Research on PD Control of Bi-axis Based on Cross-Coupling

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Abstract. Coordinated multi-axis motion control has become increasingly more practical. More and more researchers pay attention to this field. In this paper, the model of the biaxial motion system is established firstly. Then, consider the effect of the position error between adjacent axes, combined with the PD control algorithm and the cross-coupling control algorithm, a PD synchronization control strategy based on cross-coupling is proposed. The experiment results showed that the method used in this paper fully satisfies the control precision requirement of the biaxial motion control system.

Introduction

Multi-axis motion system is increasingly used in CNC machine tools, printing, packaging, textile and other fields in recent years, the main control parameters of the multi-axis cooperative motion are velocity and position[1]. The velocity co-control is mainly used for continuous production equipment to ensure reliable operation between the drive shafts according to the predetermined transmission ratio. Position coordination is mainly for CNC machine tools and robots, in order to achieve complex contour curve as the goal[2,3]. The multi-axis system is a nonlinear, strongly coupled multi-input multi-output system. How to achieve high real-time, high-precision multi-axis position synchronization is becoming a hotspot in this field.

From a mechanical point of view, due to the uneven loading of the mechanical system to each axis, this causes the axes to be out of sync. Therefore, to make the multi-axis system in the system can run according to the requirements of the synchronization indicators, we must take appropriate synchronization control algorithm to overcome the system caused by non-synchronized interference factors and uncertain factors. In the case of steady-state operation of the system, when the speed is fully synchronized, the position is also synchronized, that is, speed synchronization and position synchronization are consistent. But the dynamic process is not the case, once the two axes of different load disturbances or other unstable factors, the system in the position or speed is bound to appear out of sync. Assuming that there is a position error in the synchronization system, a more feasible approach is to adjust the speed to reduce the position difference, but this will inevitably lead to differences in the speed of the two axes, resulting in the speed of the synchronization; Also, when the speed error is adjusted, it will cause the position to be out of sync. It can be shown that the velocity synchronization and position synchronization in the multi-axis system have a coordination relationship at steady state, but the regulation in the dynamic process is mutually restricted. So the multi-axis motion system needs to take appropriate synchronization control strategy.

Cross-coupled control (CCC) is proposed by Korne firstly[4], and has been successfully applied on a conventional Multi - axis machine system. The basic idea of cross-coupled control is that when controlling the motion of a certain axis, the influence of other axes is adopted into the control of the axis to achieve the effect of synchronous coordination, for the multi-axis control system[5]. Not only takes into account the position tracking error of each individual actuator in the conventional asynchronous control, but also the position synchronization error between the axes.
In this paper, the synchronization control strategies based on cross coupling is analyzed firstly, and then the PD synchronization controller is designed based on cross coupling. Finally, the experimental results are given.

Materials and Methods

Model of Biaxial Motion System

The experimental equipment of biaxial motion system is shown in Figure 1.

![Figure 1. Experimental equipment of biaxial motion system.](image)

A model of a multi-axis motion control system can be expressed as Eq. 1:

\[ M(x) \ddot{x} + C(x, \dot{x}) \ddot{x} + F(x, \dot{x}) \dot{x} = \tau \]  

(1)

where \( \tau \) is the n×1 control input vector, \( x \) is the n×1 coordinate vector, \( M \) is the positive definite inertial matrix, \( C \) is the coriolis force vector, \( F \) is the n×1 friction disturbance vector.

Definition 1: single axis tracking error (position error) is:

\[ e = x^d - x \]  

(2)

Synchronization Control Strategy

In this paper, the balanced control strategy is adopted. The control strategy means that the controlled system does not have a unified master axis. Each axis is a master axis and a slave axis. Each axis is synchronized with each other. In each control cycle[6], each axis receives the actual position value of the other axis as a reference for its own position reference via the control network.

Definition 2: The synchronization error is the difference between the tracking error of the current axis and the adjacent axis, as shown in Eq. 3.

\[ e_1 = C_1 e_1 - C_2 e_2 \]
\[ e_2 = C_2 e_2 - C_3 e_3 \]
\[ \vdots \]
\[ e_i = C_i e_i - C_{i+1} e_{i+1} \]
\[ \vdots \]
\[ e_{n-1} = C_{n-1} e_{n-1} - C_n e_n \]
\[ e_n = C_n e_n - C_1 e_1 \]  

(3)
where \( \varepsilon_i \) is the synchronization error of \( i \)th axis, \( C_i \) is the Synchronization factor of CCC, and \( n=2 \).

The cross-coupling control schematic diagram is shown in Figure 2.

**Figure 2. Schematic diagram of the structure of the cross-coupled controller.**

**PD Synchronization Controller Based on Cross-coupled**

Definition 4: The coupling position error is the difference between the tracking errors of the adjacent two axes, expressed as Eq. 4:

\[
E = e + \alpha \varepsilon
\]

where \( \alpha \) is the coupling position error control gain, a diagonal positive definite matrix.

Design PD synchronization controller based on cross-coupled, as shown below:

\[
\tau = K_p E + K_D \dot{E} + (I + \alpha T)^{-1} K_r \dot{e}
\]

where \( K_p, K_D, K_r \) are the position control gain. Substituting Formula 5 into Equation 1 gets the Equation 6, which is described as Eq. 6:

\[
M(x) \ddot{x} + C(x, \dot{x}) \dot{x} = K_p E + K_D \dot{E} + (I + \alpha T)^{-1} K_r \dot{e}
\]

Point control strategy is adopted, \( x^d \) is a constant given value, \( x \) is the real-time acquisition value.

**Experimental and Results**

The simulation experiment block diagram is shown in the Figure 3.

**Figure 3. Simulation experiment block diagram.**
The step signal with the final value of 100 is taken as the input of the biaxial motion system. The response curve for each axis is shown in the Figure 4. The control input curve of the PD synchronization controller based on cross-coupled is shown in Figure 5.

Conclusion

The cross-coupling control algorithm takes into account the interaction between adjacent axes, the position error of the adjacent axis is taken as the input of the controlled axis, which increases the position control precision of the system. Combined with PD control, can meet the biaxial motion control system control requirements.

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