Research on stepper motor motion control based on MCU

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Abstract—**In this paper, speed control curve of stepper motor was studied for optimizing the motion flexibility and improving the motion precision of the stepper motor under the open-loop control environment based on Microcontroller Unit (MCU). Firstly, the acceleration and deceleration control curve of trapezoidal and New S model was designed respectively. Secondly, the relationship curve between control pulse and time was discretized and the stepper motor control scheme was determined. The MCU provided drive pulse for stepper motor to realize the motion control. The contrast of running accuracy of stepper motor controlled by the two kinds of acceleration and deceleration curves was carried out. The results show that the stepper motor controlled by the new S-shape acceleration and deceleration curve has great performs of small noise, high positioning accuracy and good flexibility.**

Keywords—MCU; Stepper Motor; motion control; Pulse Curve Discretization

I. INTRODUCTION

Stepper motor is a kind of electromechanical transmission transformed input digital pulse signal into angular displacement or linear displacement [1-2]. The main function of stepper motor is to drive the mobile device moving from one location to another. Generally, the moving process included three stages of acceleration speed, constant speed and deceleration speed [3-5]. At present, the rapid growth of digital electronics technologies directly influenced the development of the stepper motor [6]. With the progress of control technology, the stepper motor was used widely in numerous motion-control applications such as: robots, printers, process control systems and index table for automatic assembly machines [7-9].

However, stepper motor had some disadvantages of high over shoot and long settling time, especially driving high inertia loads [10, 11]. Therefore, the rational design of the stepper motor acceleration and deceleration curves and stable operation of the system was very important [12-15]. In this paper, we designed a new S-shaped acceleration and deceleration control curve with parabolic shape for optimizing the motion flexibility and improving the motion precision of stepper motor. Therefore, the instability of the stepper motor and the interference of the noise signal can be perfectly overcome.

II. THE DESIGN OF STEPPER MOTOR CONTROL CURVE

A. The design of trapezoid acceleration and deceleration curve

The trapezoidal acceleration and deceleration curves were shown in Fig. 1. The running process of the stepper motor included three stages: acceleration stage, uniform speed stage and deceleration stage. In the acceleration and the deceleration stage, the acceleration is the same magnitude and opposite direction, and in the uniform speed stage the acceleration is 0.

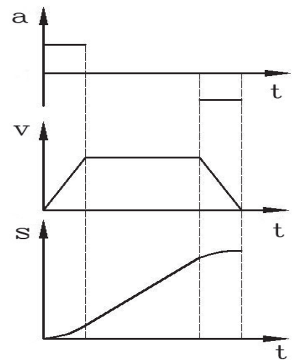


Fig. 1 The curve of step acceleration and deceleration

The acceleration equation based on the acceleration equation is as follows:

$$a(t)=\begin{cases} A & 0 \le t \le t_1 \\ 0 & t_1 < t \le t_2 \\ -A & t_2 < t \le t_3 \end{cases} \tag{1}$$

Where A is constant, t is the running time, 0-t_1、t_1-t_2、t_2-t_3 indicate the intervals of acceleration, uniform speed and deceleration ,respectively. A and t jointly determine the maximum speed and maximum operating distance of the stepper motor. As can be seen from Fig. 1, there is a mutation in acceleration at t_1 and t_2, it is indicated that the existence of a flexible shock.

According to the relation between acceleration and velocity, the velocity equation is as follows:

$$v(t)=\begin{cases} At & 0\le t\le t_1 \\ At_1 & t_1<t\le t_2 \\ At_1-A(t-t_2) & t_2<t\le t_3 \end{cases} \tag{2}$$

v(t) is the speed of the t moment, as we can see from the equation (1), the maximum running speed is related to the acceleration size A and acceleration time, and the speed changes continuously. There is no rigid impact in abstract.

According to the relation between velocity and displacement, the displacement equation can be obtained as follows:

$$s(t)=\begin{cases} \frac{1}{2}At^2 & 0\le t\le t_1 \\ \frac{1}{2}At_1^2+At_1t & t_1<t\le t_2 \\ \frac{1}{2}At_1^2+At_1t_2+At_1t-\frac{1}{2}At^2+At_2t & t_2<t\le t_3 \end{cases} \tag{3}$$

s(t) represents the running displacement at the moment of t, the distance between the 0-t_1 and t_2-t_3 segments varies is parabolic curve. The distance of the t_1-t_2 section varies is straight line.

For an actual operation requirement of the system, we can get the relation equation between acceleration and time, speed and time, distance and time by setting the running distance, running time and other conditions.

B. The design of a new S shape acceleration and deceleration

In order to avoid the rigidity impact, the speed and acceleration need to change continuously during the operation of the stepping motor. When the motor starts, stops and accelerates to the maximum speed, the acceleration tends to be 0. The acceleration and speed change of the control curve of the new S stepping motor are based on the steady running condition of the stepping motor (Fig. 2).

