Self-correcting displacement synchronization control based on cross-coupling

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Abstract: This paper proposes a self-correcting displacement synchronization control algorithm based on cross-coupling, analyzes the self-correcting module principle of the algorithm in detail, and designs and calculates the parameters selection in the algorithm. In order to verify the effectiveness of the algorithm, the system operation test is carried out before and after the self-correction module was added on a certain type of tank transfer mechanism.

1. Introduction
With the continuous industrialization and automation, single-axis motor drive can no longer meet the needs of current industrial design. Two-axis and multi-axis motor power systems are increasingly applied in the fields of aerospace, power equipment, robotics, automobiles, ships, etc. Motor synchronization technology has become a hot topic for scholars at home and abroad. The research of motor synchronization mainly focuses on the synchronous speed of multiple motors. However, due to the large size, heavy weight and various shapes of the system load, in the design of load transmission system, synchronization of motor displacement has attracted more attention.

This paper designs a self-correcting displacement synchronization algorithm based on cross-coupling to realize the precise synchronization of the motor displacement of the dual-drive or multi-drive system. The test is verified on a box transfer device.

2. Algorithm Description

2.1. Cross-coupling control
The cross-coupling synchronous control method is used to solve the problem of uncoordinated operation of each unit caused by external factors in a multi-motor system, and realizes coordinated operation by establishing a coupling relationship between the controlled objects in the system. This control strategy can offer synchronous feedback as required, which greatly improves the synchronization accuracy. The system structure of the cross-coupled displacement synchronous control is shown in Figure 1.
For the performance requirements of the dual-drive system, it is necessary to ensure the real-time synchronization of the displacement of the two motors during the operation. Therefore, in the design of the controller, the motor displacement is taken as the control target, the motor speed as the control object, and the actual displacement difference between the motors as the speed regulation factor. The cross-coupling principle is used to adjust the motor speed so as to ensure the displacement synchronization of dual/multiple motors.

2.2. Self-correcting displacement synchronization algorithm based on cross-coupling

During the operation of the dual-drive system, its status is affected by external multi-factors. When they change, the interference value TL increases sharply in Figure 1, and the system synchronization decreases. If it exceeds the adjustment capability of the system parameters K1 and K2, displacement difference between the motors would even exceed the limit, resulting in system shutdown. To avoid that and ensure the full flow of synchronization, this paper introduces a self-calibration module in controller design to achieve better control through online identification and correction of control parameters\(^2\). The self-correcting module structure is shown in Figure 2.

![Figure 1. The system structure of the cross-coupled displacement synchronous control](image)

Through the actual displacement difference and the startup of comparison control module of difference upper limit, the parameter adjustment unit retrieves the current parameters K1, K2 from the recording unit. Combined with the actual displacement difference ΔS, based on the parameter adjustment formula, while maintaining the K1 value, new parameter K2* is calculated online. The speed of the motor 2 is adjusted until the system resumes smooth synchronization. Then turn off calibration module to ensure the parameter consistency of the system under stable conditions.

In order to ensure the greatest stability of the system, the parameter K1 of the motor 1 is kept
unchanged during adjustment. Adjust the speed parameter $K_2$ of the motor 2 based on the current displacement difference while consider the characteristics of the dual-drive system. The parameter adjustment formula is:

$$K_i^* = (1 + \delta) K_i$$

$\delta$ is the adjustment factor $\delta = \frac{\Delta s^2}{(s_1 - s_2) T_{\Sigma}}$, $s_1$ and $s_2$ are the actual displacement of the motor, $\Delta s = \text{abs}(s_1 - s_2)$ is the absolute value of the displacement difference, and $T_{\Sigma}$ is the regulator parameter, which needs to be selected according to the characteristics of the motor.

As the control object of the system, the adjustment parameters is calculated based on characteristics of the motor speed and the traditional PID control correction system, while considering the elimination of static differences to avoid the introduction of high-frequency interference and other factors. It is also based on the frequency response characteristics of the system and adopted a IF bandwidth range of $T_{\Sigma} \approx 5 \sim 6$ to ensure follow ability and anti-interference of the system.

3. Algorithm verification

In order to verify the effectiveness of the displacement synchronization algorithm, this paper tests the control algorithm on a certain type of box transport mechanism. The transfer mechanism is shown in Figure 3.

![Figure 3. The structure of transfer mechanism](image)

As shown in the figure, the two motors in the transfer mechanism drive the box to move linearly along two directions respectively. In order to avoid jam caused by the displacement difference between two axes, the displacement of the two motors must be synchronized. The transfer mechanism control process is as follows: transmit a speed control signal generated by the DSP to the servo drive motor. Internal encoder of the drive transmits the position and velocity signals in real time via CAN bus. In order to verify the effectiveness of the algorithm, the control effects before and after adding the correction module are compared under normal and artificial working status.

- Normal working status

In the experiment, the speed of the two motors in the X direction is set to 1000 rpm. According to the mechanical design data of the transport mechanism, the upper limit of the displacement difference is set as $\Delta s_0 \leq 1700$. When the actual displacement difference is greater than $\Delta s_0$, the system gives out a warning and stops working. The speed before and after self-correction module is added and the displacement difference curve of the two motors under normal working conditions are shown in Figure 4 and Figure 5.
It can be seen by comparing Figure 4 and Figure 5 that the control ability of the system in acceleration and constant speed sections of the motor is relatively stable with small displacement difference. The speed and displacement of the two motors maintain good synchronism, and the main displacement difference appears in the deceleration section. After the system decelerates, the displacement difference increases significantly. Before the self-correction module is added, the displacement difference does not exceed $\Delta s_0$, but the adjustment ability is limited, and synchronous control is not precise. After the self-correction is added, activate the self-correction module when the displacement difference increases, and the system adjustment capability is enhanced. After a short adjustment, the displacement difference is significantly reduced and remains stable until the end of the transfer. Therefore, under normal conditions, the self-correction module has an obvious optimization effect on the control algorithm.

Moreover, the artificial working status

In order to verify it in a variety of working conditions, this paper adds a large disturbance in the way of mechanical jamming during the operation of the transport mechanism, and adds a large displacement difference to test the control ability of the algorithm. The system speed and displacement difference curves are shown in Figure 6 and Figure 7.
Figure 6. The curve of the speed/displacement difference before using the module (b)

Figure 7. The curve of the speed/displacement difference after using the module (b)

As seen from the above two figures, before the module is added, the control system adjusts the displacement difference by adjusting the motor speed when the external disturbance is generated. However, due to the limitation of the adjustment capability, the displacement difference quickly exceeds the upper limit. The protection function is activated to stop the motor. After adding the self-calibration module, the ability to adjust the interference is improved. After adjusting the motor speed, the influence of the disturbance is overcome. After a short adjustment, the displacement difference is restored smoothly until the end of the operation.

4. Conclusion
This paper puts forward a self-correcting displacement synchronization control algorithm based on cross-coupling, analyzes self-correcting module principle of the algorithm in detail, and designs and calculates the parameters selection in the algorithm. Based on a certain type of tank transfer mechanism, this paper conducts a comparison test before and after the self-correction module is added under normal conditions and artificial disturbances. The data has proved the effectiveness of the algorithm.

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