Research on Design and Simulation of Drive Power Supply Based on Linear Motor

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Abstract. In many fields, such as transportation, logistics, aerospace industry, industrial automation, etc., linear motion is required. The traditional approach is to use a rotating motor, after a series of conversion mechanisms, and then push the load to make a linear motion. However, this method not only has shortcomings of low efficiency, low precision, high cost, slow response, but also causes a lot of energy loss during the motion conversion process. The emergence of linear motors has made these problems well solved. The driving power supply can provide a stable working voltage for the linear motor and keep the working state of the motor, so it is the core device of the linear motor.

1. Introduction

At present, conventional rotary motors are often used in industrial production or in applications where motors are required in daily life. If it needs to use a rotary motor to drive the object for linear motion, it is necessary to add intermediate devices such as ball screws and cams. Unlike rotary motors, linear motors can directly drive loads for linear motion without a motion conversion mechanism. This has led to an increase in the responsiveness and control accuracy of the equipment. In addition, the shortcomings of noise, friction, wear, vibration and motion lag caused by mechanical transmissions are also effectively contained.

Linear motors cannot be started directly from the power supply, it must be driven by a power source. Therefore, the position of the drive power in the motor is very important, and its quality will directly affect the overall performance of the motor. A qualified drive must have a wide speed range, high precision positioning, stable speed, fast response, strong overload capability and reliability. These requirements are indispensable.

2. Model design of driving power for linear motor

2.1. Drive power topology and chip selection

The topology model of the motor drive power circuit generally has four types, namely, buck circuit, boost circuit, forward circuit, and flyback circuit. Generally considering the safety issue, the primary and secondary of the circuit need to be isolated, so the forward and flyback circuits are preferred. Among them, the number of components required for the flyback circuit is the smallest. Therefore, the functions and properties of the flyback circuit are more suitable for the design of the linear motor drive power supply.

The UC3842 is a high-performance current-mode controller with a fixed frequency and a single-ended output that directly drives the power tube. The chip contains circuit blocks such as error amplifier, PWM comparator, PWM latch, oscillator, internal reference power supply and undervoltage lockout. Its peripheral circuit structure is relatively simple and full-featured. The UC3842 chip has a voltage regulation as low as 0.01%, an operating frequency of up to 500kHz, and a startup current of less than 1mA. In addition to this, the chip can be isolated from the grid by using a high frequency voltage device. Therefore, based on the comprehensive consideration of the circuit requirements, the UC3842 chip was finally selected as the driver chip.

2.2. Parameter calculation

Input voltage: $u_{\mathrm{i}} = 28V$（AC）;

Output voltage: $U_{\mathrm{o}} = 10V$, $U_1 = 20V$ (Chip startup voltage);

Output current: $I_{\mathrm{o}} = 0.3A$;

Operating frequency: $f_s = 60kHz$;

Maximum duty cycle: $D = 0.45$;

Effectiveness: $\eta = 80\%$;

Ripple coefficient: $\gamma < 2\%$

(1) Rectified voltage:

The input AC voltage is 28V. After full-bridge rectification, the DC voltage value is 1.414 times before rectification:

$$U_i = 2.8 \times 1.414 = 40V \tag{1}$$

(2) Transformer turns rati:

$$n_1 = \frac{U_i D}{U_h (1-D)} = \frac{40 \times 0.45}{(10+0.5)(1-0.45)} = 3.11 \approx 4 \tag{2}$$

$$n_2 = \frac{U_i D}{U_h (1-D)} = \frac{40 \times 0.45}{(20+0.5)(1-0.45)} = 1.6 \approx 2 \tag{3}$$

U_h is the sum of the output voltage value and the voltage drop of the rectifier diode of 0.5V.

(3) Primary current of the transformer:

$$I_i = \frac{P_i}{U_i} = \frac{3.75}{40} = 0.09A \tag{4}$$

(4) Number of turns of the primary and secondary sides of the transformer:

Common transformer core models and their parameters are shown in Table 1.

The core of the model E-E18 is selected, and the material is selected from ferrite. When the temperature is 100 ° C, the magnetic core material has a saturation magnetic induction of 0.3 T and a peak magnetic induction of 0.16 T.

Table 1. Part of the core model and parameters.

