Journal of ELECTRICAL ENGINEERING, VOL. 56, NO. 11-12, 2005, 327–330

COMMUNICATIONS

MICRO–DRIVER FOR ULTRASONIC MOTOR BASED ON COMPLEX PROGRAMMABLE LOGICAL DEVICE

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First, the relation between the output voltage and energy efficiency of an ultrasonic motor driver and the duty cycle of the driving pulse is analyzed. The rationality of 37 % duty cycle is proved in this paper. Then a mini-driver based on CPLD for ultrasonic motor is designed and manufactured. The driver is applied to a TRUM-45 type traveling-wave ultrasonic motor developed by our Research Center. Experimental results show that this scheme is valid and feasible. Compared with the original driver composed of separate logical circuits, this mini-driver can be reduced by 66 % in volume and 40 % in element numbers, which fulfils the demand of practicability for general engineering.

K e y w o r d s: ultrasonic motor, driver, CPLD

1 INTRODUCTION

As a novel motor, UltraSonic Motors (USM) exhibit advantages over conventional electromagnetic motors. For example, USM can produce a relative high torque at a low speed with a high efficiency, and the torque produced per unit weight is high. These features are useful for utilizing as gearless actuators or direct servo drives. The motors have recently been applied as direct drive actuators for articulated robots, actuators for control valves and a positioning table of machine tools because they require quick response and precise position control of actuators. Some experts even predict that USMs will replace micro electro-magnetic motors in certain special areas in the future.

But in order to drive the USM, a special driver is required, which has been an obstacle for replacement of traditional motors by USMs. If the driver has a big volume, promotion of USM would be more difficult. Therefore, to meet the basic requirements, the volume of the driver must be reduced to the greatest extent so as to exploit the particular advantages of USMs in more areas.

The current used scheme of USM driver is shown as Fig. 1. The signal-generating circuit is composed of discrete components, which leads to the big volume of the driver. In this paper, a signal-generating circuit is constructed, which reduces the driver's volume greatly, fulfils the demand of practicability for general engineering.

The function of the signal-generation circuit is to produce 4 signals $q0 \sim q3$ with 90° phase difference. These signals are used to drive the 4 MOSFETs to get a square wave with high voltage. Two inductances are in series with the transformers as filters to get high voltage sinusoidal signals for the driving of USM, as shown in Fig. 2.

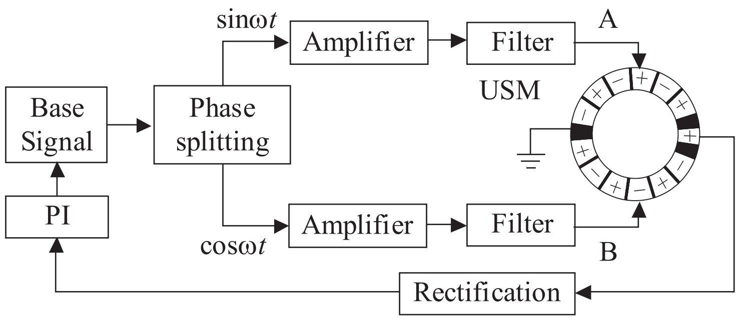

Fig. 1. The scheme of USM's driver.

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ISSN 1335-3632

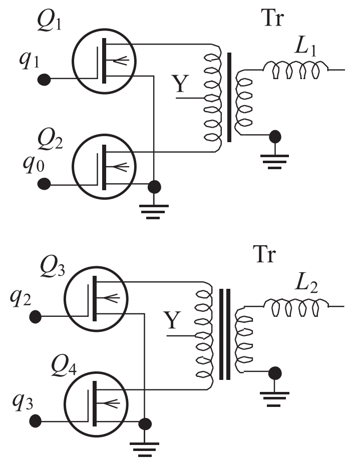

Fig. 2. The amplifier circuits of USM driver.

2 SYSTEM DESIGN

The duty ratio of the driving signal produced by the signal-generation circuit is mostly selected as 25 % and 50 % currently. The logic circuits are simply to implement for both situations. Since the proportion of the fundamental wave is little for the duty cycle of 25 %, the driving efficiency is relatively low. For the case of a 50 % duty cycle, however, although the proportion of the fundamental wave is relatively high, there is an incipient fault of direct current through the MOSFETs. To solve this problem, an extra dead-zone circuit must be added, which will increase the driver's volume undoubtedly. If we can assemble the circuit mentioned above into one component, the driver's volume is surely to be reduced largely.

At first, we must choose a suitable duty cycle. In fact, only in certain duty cycle that the energy efficiency, that is the effective energy in the output voltage to drive the USM, can reach its maximum.