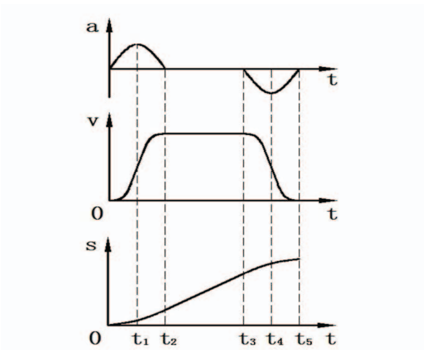


Fig. 2 The curve of new S shape acceleration and deceleration

As illustrated in Fig. 2, the acceleration equation can be expressed as:

$$a(t)=\begin{cases} -At^2+Bt & 0\le t\le t_1 \\ 0 & t_1<t\le t_2 \\ At^2-(2TA+B)t+T^2A+TB & t_2<t\le t_3 \end{cases} \tag{4}$$

Where A and B are constants, t is the running time, T is the time interval constant from t_1-t_4, t_1-t_2、t_2-t_3、t_3-t_5 , which indicate the interval of acceleration, uniform and deceleration, respectively. It can be seen from the formula that the acceleration changes are continuous, and there is no flexible shock in the theory of system motion.

The equation between velocity and time as：

$$v(t)=\begin{cases} -\frac{A}{3}t^3+\frac{B}{2}t^2 & 0\le t\le t_2 \\ -\frac{A}{3}t_2^3+\frac{B}{2}t_2^2 & t_2<t\le t_3 \\ \frac{A}{3}t^3-\frac{2TA+B}{2}t^2+(T^2A+TB)t+v(t_2)+c_1 & t_3<t\le t_5 \end{cases} \tag{5}$$

where $c_1=(T^2A+TB)t_2+\frac{2TA+B}{2}t_2^2-\frac{A}{3}t_2^3$.

v(t) is the speed of the stepper motor at the t moment. It is derived from the change of the acceleration to a parabolic curve. In theory, the system speed is continuously changing, and there is no rigid impact.

Then we can derive the equation between moving distance and time as:

$$s(t)=\begin{cases} -\frac{A}{12}t^4+\frac{B}{6}t^3 & 0\le t\le t_2 \\ -\frac{A}{12}t_2^4+\frac{B}{6}t_2^3+v_2(t-t_2) & t_2<t\le t_3 \\ \frac{A}{12}t^4-\frac{2TA+B}{6}t^3+\frac{T^2A+TB}{2}t^2+v(t_2)t+s(t_2)+c_1t+c_2 & t_3<t\le t_5 \end{cases} \tag{6}$$

s(t) is moving distance at the moment of t,
where

$$c_2=-\frac{A}{12}t_2^4+\frac{2TA+B}{6}t_2^3-\frac{T^2A+TB}{2}t_2^2-\left[v(t_2)+c_1\right]t_2$$

When the operating conditions such as running distance and running time are determined according to the actual needs, the constant A, B and the time constant T can be determined. The relationship between acceleration and running time, velocity and running time, running distance and running time is also determined.

III. CONTROL SCHEME DESIGN

The stepper motor is running under the discrete pulse signal. Firstly, deduce the relation curve between the driving pulse and the time and discretized the curve, determine the number of drive pulses corresponding to each discrete segment. Then the MCU provides the driving pulses for stepper motor according to the number of pulses in each discrete section; let the stepper motor move under the designed curve.

According to the operating principle, the formula is as follows:

$$v=2\pi N\times \mathrm{r} \tag{7}$$

Where v is straight line speed; N is spindle speed of stepper motor; r is axis radius of stepper motor.

Assumed that the revolution of the stepper motor required the number of pulses are f(n), and f(n) can be expressed as follows:

$$f(n)=\frac{360°}{\theta_e} \tag{8}$$

Where θ_e represents the step angle of the stepper motor.

Assume that the pulse required for the motor rotation is f(t), f(t) can be expressed as follows:

$$f(t) = f(n) \times N \tag{9}$$

Since the spindle speed of stepper motor N changes with the running time, so f(t) is also changes with the running time.

