Application of S-curve Acceleration and Deceleration in Winding of Bond-Wire

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Abstract: In order to solve the problem of abrupt acceleration in the starting process of microwire winding machine, an improved s-curve acceleration and deceleration system was applied to winding control system. Analysis of stepping motor's torque-frequency characteristic curve, the frequency according to the S-shaped acceleration and deceleration curve drive motor, angular acceleration and torque adapt. Firstly, the traditional seven-section s-curve acceleration and deceleration mathematical model is studied. On this basis, the Logistic function is used to improve the s-curve acceleration and deceleration calculation method for the winding machine control system. The experiment verifies that the STM32 controller is used in the winding experiment platform. The traditional method and the improved method are tested respectively. The results show that the improved s-shaped acceleration and deceleration control effect is more stable under the condition of 20r/s high-speed winding, This ensures the successful start of high speed winding operation of microwire.

Keywords: *Stepping Motor; Winder; S-Curve Acceleration; STM32；*

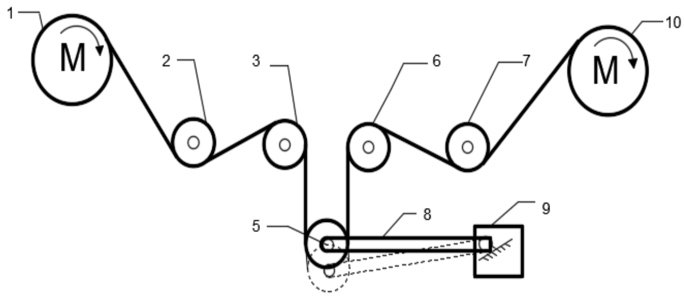
I. INTRODUCTION

Electronic packaging technology and adhesive materials have a direct impact on the quality and service life of electronic products, so it is necessary to study the packaging technology[1]. Bond wire is the core material used in packaging, the production of bond wire includes drawing, annealing and winding process, in the bond wire winding process winding machine equipment is essential. Because of the thin diameter of the bond line and the very small tension, it is necessary to start and stop the winding machine smoothly during acceleration and deceleration. In order to improve the control precision of stepper motor, a7-section asymmetric S-curve acceleration and deceleration control method was proposed, and eight possible acceleration curves were deduced and planned according to the characteristics of trajectory segments[2]. The traditional seven-segment acceleration and deceleration S-curve is optimized and applied to the stepping motor, which improves the smoothness of start and stop and eliminates the inflection point of the original acceleration curve[3]. According to the mathematical relationship of speed, acceleration and variable acceleration, the s-shaped curve number equation is derived for the hoist, and the programmable controller (PLC) is used for programming modeling and testing, which improves the comfort of the hoist[4].The s-curve algorithm is applied to the control of FDM3D printer stepper motor and the electric stair climbing wheelchair, which has been effectively improved and the flexibility has been improved through the experimental verification[5].

In this paper, the s-shape control algorithm of logistic function is improved to control the start and stop of the winding of bond line, and the s-curve algorithm is used to realize the process of acceleration gradually increasing and then decreasing to 0, so as to avoid the influence of impact force when the winding machine starts and stops, and improve the stability of the system. In the winding control test, the application of s-curve acceleration and deceleration control algorithm is realized by using STM32 as the control chip through the software system, which greatly improves the smoothness of start and stop of winding machine and the winding effect.

II. ANALYSIS OF WINDING MACHINE SYSTEM STARTING PROCESS

The winding machine system is mainly composed of two stepping motors, an Angle sensor tension control module, several traverse wheels and cycloid modules. The system diagram is shown in Fig. 1.



1. Steel wheel 2,3,6,7. guide roller 5. balance wheel 8. oscillating bar 9. Tension motor
10. take-up wheel

Fig. 1 Systematic sketch of winding machine

In Figure 1, when winding machine is started, the winding stepper motor rotates clockwise according to the set acceleration curve to drive the traverse wheel 5 to move upward, and the balance wheel 5 drives the balance bar to rotate clockwise. At this time, the tension motor provides constant tension for the system, and the Angle sensor detects the rotation Angle of the balance bar. When the rotation Angle of the balance bar is greater than the set value, the winding stepper motor is opened. The greater the tilt Angle value of the balance bar is, the greater the rotation speed of the stepping motor will be, so as to achieve equal linear speed winding. For this system, the winding stepper motor is active, and the paying stepper motor is driven. If the system is to be kept stable, the starting process of the winding stepper motor should be guaranteed to be stable, otherwise the Angle of the balance rod will be greater than the theoretical position value due to the inertia effect; Also ensure that the line stepping motor to be cushioned. The Angle signal of the balance bar detected by the Angle sensor will fluctuate after filtering, so the corresponding speed value of the Angle value should be softened in the process of starting, and the acceleration should not be too large.