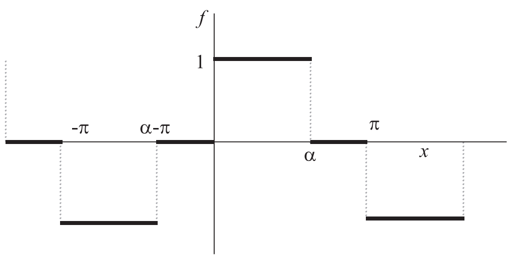

Fig. 3. The waveform of the transformer.

The waveform of the transformer is shown as Fig. 3, and it can be expressed as:

$$f(x)=\begin{cases}1 & -\pi\le x<\alpha-\pi\\ 0 & \alpha-\pi\le x<0\\ 1 & 0\le x<\alpha\\ 0 & \alpha\le x\le\pi\end{cases} \tag{1}$$

Using Fourier decomposition, this function can be expressed as:

$$f(x)=a_0+\sum_{k=1}^{\infty}(a_k\cos kx+b_k\sin kx)$$

$$=a_0+\sum_{k=1}^{\infty}c_k\sin(kx+\beta) \tag{2}$$

where:

$$a_0=0$$

$$a_k=[\sin k\alpha-\sin k(\alpha-\pi)]/k\pi$$

$$b_k=[1+\cos k(\alpha-\pi)-\cos k\pi-\cos k\alpha]/k\pi$$

$$c_k=\sqrt{a_k^2+b_k^2},\quad \beta=\operatorname{arctg}\frac{a_k}{b_k}$$

The duty ratio of the driving signal is $D=\frac{\alpha}{2\pi}$. Figure 4 shows the relations of the amplitudes of harmonic waves with the duty ratio. It can be seen from this figure that the amplitude of fundamental wave increases with D approximately linearly. Although bigger amplitude is better for the driving of USM, the energy efficiency must be considered yet. The waveform of the transformer is square wave, moreover the USM need sine waveform to work, that is, all the harmonic energy besides the fundamental wave are consumed by heat. Therefore, in order to choose a suitable duty ratio to get highest energy efficiency, we must analyze the relationship between the energy efficiency and driving duty ratio.

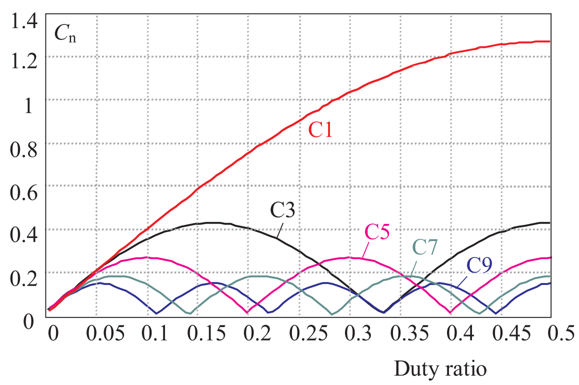

Fig. 4. The relationship between the amplitude of harmonic and duty ratio.

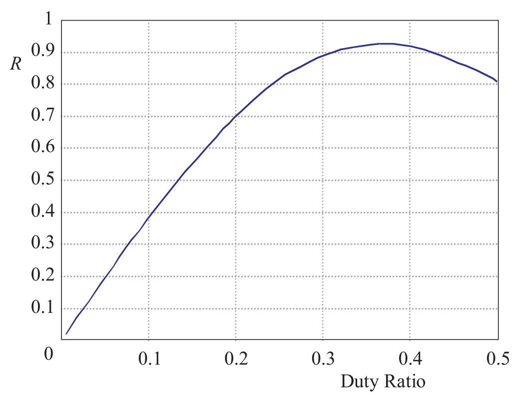

Fig. 5. Relationship between energy efficiency and duty ratio.

We know that the fundamental energy W1 within one period is:

$$W_1 = \int_{-\pi}^{\pi} f_1^2(x)\mathrm{d}x = (a_1^2 + b_1^2)\pi$$

And the square wave energy from the transformer W is:

$$W = 2\alpha$$

Therefore, the energy efficiency R can be defined as:

$$R = \frac{W_1}{W}$$

Figure 5 is the relationship between R and D. This figure shows that the maximum of R appears when D is about 0.37. Therefore, it is better to set the duty ratio D to 0.37 in all frequencies to achieve the highest energy efficiency. If we use a discrete logic device to realize this purpose, the driver's volume would be much bigger. However, CPLD can fill the command easily.

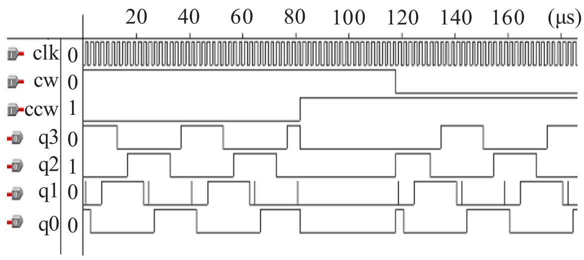

Fig. 6. Simulation of CPLD.

