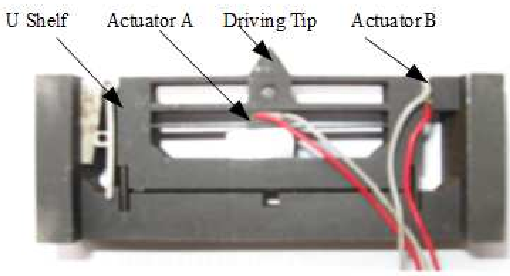

Fig. 1. Structure of the motor stator

The driving principle of the linear motor is shown in Fig.2. The driving tip which contacts the slider produces a vibrating motion corresponding to the displacement generated by two piezoelectric actuators. This motion generates a friction force difference between the upper and lower surfaces of the slider, which causes its movement. Sinusoidal waves were used to make ellipsoidal loci which would generate friction differences on the slider. The ellipsoidal locus is a representative motion that generates a driving friction force in ultrasonic linear or rotary motors using piezoelectric elements.

When piezoelectric actuator A and B are driven by sinusoidal electrical input signals, the respective elongated displacement ?L_a in the x-axis, and ?L_b in the y-axisare as follows:

$$L_a(t) = D\sin(2\pi ft) + D_0 \tag{1}$$

$$L_b(t) = D\sin(2\pi ft + \theta) + D_0 \tag{2}$$

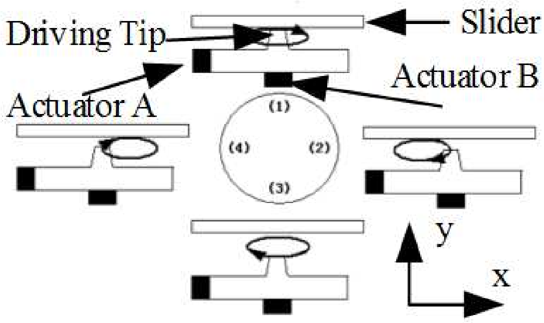

Fig. 2. Driving Principle

where D is the amplitude of the elongated displacement of the actuators A and B. D0 is the offset displacement resulting from the applied offset voltage; f is the frequency, and θ is the phase angle difference applied to actuators A and B. In such conditions, the displacements of the driving tip in the x-axes and y-axes are vibrational loci.

As another possible driving signal, trapezoidal wave input can be applied to the piezoelectric actuators causing a rectangular locus. The horizontal displacement of the vibration locus generates a linear motion of the slider, while vertical displacement changes the vertical force that determines the friction force of the slider. As a result of the factors mentioned above, direction of movement, displacement, and velocity of the slider depend on the vibration locus.

3. DRIVING CIRCUIT DESIGN

Drive circuit for piezoelectric actuator is a key part, in our design a half bridge is presented to drive the actuators, as shown in Fig.3. An inductor in series with the actuator was used to produce a L-C-R resonant circuit.

The driving voltage for actuator is realized by turning on the switch S1 and switch S2 alternatively around the resonant frequency. During one half of the cycle S1 is turned on to provide energy from the voltage source Vs, then S2 is turned on and S1 is turned off for the second resonant half cycle, and the energy is released. The series L-C-R circuit current for a step input voltage V0 with initial actuator voltage V0 and series inductor current i0 is given by

$$i(\omega t) = \frac{V_s - V_0}{\omega L} e^{-\alpha t} \sin \omega t + i_0 e^{-\alpha t} \frac{\omega_0}{\omega} \cos(\omega t + \phi) \tag{3}$$

where$\omega^2 = \omega_0^2(1-\xi^2) = \omega_0^2 - \alpha^2\omega_0 = \frac{1}{\sqrt{LC}}\alpha = \frac{R}{2L}??\xi = \frac{R}{2\omega_0 L}\tan(\phi) = \frac{\alpha}{\omega}$, ξ is the damping factor. The actuator voltage is important because it specifies the energy retained in the L-C-R circuit at the end of each half cycle. The voltage over the