The commonly used acceleration curves of stepping motor include linear curve, exponential curve, logarithmic curve and S-shaped curve[6]. The acceleration curve is shown in Fig. 2.

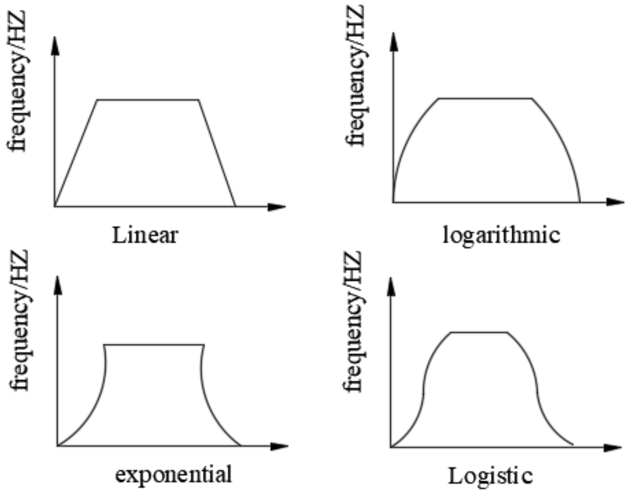


Fig. 2 Common acceleration curves

As shown in Fig. 2, the advantages of linear curve are that the acceleration is constant in the process of acceleration and deceleration, the algorithm is simple, and the response speed is fast. However, the abrupt acceleration at the end point of acceleration and the starting point of deceleration will cause strong vibration to the system. The advantage of exponential curve is that the acceleration changes gently in the acceleration process, and the motor can adapt smoothly to the acceleration and deceleration process. However, there are abrupt acceleration changes at the end of the motor acceleration and the starting point of deceleration. The advantage of logarithmic curve is that the acceleration changes gently, but the disadvantage is that the algorithm is complex. The acceleration of the S-shaped curve is very small at low frequency and high frequency, and the acceleration changes very gently, without causing impact to the system.

III. DESIGN AND IMPLEMENTATION OF S-SHAPE ALGORITHM

A) Torque-frequency characteristics of motor

Fig. 3 shows the torque-frequency characteristic curve of stepping motor.

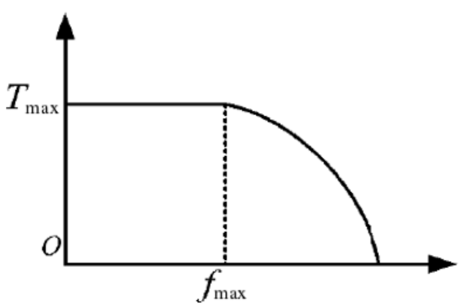
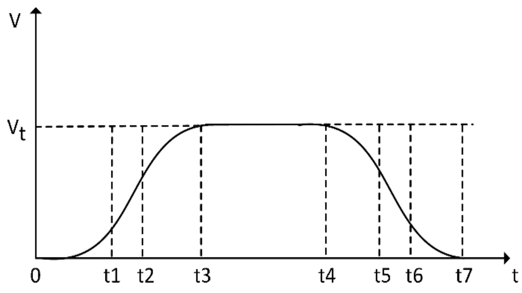


Fig. 3 Torque-frequency characteristic curve

When the operating frequency of the motor is greater than a certain defined value, the output torque of the stepping motor gradually decreases with the increase of frequency [7]. Combined with the torque-frequency characteristics of stepping motor and the dynamics model of stepping motor, it is deduced that when the frequency of stepping motor drives the motor according to the S-shaped acceleration and deceleration curve, the angular acceleration of stepping motor can adapt to the output torque of the motor.

B) Traditional seven - stage S - shaped acceleration and deceleration

The traditional seven-stage S-shaped curve is divided into seven mathematical models according to the different acceleration changes, corresponding to the seven stages of the winding process: acceleration, uniform acceleration, deceleration, uniform velocity section, acceleration and deceleration section, uniform deceleration section and deceleration section [8]. The traditional seven-segment s-shaped curve mathematical model is shown in Fig. 4.



(a) Seven section S curve

$$v(t)=\begin{cases} v_0+\frac{1}{2}at^2 & 0\le t\le t_1 \\ v_1+at & t_1\le t\le t_2 \\ v_2+at-\frac{1}{2}at^2 t_2\le t\le t_3 & \\ v_3\ t_3\le t\le t_4 & \\ v_4-\frac{1}{2}at^2 t_4\le t\le t_5 & \\ v_5-at & t_5\le t\le t_6 \\ v_6-at+\frac{1}{2}at^2 t_6\le t\le t_7 & \end{cases}$$

(b) A seven-paragraph mathematical formula

Fig. 4 Seven - stage S-curve acceleration and deceleration

A) *C) Improved S-shaped acceleration and deceleration*

In view of the complicated and long operation time of the traditional seven-section S-curve acceleration and deceleration operation, the logistic function is improved to match the actual start-up demand of winding machine, reduce the operation amount, and improve the stability and sensitivity. The logistic regression function is expressed in formula (1)[9].

$$f(x)=1/(1+e^{-ax}) \qquad (1)$$

Where a (a>0) represents the degree of skew of the S-curve, and this function is symmetric about the midpoint of the interval in a certain interval.