Core model	A_e / mm^2	V_e / mm^2
E-E14	14.5	300
E-E18	39.5	960
E-E22	78.5	2550

The number of turns of the original and secondary side of the transformer can be obtained as:

$$N_1 = \frac{U_i D}{A_e \Delta B f_s} = \frac{40\times 0.45}{39.5\times 10^{-6}\times 0.16\times 2\times 60\times 10^{3}} = 23.7 \approx 24 \tag{5}$$

$$N_2 = \frac{N_1}{n_1} = \frac{24}{4} = 6 \tag{6}$$

$$N_3 = \frac{N_1}{n_2} = \frac{24}{2} = 12 \tag{7}$$

3. Simulation and analysis of driving power model

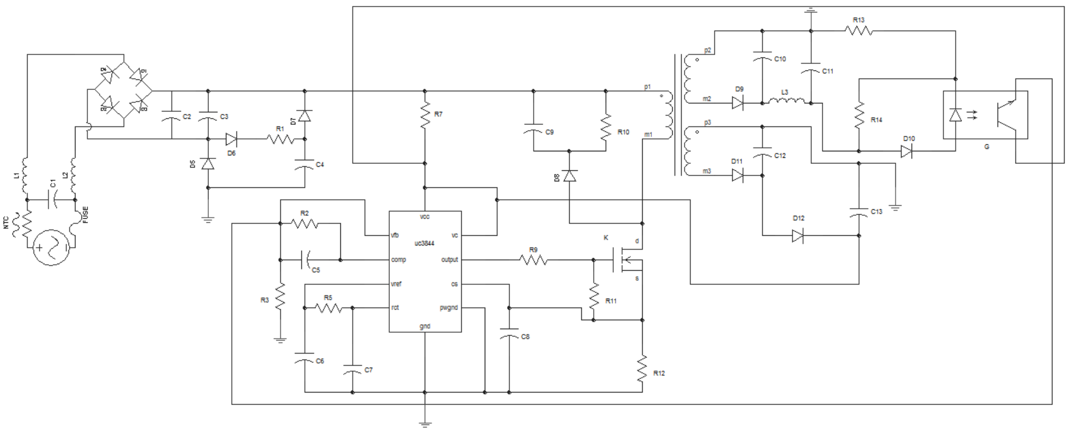

Figure 1. Linear motor drive power circuit.

Figure 1 shows the drive power circuit diagram of a linear motor. It mainly consists of surge protection circuit, EMI filter circuit, rectifier circuit, PFC circuit, UC3844 chip peripheral circuit, buffer circuit, transformer and optocoupler feedback circuit.

3.1. Chip external circuit

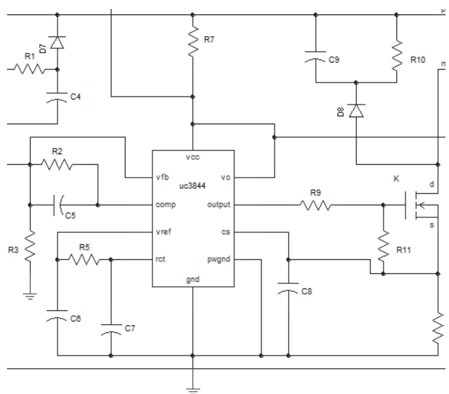

Figure 2. Chip external circuit.

Figure 2 shows the external circuit diagram of the chip. After receiving the feedback information from the output, the chip compares it with the ideal output, and then generates a pulse width modulated wave for controlling the on/off of the external switch to ensure a stable output. Even if the output voltage is deviated, the circuit can be corrected in time by adjusting the duty cycle of the PWM wave.

Figure 3 shows the waveform at the rct pin of the UC3844 chip, which is a uniform standard triangular sawtooth wave. From the graph, take two points at the same position in the adjacent cycle for analysis, and the operating frequency of the chip can be read as:

$$f=\frac{1}{T}=\frac{1}{X_2-X_1}=\frac{1}{164.24-147.81}=\frac{1}{16.43}\approx 60kHz \tag{8}$$

The switching frequency of the circuit is $f_s=60kHz$, it is the same as operating frequency of the chip, so the chip can work normally.