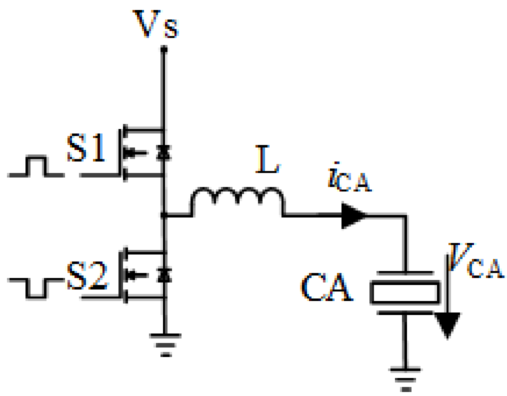

Fig. 3. Drive circuit

actuator is

$$V_{CA}(\omega t) = V_s - V_s \frac{\omega_0}{\omega} e^{-\alpha t} COS(\omega t - \phi) \tag{4}$$

The supply voltage for the piezoelectric actuator should between -20V to +100V. The driving voltage of the piezoelectric actuator is asymmetry. The absolute value of the negative voltage is relatively small. The negative voltage generated through resonant direct drive will exceeds actuator's allowable value. We present a bias circuit to solve this problem. The driving principle with bias circuit is shown in Fig.4(a), so the input voltage for an inductor and the actuator is as Fig.4(b). The negative voltage on the actuator can be eliminated or reduced through adjusting the V_{offset} which is generated by a dc-dc circuit.

4. RESULTS

To evaluate the presented circuit, experiments were carried out on the linear motor. The driving voltage is 0V-100V, electrical capacitance is 0.25μF, the series inductor is 21mH, and operating frequency is 1.5~2.5kHz. Fig.5 is the driving voltage over the actuator with driving frequency is 1.5kHz. Fig.6 is the driving voltage with the driving frequency is 2.1kHz. The experiments show that the presented circuit can realize the driving voltage with different frequency, which is needed for the linear motor. Under the frequency of 2kHz and voltage amplitude of 100V the consumed electric power is 7.1W with the presented resonant circuit, while the linear drive mode is 11.5W. The consumed power of presented circuit is only 61.7 percent of the linear mode.

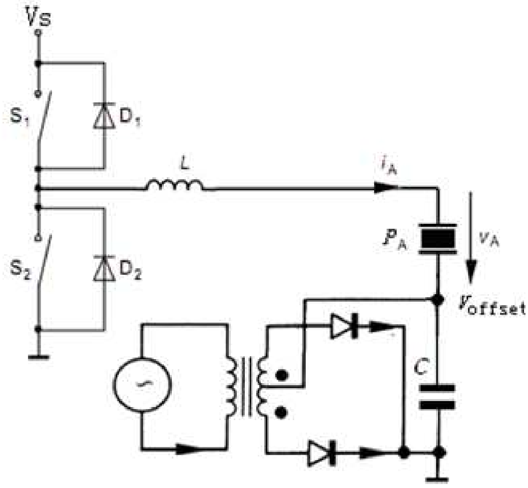

Fig. 4. Offset circuit and driving signal

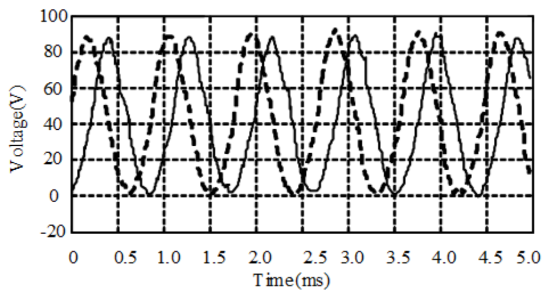

Fig. 5. Driving frequency is 1.5kHz

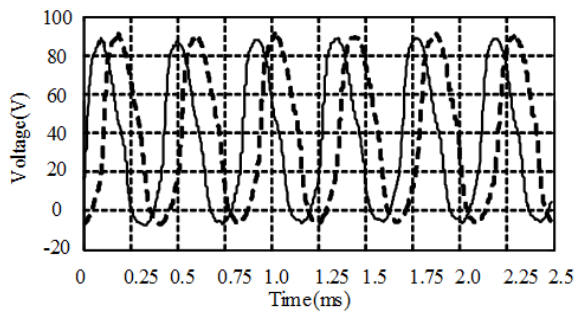

Fig. 6. Driving frequency is 2.1kHz

5. CONCLUSIONS

New type linear motor based on piezoelectric actuator is a large capacitive load, to achieve efficient drive a resonant drive circuit has been presented in this paper. Compared with the linear amplifier the presented circuit can drive the motor with less electric power. The present circuit has small electronic components, which is suitable for miniaturization and integration.

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