Research on high power servo turning control

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Abstract. The paper studies the turning control of high power servo system, using variable structure control method, for constant acceleration constant deceleration control and according to kinematics theory, two control methods related to time and error are proposed. Through analyzing the characteristics of high power servo system, combine the torque relationship between the braking angle and the turning control, an accelerated guidance control method is proposed.

1. Introduction
The high power servo system has the characteristics of large moment of inertia, high control accuracy and fast running speed. It requires quick start, stable operation and precise stop during turning, and quick brake and short braking distance during braking. The traditional PID control algorithm cannot meet the requirement of servo system for high-performance turning. In order to achieve the system index, this paper studies the turning technology of high power servo system. In view of the limitations of traditional PID control, based on the kinematics law, starting from the practical application, this paper adopts the variable structure control algorithm and significantly improves the performance of turning control of high power servo system, which achieves satisfactory control results.

2. Variable structure control
Variable structure control is a comprehensive method of modern control theory. When the state of the system reaches the value of switching function, the system automatically switches from one structure to another. In essence, VSC has switching characteristics and is suitable for linear and nonlinear systems. The variable structure control system can adjust the change of the controller structure, so that the control system can adapt to the change of the internal parameters and the disturbance of the external environment of the controlled object, so as to ensure that the system performance can meet the expected requirements. Variable structure control can improve the dynamic quality of the system and make the system achieve high regulation accuracy and fast response speed with strong robustness, which breaks through the performance limit of the traditional control design and reasonably solves the balance problem between the dynamic performance index and the static performance index [1].

Figure 1 Speed-time curve of ideal turning
Figure 1 shows the speed-time curve of ideal turning. Zone I is the large error zone. In order to reduce the error rapidly, Bang-Bang control (time-optimal algorithm) is used in this zone. Given the maximum output speed of the motor, the servo system can respond quickly so as to shorten the turning time.

For Bang-Bang control algorithm, refer to formula (1):

\[
V = \begin{cases} 
+ V_{\text{max}}, & e > S_z - S_i \vspace{1mm} \\
-V_{\text{max}}, & e < -(S_z - S_i) 
\end{cases}
\]

(1)

In formula (1), \( V \) is the real-time speed of the system, \( V_{\text{max}} \) is the maximum speed of the system, \( e \) is the real-time error of the system, \( S_z \) is the total distance of the turning operation, and \( S_i \) is the operation distance of zone I. Once the turning position covers zone I, the servo system can be controlled by Bang-Bang.

Zone II is constant deceleration zone. Considering that the load moment of inertia of high-power servo system is large, in order to make the output speed of the motor shaft reduce rapidly to avoid large overshoot and oscillation times in the turning curve, the quick braking should be carried out with a large acceleration in this zone.

However, in practice, due to the difference between the theoretical calculation and the actual load movement, only using constant deceleration control cannot make the servo system stop accurately and stably at the target position. Under the premise of not changing the control law of zone II, the method of having constant deceleration control in advance is proposed, and the control zone, zone III, is added to make the system move to the target position quickly, stably and accurately.

Figure 2 shows the speed-time curve of variable structure turning, which is divided into zone I, zone II and zone III. Zone I is Bang-Bang control zone, zone II is constant deceleration control zone and zone III is PID control zone. The end part of zone I and the start part of zone II in Figure 1 are taken as zone II in Figure 2, which means that deceleration control is carried out in advance to prepare for the stability control in zone III. Zone III in Figure 2 shows that when the motor speed is reduced to a certain value, the residual error is also small. At this time, PID control can make the servo system accurately stop to the target position without overshoot.

For constant deceleration control in zone II, setting a proper acceleration \( a \) when decelerating, referring to PID control algorithm, and corresponding the speed and error, it can be obtained from kinematic speed, acceleration and displacement formula that:

\[
V_z^2 - V_i^2 = 2a(S_z - S_i)
\]

(2)

In formula (2), \( a \) is acceleration, \( S_z \) is the area calculated by velocity \( V_z \) and time, and \( S_i \) is the area calculated by velocity \( V_i \) and time.

According to the constant deceleration characteristics of zone II in Figure 2 and the kinematic formula of formula (2), the reference formula of constant deceleration control algorithm related to error can be obtained (3):
In formula (3), $S_{III}$ is the operation distance of zone III.

Formula (3) gives the function of the current velocity and the current position error, where the velocity is the square root function of the error. In this function, the maximum velocity is known, and the maximum acceleration is determined by the maximum output torque of the system, which can be obtained by calculation and be properly corrected. The total operation distance of turning is calculated from the turning target position and the current position. The operation distance of zone I, zone II and zone III is divided according to the actual load characteristics and is improved in the test.

The area size of zone I determines the speed of turning movement of the servo system. The larger the zone I is, the faster the turning is. Zone II is the transition zone, which plays a braking role in the turning movement. When the braking acceleration is constant, the area size of zone II determines the system speed when the it moves to zone III, which plays an important role on stable stop in the zone III. Zone III is the end zone of the system. When entering this zone, the speed of the servo system is low and the error is small, so only proportional control is adopted. Zone III determines the stability and stop position accuracy of the system.