Through the equations (7), (8) and (9), the relationship between f(t) and velocity is expressed as follows:

$$f(t) = \frac{360°}{\theta_e} \times \frac{v}{2\pi r} \tag{10}$$

The relationship between the pulse and the time required by the stepper motor under the control of trapezoidal curve is as follows:

$$f(t) = \begin{cases} \dfrac{360°}{\theta_e \times 2\pi r} At & 0 \le t \le t_1 \\ \dfrac{360°}{\theta_e \times 2\pi r} At_1 & t_1 < t \le t_2 \\ \dfrac{360°}{\theta_e \times 2\pi r} (At_1 - At) & t_2 < t \le t_3 \end{cases} \tag{11}$$

The relationship between pulse and time required for stepping motor rotation under the control of new S shape curve is as follows:

$$f(t) = \begin{cases} \dfrac{360°}{\theta_e \times 2\pi r}(-\dfrac{A}{3}t^3 + \dfrac{B}{2}t^2) & 0 \le t \le t_2 \\ \dfrac{360°}{\theta_e \times 2\pi r}(-\dfrac{A}{3}t_2^{\,3} + \dfrac{B}{2}t_2^{\,2}) & t_2 < t \le t_3 \\ \dfrac{360°}{\theta_e \times 2\pi r}(\dfrac{A}{3}t^3 - \dfrac{2nA+B}{2}t^2 + (n^2A + nB)t + v(t_2) + c_1) & t_3 < t \le t_5 \end{cases} \tag{12}$$

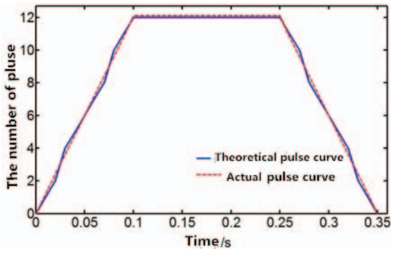
where $c_1 = \left(n^2 A + nB\right)t_2 + \frac{2nA+B}{2}t_2^{\,2} - \frac{A}{3}t_2^{\,3}$.

Through the above derivation process, we can get the relationship between the stepper motor driving pulse and the running time. The driving pulse curve is symmetrical, and the deceleration process is regarded as the inverse process of acceleration process.

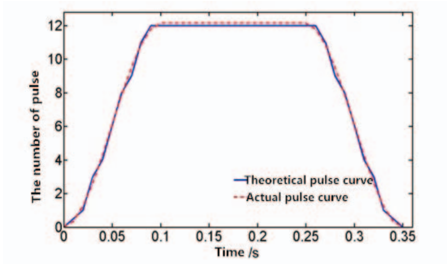
Then we can calculate the number of driving pulses in each discrete section. If the MCU provides driving pulses for the stepper motor according to the number of pulses, then the stepper motor can be operated by the designed curve. When writing the program, the acceleration or deceleration segment, the number of interrupts in the uniform, and the number of drive pulses in each interrupt need to set up as the most important part. When the program is running, the microcontroller sends a pulse each time, the number of pulses in the corresponding time interval is reduced by 1, until the pulse number is 0 in that time interval, and the operation of the next time period is completed until the completion of the movement process.

IV. EXPERIMENT ANALYSIS OF STEPPER MOTOR OPERATION

Contrast experiments that the stepper motor controlled by Trapezoid acceleration/deceleration curve and new S-shaped acceleration/deceleration curve were carried out. If the shift distance of the mobile platform is 25 mm; the acceleration and deceleration distances are 5 mm; the acceleration and deceleration time are 0.1 s; the step angle of stepping motor is 1.8 degrees; the stepper motor driver is set to eight frequency division; the acceleration and deceleration times are divided into 10 segments, each of which is 0.01s, the uniform running time of the step motor is calculated as 0.15s. Comparison between theoretical calculation pulse curve and design pulse curve is shown in the Fig. 3.



(a) Trapezoid pulse curve comparison



(b) New S shape pulse curves comparison

Fig. 3 Pulse curve contrast

According to the pulse curve the stepper motor is run with the trapezoidal pulse control curve and the flexible positioning pulse control curve. The stepper motor runs 20 times under each control curve. The two experiments results are shown in Fig. 4. We can see that the operating error of stepper motor under the control of trapezoidal curve is significantly higher than the stepper motor under the control of new S-shape curve. The operating vibration of stepper motor under the control of new S-shape curve is smaller and running more smoothly.

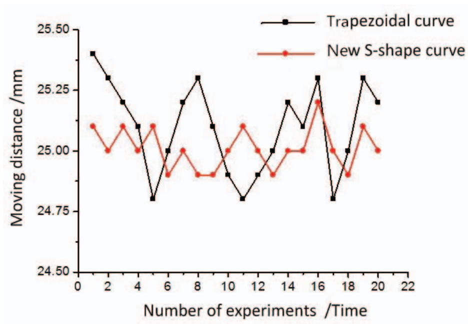


Fig. 4 The result of the experiment

V. CONCLUSION

In this paper, the trapezoidal curve and the new S-shaped curve are theoretically deduced, and the two control curves are verified in a step motor which is controlled by the MCU. The actual experiments show that the noise of the stepper motor under the control of the new S-shaped curve is lower and the positioning accuracy is higher than that of stepper motor under the control of the trapezoidal curve. So the new s-shaped curve is better to meet the actual application requirements.

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