Motion performance analysis and control mode design for the cross slide

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Abstract. The motion control system which is constructed by using the programmable controller and the motion controller has been widely applied to various mechanical systems. This paper takes a cross slide as an example, the motion control system is composed of the GE FANUC PAC and DSM324i, and the movement performance simulation model is established. The motion performance by linear acceleration and deceleration algorithm in the case of two axis synchronous movement is analyzed. The relation between the displacement command and the parameters of the acceleration and the velocity is derivated, and the trajectory curve of movement performance under a variety of instruction is gained. The control instruction meet the linear motion is designed by the model.

1. Introduction
With the new motion controller appearance constantly, the motion control system composed of the motion controller and the programmable controller (PLC) which can meet customer demand has been widely used in mechanical system, such as the fixed-length cutting machinery, the leather cutting machinery, the carton customized mechanical and the rotating knife cutting machine, etc. This kind of motion control system mainly used for the positioning control of variable distance [1], in addition to achieve a single axis of motion control, also can realize multi-axis linkage control to complete some contour control requirements.

The cross sliding table is consisted of two groups of slider, ball screw and rail. One shaft is mounted on the other axis to form a cross. It can be moving along X, Y direction respectively, or completing the corresponding curve trajectory by two axis synchronous motion. The motion control system using DSM324i and PAC System RX3i programmable controller, can solve the complex single axis and multi-axis motion control [2]. The the block diagram of system structure is as Figure 1.

![Figure 1. Block diagram of system structure.](image-url)
First, the control instruction is programmed on the internal of PAC. And then PAC instructions will be sent to motion controller. The motion position and speed instructions will be converted to servo control signal to drive the servo motor moving. The motion program is created through programming design of DSM324i. Each motion program is required to set the axis acceleration, the maximum speed, the given target point and acceleration model. When the corresponding exercise program is triggered, the motor will be started. The two axis movement program is as follows.

**PROGRAM 1 MULTI-AXIS**

ACCEL AXIS1 (Acc1)  
ACCEL AXIS2 (Acc2)  
VELOC AXIS1 (Vmax)  
VELOC AXIS2 (Vmax)
SYNC  
PMOVE AXIS1 (Xp), ABS, LINEAR  
PMOVE AXIS2 (Yp), ABS, LINEAR  
ENDPORG

Where, Acc1 and Acc2 are the values of the acceleration, the Vmax is the maximum feed rate of the shaft, the Xp and Yp is the target point of the location. The synchronous movement instructions are used here.

In order to investigate the cross slide movement performance, a simple path are designed as shown in Figure 2 in the dotted line. Where the path 1 is the uniaxial motion. The path 2 is the two axes linkage movement along the 45° oblique line. The path 3 and 4 are the two axis movement in different quadrants.

**Figure 2.** The trajectory of two axis synchronous mode.

The synchronous movement is a simple synchronous movement under the uniaxial motion control. Due to the axis movement is subject to their maximum velocity and acceleration respectively, its trajectory is irregular, which appeared in Figure 2 lines 1'-2'-3'-4'. It is seen that the trajectory of uniaxial and 45° oblique line motion can meet the requirements of motion control, and the other two kinds of trajectory appeared larger deviation compared to the theory trajectory.

2. The movement performance simulation mathematical modeling

Because the shaft control is respective independent in the motion controller, its motion is in accordance with the time of itself acceleration [3-5]. Synchronous instruction is only synchronized with the start of the movement, and is meet the requirements of the deceleration to reach the target at the same time, which leads to the movement of each axis will be calculated in accordance with its own parameters. Therefore, according to the different displacement of the shaft, three kinds of situations are discussed. Where, the axis which the target point project on the coordinate has longer motion displacement is called the long axis, the other is the short axis.
The displacement of the two axes is long enough. Both the long axis and the short axis can complete a whole process including acceleration and deceleration. Only one of the axial displacement is sufficient. That is, the long axis can be completed a complete acceleration and deceleration process, and the short axis can not reach its maximum speed value. The displacement of the two axes is not long enough. Both the long axis and the short axis can not reach its maximum speed value.

2.1. Both two axes can run a whole acceleration and deceleration process

The independent control shaft synchronous movement must be abide by the two rules. The first rule is the priority of slowing down, that is, no matter how much the long axis displacement difference from the short axis’s, they must be stopping at the same time (the velocity must be slowing down to zero at the same time).

The second rule is started at the same time, the acceleration is preferred. When a given acceleration, speed instruction cannot be achieved at the same time, give priority to meet the same acceleration, and the maximum velocity can be different. The velocity curves of the long axis and short axis are shown as Figure 3. \( V_L \) is long axis velocity, \( V_S \) is short axis velocity.

![Figure 3. The velocity curve schematic.](image)

Where \( t_{L1}, t_{L2}, t_{L3} \) is respectively the three periods of the acceleration time, constant speed time, deceleration time of the long-axis. The \( t_{S1}, t_{S2}, t_{S3} \) represents three stages of the short-axis. The trapezoidal area is corresponding to the displacement of major axes \( S_{Long} \) and minor axes \( S_{Short} \).