Figure 3 shows the speed-error curve of turning. The error in zone I is the largest, and the output speed remains the largest within the error range in this zone. In zone II, the output speed decreases with the decrease of the error, where the relation between output speed and error is square root. The output speed of zone III decreases with the decrease of error. When the error approaches zero, the output speed also approaches zero.

In the digital control of servo system, the output variable is discrete, and the output interval is related to the instruction cycle and sampling period. When the servo system moves into zone II, the output speed can be determined by acceleration and time because the zone is controlled by constant deceleration. From the formula of kinematic velocity, acceleration and time, we can get:

$$V_{z} - V_{i} = at_{z} - at_{i}$$

In formula (4), $t_{i}$ and $t_{z}$ refer to the moment when the speed is zero, and $V_{i}$ and $V_{z}$ are the speeds at $t_{i}$ and $t_{z}$, respectively.

In zone II, the reference formula of time-dependent constant deceleration control algorithm can be obtained (5):

$$V = \begin{cases} 
+\sqrt{2}\left(\frac{V_{max}}{a(t-t_{II})}\right) & S_{III} < e \leq S_{II} - S_{I} \\
0 & t_{II} \leq t < t_{III} \\
-\sqrt{2}\left(\frac{V_{max}}{a(t-t_{II})}\right) & -(S_{II} - S_{I}) \leq e < -S_{III} 
\end{cases}$$

In formula (5), $t_{II}$ and $t_{III}$ are the moment of entering and leaving zone II respectively, and $t$ is the moment of current output after discretization in zone II.
The point of adopting formula (5) in turning movement of servo system is that when the position feedback enters zone II, the speed of each output cycle can be obtained from the relationship between acceleration and current moment.

In the computer digital control, the timer is generally used for information sampling and output. Compared with the control algorithm of formula (3), the control algorithm of formula (5) is simpler and easier to realize.

3. Accelerated guidance control

The moment of inertia of high power servo system is large. Although the maximum speed command is given directly when starting, the load speed cannot reach the maximum immediately but needs a certain time. The acceleration time of load speed from zero to the maximum is determined by the motor output torque, system deceleration ratio and moment of inertia. When the motor and reducer are fixed, the greater the moment of inertia of load, the longer the acceleration time.

Due to the large number of load structure components, heavy mass and large moment of inertia, in case of 'runaway' and other abnormal conditions, the high power servo system will be great damaged, which will lead to load damage and even personal safety problem [2]. Generally, a proper braking angle will be proposed in the design, and the load speed is required to be reduced from the maximum to zero within the braking distance, so as to ensure the overall safety of the system.

The saturated output of the driver may cause the large input current of the motor in short time to exceed the maximum allowable current of the motor in the working situation with frequent turning. When the current produces enough magnetic field strength, it will enhance the activity of the internal magnetic domain of the permanent magnet material and disturb their arrangement law, so that the magnetism of the permanent magnet material appears significantly decline. For the AC servo motor, with the accumulation of the action time, it will cause the amplitude of the counter electromotive force to drop significantly, and the waveform of the counter electromotive force will be distorted, resulting in the demagnetization of the motor [3,4].

Based on the above analysis, when the high power servo system is in turning control, because the maximum torque of the motor selected according to the braking angle is far greater than the requirement of the motor torque for the turning time, on the premise of meeting the requirement of the servo system for the turning time, the paper puts forward the guidance control of the motor speed and acceleration to limit the maximum output current of the motor, so that the motor can work stably for a long time.

Figure 4 Speed-time curve with accelerated guidance control

Figure 4 shows the speed-time curve with accelerated guidance control. In order to limit the motor current, the original Bang-Bang control zone is changed into acceleration zone and constant speed zone. The acceleration zone can be controlled by formula (3) or formula (5). When the motor speed reaches the maximum, it operates at a constant speed with the maximum speed. When the load feedback position enters zone II, the corresponding constant deceleration control is carried out; when the load feedback position enters zone III, the PID control of the final error section is carried out.

The acceleration of acceleration section and deceleration section shall be subject to the actual debugging. First, calculate an acceleration based on the maximum torque of the motor, and then calculate an acceleration based on the required turning time of the system. Select a suitable value between the two accelerations for the test, and modify it according to the test results, so as to meet the
requirements of the turning time of the system and achieve the purpose of limiting the output current of the motor.

4. Conclusion

In this paper, starting from the practical application, the turning control of high power servo system is studied. First, the ideal turning curve is analyzed, then the variable structure control algorithm is introduced, then the Bang-Bang control is improved by limiting the input current of the motor in the acceleration stage with the accelerated guidance control algorithm. The turning control algorithm described in this paper has the advantages of simple debugging, convenient implementation and strong portability, which can be used for reference in the application of servo system turning control.

References

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