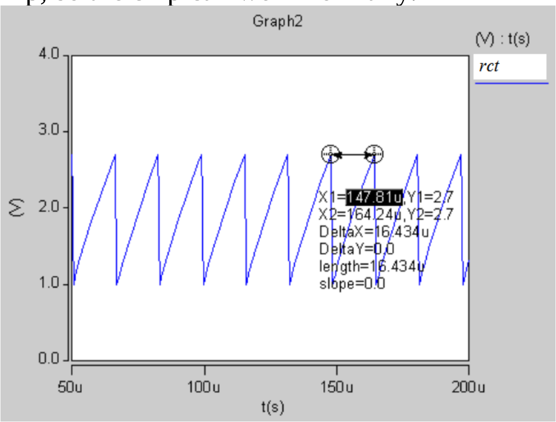

Figure 3. The waveform diagram of the rct pin of the chip.

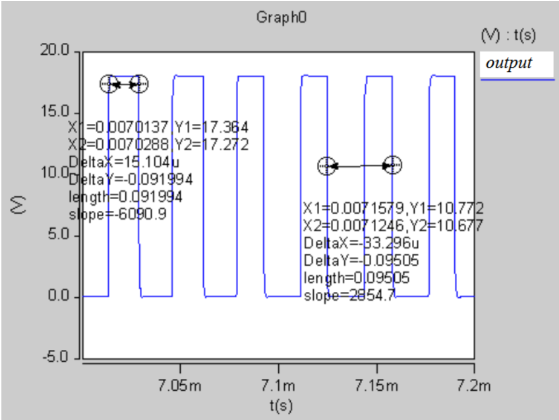

Figure 4. The waveform diagram of the output pin of the chip.

Figure 4 shows the waveform of the chip output, which is a PWM wave. When the voltage is 0, the switch connected to the port is disconnected, and when the voltage is positive, the switch is turned on. The ratio of the time when the voltage is not 0 in one cycle to the duration of one cycle is the duty cycle of the PWM wave. When the output voltage deviates, the feedback will provide a signal to the chip in time, and the output voltage will be adjusted by controlling the duty cycle of the PWM wave to return it to the normal value.

By analyzing the waveform, the duty cycle of the PWM wave can be calculated as:

$$D=\frac{t_{on}}{t_{on}+t_{off}}=\frac{X_2-X_1}{X_2'-X_1'}=\frac{0.0070288-0.0070137}{0.0071246-0.0071579}=0.453 \tag{9}$$

It is not much different from the $D=0.45$ shown in the indicator, so it meets the design requirements.

3.2. Output circuit

Figure 5 shows the circuit diagram of the output of the drive power supply. It is divided into two outputs, one for driving a linear motor, the designed output voltage is 10V, and the output current is 0.3A. The other output voltage is 20V, which is used to start the chip UC3844 and ensure its normal operation.

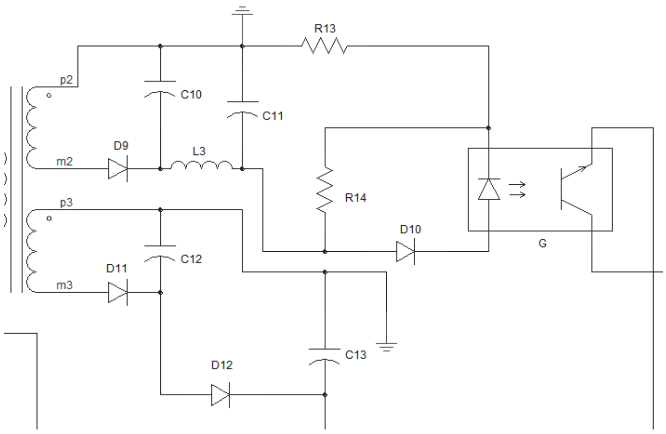

Figure 5. The output circuit of the drive power.

Figure 6 shows the waveform of the voltage of the circuit that outputs 10V. It can be seen from the figure that after the voltage rises for a period of time, it is stable at around 10V. After analyzing the two points with large difference in amplitude after voltage stabilization, the ripple coefficient of the voltage can be calculated as:

$$\gamma = \frac{Y_2 - Y_1}{U_o} \times 100\% = \frac{10.142 - 10.021}{10} \times 100\% = 1.21\% \tag{10}$$

From the calculation results, it can be concluded that the ripple coefficient of the 10V output voltage is $\gamma < 2\%$. So it meets the design requirements and has good voltage stability.