The acceleration curve is shown in Fig. 5.

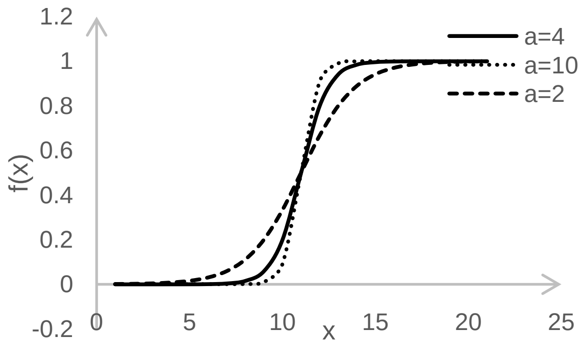


Fig. 5 S-curve with different slopes

The stepper motor starts from a fixed starting frequency, and the starting frequency is not 0, so the minimum value of f(x) is not 0. Where the independent variable x represents time and f(x) represents frequency. In order to make f(x) meet the acceleration and deceleration requirements of stepper motor, it is necessary to improve the S-shaped curve. The improved expression is as shown in Equation (2).

$$f(x) = A + B/(1 + e^{-ax}) \quad (2)$$

Where A represents the distance the curve is shifted up, B represents the height of the curve as $f_{max} - f_{min}$, and B represents the amount of shift along the X-axis.

In order to make the stepping motor speed up stage more stable, it needs to be in the whole process of acceleration S curve must be symmetrical. Transform formula (2) as follows:

$$f(x) = A + B/(1 + e^{-a(x-d)/d}) \quad (3)$$

d is half of the s-curve.

Assume that the starting frequency of stepper motor is fre_start, the frequency of acceleration termination stage is fre_end, and the total number of steps to be taken in the whole acceleration stage is $step\_num$. The mathematical expression obtained from (3) is as follows:

$$f(x) = fre\_start + \frac{fre\_end - fre\_start}{1 + e^{-flexible\ (x - \frac{step\_num}{2})/\frac{step\_num}{2}}} \quad (4)$$

$flexible$ represents the degree of tilt of the S-curve. It can be concluded from Fig. 5 that the larger the flexible value is, the more obvious the tilt of the S-curve will be, and the shorter the entire acceleration process time will be. Generally, when flexible is set between 4-6, the S-shaped curve obtained is relatively ideal.

D. Scheme of s-shaped curve acceleration and deceleration

The process of acceleration and deceleration of the stepping motor is composed of the starting frequency and the transformation frequency, and the S curve is the part of the transformation frequency. Using STM32 control chip, select timer to control the pulse frequency so as to realize the control of motor speed S curve movement. The controller not only generates the pulse signal, but also changes the timer's automatic loading value ARR. The count frequency does not change after the timer is initialized, but changing the autoload value can change the interrupt frequency, and the pulse frequency changes accordingly.The output PWM frequency of the timer is shown in equation (5).

$$fre = CLK/((ARR + 1)(PSC + 1)) \quad (5)$$

CLK :84 MHZ; The value of ARR ranges from 0 to 65535. PSC is the pre-divided frequency.

Set timer counting frequency to 42MHz, PSC=1; Then the timer automatically loads the value ARR:

$$ARR = 42000000/fre - 1 \quad (6)$$

The calculated ARR value is stored in the line_arry[] , so that the value of the automatic loading register of the stepper motor during its running phase is obtained.

Run the S-shaped algorithm at system initialization to get the corresponding array line_arry[]. Set the acceleration sign to 1 for a start signal and the deceleration sign to 1 for a stop signal. The timer interrupt service function determines whether to speed up or slow down by determining the flag bit. The flow chart of timer control stepper motor is shown in Fig. 6.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The winding experiment platform built is shown in Fig. 7. The balance wheel is connected with the pendulum rod inside the test box, and the tension of the pendulum rod is provided by the hollow cup motor. At the same time, the connection Angle sensor reads the swing rod Angle.The traditional S - curve algorithm and the improved S - curve algorithm are tested respectively.