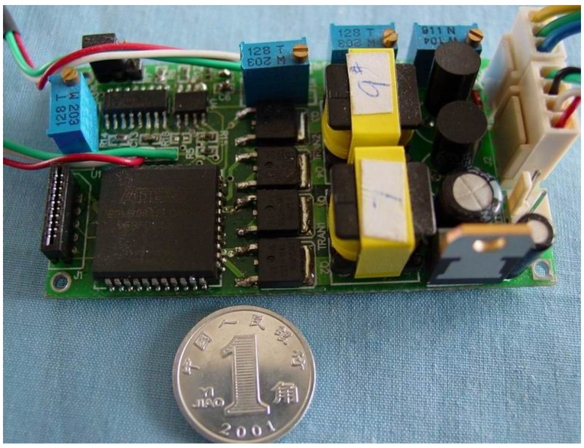

Fig. 7. The picture of the new USM driver.

CPLD has the features of large capacity, easy design and maintenance [6]. Figure 6 is the simulation result of the proposed scheme, where, clk is the clock signal with adjustable frequency, cw and ccw are the command signal for CW,CCW and STOP, $q0 \sim q3$ are the output signals for the driving of MOSFETS with duty ratio 0.37. Although the signal $q1$ has some 5 ns width burrs in the simulation result, they will be filtered by the pin-capacitance, and it has no affect to the drive of MOSFET.

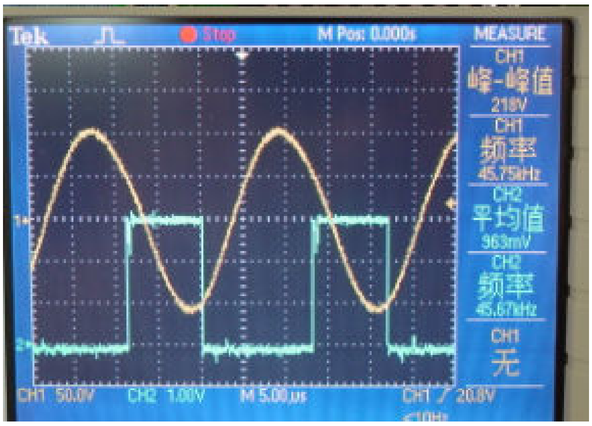

Fig. 8. The waveforms of MOSFET and output voltage.

3 EXPERIMENTAL RESULTS

The driving system is composed of VCO, CPLD (EPM7064S by ALTERA Corp.), MOSFETS, transformers and frequency tracking circuit, as shown in Fig. 7. We use this driver to run a TRUM-45 USM manufactured by our research center, where the driving frequency is 45.75 kHz, the input voltage is 12 V, the input current is 0.4 A, the output voltage is 218 V_{p-p} and the motor speed is 125 rpm. The actual waveforms of MOSFET and output voltage are shown in Fig. 7. We can see from this figure that the driving signal of MOSFET has no burr and the duty ratio is 0.37. The motor works well, experimental results validate the proposed scheme.

Table 1 is the comparison of the proposed driver with prototype driver with the same functions. The new driver based on CPLD reduces by 66 % in volume and 40 % in component numbers.

Table 1. Comparison of the proposed driver and prototype driver.

	Volume (mm^2)	Components
Prototype driver	105 × 75	91
Proposed driver	71 × 38	51

The speed and temperature curves under open and closed loop are shown in Fig. 9. The fluctuation of speed under closed loop is limited within 5 rpm; the driving system has perfect frequency tracking function.

4 CONCLUSION

A new USM driver based on CPLD is proposed in this paper. The proposed scheme has the features of simple construction, high energy-efficiency and easy maintenance. Compared with prototype driver, the new driver decreases in volume and component number greatly, whereas the performance keeps the same, which fulfils the demand of practicability for general engineering.

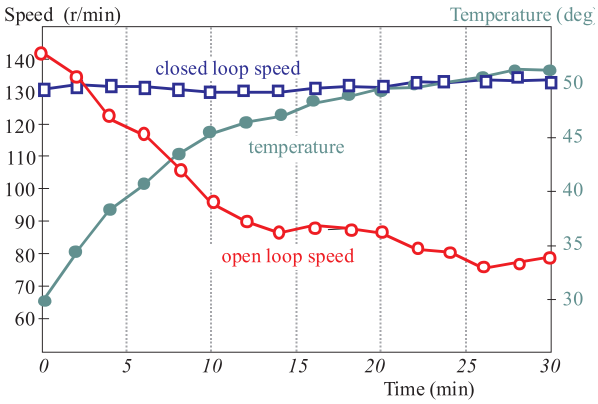

Fig. 9. Curves of motor speeds and temperature.

Acknowledgement

This work was supported by the Natural Science Foundation of China (50235010).

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Received 13 April 2005

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