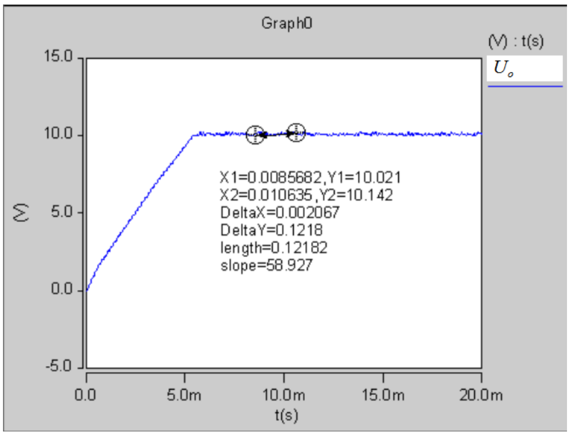

Figure 6. Voltage waveform of 10V output circuit.

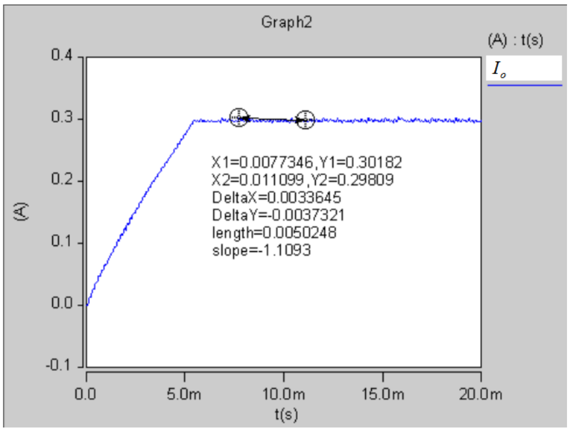

Figure 7. Current waveform of 10V output circuit.

Figure 7 shows the waveform of the current of the circuit that outputs 10V. It can be seen that the output current floats above and below 0.3A and is substantially equal to 0.3A. It conforms to the design. The output current ripple factor is:

$$\gamma = \frac{Y_2 - Y_1}{I_o} \times 100\% = \frac{0.30182 - 0.29809}{0.3} \times 100\% = 1.24\% \tag{11}$$

From the calculation results, it can be concluded that the ripple coefficient of the 10V output current is $\gamma < 2\%$. The current stability is good.

The operating voltage of UC3844 chip is between 10-34V, and its starting voltage is 16V. The voltage of 10-16V can't make the chip start working but can maintain its normal operation. When the chip is lower than 10V, the chip stops working, so the second output voltage is designed to be larger than 16V.

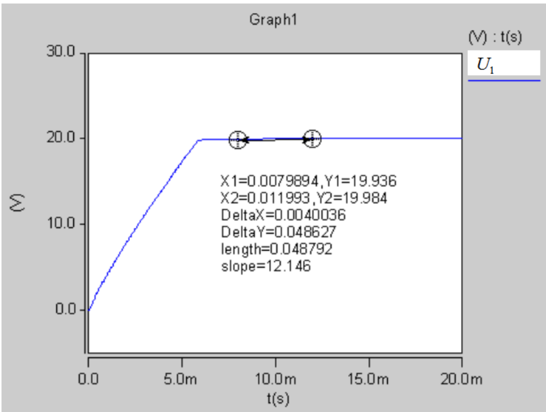

Figure 8. Voltage waveform of 20V output circuit.

Figure 8 shows the waveform of the voltage of the circuit that outputs 20V. After analyzing the two points with large difference in amplitude after voltage stabilization, the ripple coefficient of the voltage can be calculated as:

$$\gamma = \frac{Y_2 - Y_1}{I_o} \times 100\% = \frac{19.984 - 19.936}{20} \times 100\% = 0.24\% \qquad (12)$$

From the calculation results, it can be concluded that the ripple coefficient of the 10V output voltage is $\gamma < 2\%$. So it meets the design requirements and has good stability.

4. Conclusion

Linear motors do not require a motion conversion mechanism to provide direct linear motion to the load. It has some advangtages, such as a simple structure, low mechanical loss, easy control and adjustment, so it is more suitable for high-speed, high-precision linear motion than rotary motors, such as maglev trains and finishing platforms. The driving power supply is the core device of the linear motor, and its performance will directly affect whether the motor can operate normally. Based on the research status of related fields, this paper analyzes the driving power of linear motors by using Saber simulation software, and designs a driving power supply circuit that meets the performance requirements.

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