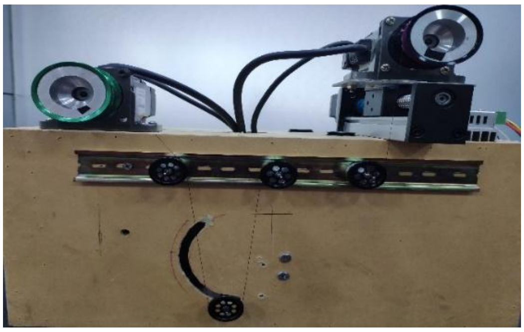


Fig. 7 Experimental platform

The experimental results of traditional S-curve acceleration and deceleration are shown in Fig. 8. The abscissa represents the number of steps of the stepper motor, and the ordinate represents the automatic loading value ARR of the timer. The value of ARR is inversely proportional to the motor speed. When the value of ARR increases, the stepper motor speed decreases; otherwise, the stepper motor speed increases. According to the figure, in the acceleration and deceleration of the traditional S-curve, there are obvious acceleration mutations at both the end point of acceleration and the starting point of deceleration. The calculation is complicated and the model is not universal.

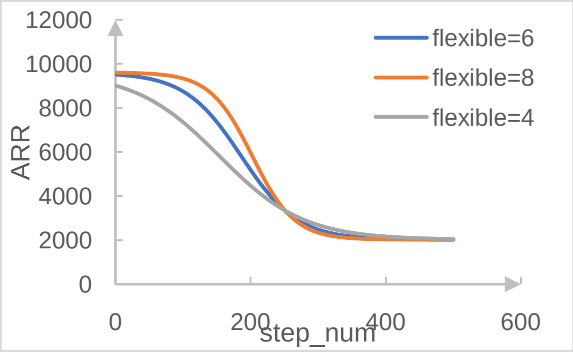


Fig. 8 Seven-section S_curveoutput curve

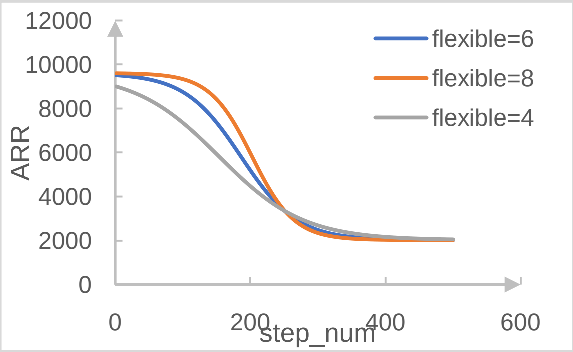


Fig. 9 Flexible value output comparison curve

Fig. 9 is the curve comparison diagram of the improved S-acceleration and deceleration curve with different flexible values and different target speeds, where fre_start=4300Hz, fre_end=20800Hz, $step\_num$=500.

The complete acceleration and deceleration of S curve is shown in Figure 10. $flexible$=6, $step\_num$=500, and the number of steps in uniform operation is run_step=520. The deceleration curve is completely symmetrical with the acceleration curve, but it is only backward, so the number of steps and acceleration steps are the same as 500. According to the result graph, the s_curve acceleration and deceleration can eliminate the abrupt acceleration, and the acceleration and deceleration can be stable when the winding machine starts and stops, enhancing the stability of the system, and the model has strong universality. After the algorithm is encapsulated, if the target speed is changed,

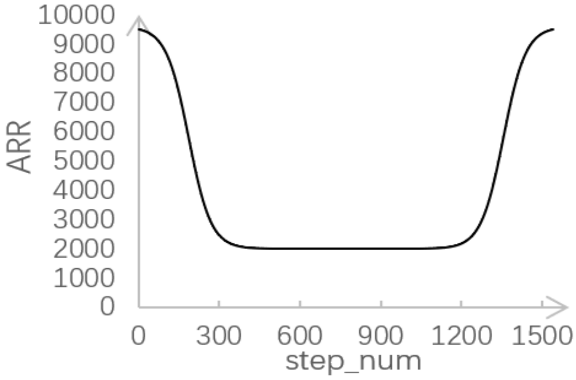


Fig.10 Complete S trajectory

CONCLUSION

In winding control system, smooth start-stop is an important part of system operation. In this paper, by analyzing the characteristics of the torque frequency of the stepping motor, it is deduced that when the frequency of the stepping motor drives the motor according to the S-shaped acceleration and deceleration curve, the angular acceleration of the stepping motor can be adapted to the output torque of the stepping motor. Then the traditional seven-segment S-curve acceleration and deceleration mathematical model is analyzed, and the algorithm of Logistic S acceleration and deceleration is improved and applied to the winding control system, and the software implementation process is analyzed. Finally, STM32 is used as the control chip to carry out many experiments and comparative analysis on the winding system experiment platform, and it is proved that the algorithm can easily realize the winding machine accelerating start, uniform operation and decelerating stop. The test result is well, the operation is stable and there is no loss of step, stall and so on.

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