Due to the acceleration and deceleration times are the same in long-axis, so \( t_{L1} = t_{L3} = \frac{V_{max}}{A} \). Long axis speed curve is an equilateral trapezoid, the trapezoidal area of long axis is the total displacement as follow:

\[
S_{long} = (t_{L2} + t_{L1})V_{max}
\]  

(1)

The total times \( t \) is:

\[
t = \frac{S_{long}}{V_{max}} + \frac{V_{max}}{A}
\]  

(2)

So \( t_{L2} = t - 2t_{L1} \). The short shaft total movement time is the same as the long axis’. which have complete three sections of curves, so the first stage of the short axis is the same as the the long axis. The minor axis \( t_{S1} = t_{L1} \). The short shaft speed curve area is its displacement, so \( t_{S2}, t_{S3} \) can be solving as following function group.

\[
\begin{align*}
S_{short} &= \frac{1}{2} t_{L1} V_{max} + t_{S2} V_{max} + \frac{1}{2} t_{S3} V_{max} \\
t &= t_{S1} - t_{S2} - t_{S3}
\end{align*}
\]  

(3)

According to \( t_{S3} \) can calculate the minor axis deceleration value.

\[
A_s = \frac{V_{max}}{t_{S3}}
\]  

(4)
2.2. *Only one of the axial displacement is sufficient*

Only one axis is long enough, the long axis can complete three stages moving, but the short axis only exist two stages, that is, acceleration and deceleration phase, there is no uniform phase. According to the deceleration priority principle, it can be known that the long axis and the short axis must simultaneously decelerate to zero, so the total time is the same. The short axis of the maximum speed is unknown. Set the maximum speed of the short axis is $V_{\text{short max}}$.

\[ V_{\text{max}} = \frac{2S_{\text{short}}}{t} \]  

(5)

According to the principle of starting priority, the starting stage acceleration is still the acceleration $A$, then:

\[ t_{s1} = \frac{V_{\text{max}}}{A} \]  

(6)

The short axis deceleration time is $t_{S3} = t - 2t_{S1}$, $t_{S2} = 0$, and the short axis deceleration:

\[ A_s = \frac{V_{\text{max}}}{t_{S3}} \]  

(7)

2.3. *Neither of axes can run a whole acceleration and deceleration process*

As the long axis and short axis motion path is short, there is no uniform motion phase but the acceleration and deceleration process. It can’t accelerate to the maximum speed. Set the long axis has the same period of acceleration and deceleration, $t_{L1} = t_{L3}$, $t_{L2} = 0$.

\[ t_{L1} = t_{L2} = \frac{1}{2} \sqrt{\frac{4S_{\text{long}}}{A}} \]  

(8)

\[ v_{\text{L max}} = \frac{A}{2} \sqrt{\frac{4S_{\text{long}}}{A}} \]  

(9)

Similarly, according to the principle of deceleration priority, the short axis movement parameters are calculated by the formula above.

Set Figure 2 curve motion parameters: the maximum velocity is 50mm/s, the acceleration is 100mm/s$^2$, the acceleration model is linear acceleration, its speed curve simulation is shown in Figure 4.

![Figure 4. The velocity curve of the trajectory.](image_url)
3. Improved design of control instructions

In order to realize the linear trajectory motion, the motion parameters of the short axis need to be modified according to the motion state of the long axis. So the linear slope of the straight line is kept constant during the synchronous movement. That is,

\[ K = \frac{S_{Long}}{S_{Short}} = Const \]  

(10)

Where, taking the first case as an example, in the three time periods, the short axis acceleration and maximum speed will have a corresponding decline in order to meet its displacement distribution ratio, then:

\[
\begin{align*}
S_{Long} &= \frac{1}{2} A_L t_1^2 \\
S_{Short} &= \frac{1}{2} A_S t_1^2 
\end{align*}
\]

(11)

Where, \( t_{L1} = t_{S1} \), \( A_L = A \), \( S_{Long}/S_{Short} = K \), so,

\[ A_s = \frac{S_{max}}{S_{Long}} A = \frac{A}{K} \]  

(12)

For the constant speed section,

\[
\begin{align*}
S_{Long} &= V_{max} t_2 \\
S_{Short} &= V_{max} t_2 
\end{align*}
\]

(13)

Where, \( t_{L2} = t_{S2} \), \( V_{Lmax} = V_{max} \), \( S_{Long}/S_{Short} = K \).

\[ V_{max} = \frac{S_{max}}{S_{Long}} V_{max} = \frac{V_{max}}{K} \]

(14)

The deceleration phase calculation is the same as the acceleration phase calculation. The motion control parameters of acceleration and the maximum speed of the short axis can be designed according to the ratio of slope value. The velocity curve of the improved design of control instructions is shown in Figure 5. It is seen that the section 3 and 4 in X-axis is different from that is in the Figure 4. It results a symmetric velocity curve in X-axis.

![Figure 5](image_url)

**Figure 5.** The velocity curve after improved design of control instructions.
Actual motion path is also consistent with the instruction value, after doing the improvement on the design of control instruction. It is shown Figure 6. It is found that the 3 and 4 segment is not existed the path of the large deviation which in Figure 2.

4. Conclusions
In some motion control systems, because of the absence of interpolation, the influence of motion parameters of each axis and motion coordination must be taken into account in the control designing for multi-axis motion. Otherwise it will lead to the deviation of the moving trajectory and acceleration and deceleration incongruity, and resulting in not running in accordance with the ideal state of motion.

5. References
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