A Zero Point Offset Monitoring Method of Rotation Axis Based on Siemens 840D System

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Abstract: In order to monitor the abnormal condition that the zero point of the encoder does not coincide with the actual mechanical zero position in the full-closed control loop of a rotating axis, a Siemens 840D numerical control system based on abnormal condition inspection method is proposed. According to the gathered data by the measurement system of a rotating axis servo motor, the logical comparison program in PLC (Programmable Logic Controller) is developed to monitor the zero point of rotating axis by using Siemens 840D numerical control system and STEP7 software platform. The verification experiment results show that the proposed method can quickly identify the abnormal displacement of the zero point for a rotating axis and disable the servo motor in time, which can effectively avoid the poor quality problem caused by the abnormal condition in rotating axis.

1. INTRODUCTION
The five axis CNC (Computer numerical control) machine tool has the characteristics of fast feed speed and high precision, which makes it possible to process complex curved surface parts. The measurement system of each axis of five axis CNC machine tool adopts the form of full-closed control loop, as shown in Fig 1. As the last link, the position loop feedback device realizes the full closed loop control of the machine axis to ensure the machining accuracy. The common position feedback devices are grating ruler, photoelectric encoder, magnetic gate, etc., which must have high accuracy and sensitivity [1].
The position feedback system relies on two internal relative moving components (such as reading head and grating) to realize feedback of position. During installation, the two components are fixed on two relative moving components of the measured axis. For the rotating axis, the device can be roughly divided into integral type and split type based on its structure. The encoder is the common integral position feedback device, as shown in Fig 2. The distance between the reading head and the dial has been adjusted by the manufacturer. The rotary parts of the encoder are fixed on the rotating axis by mechanical locking, and driven by static friction [2]. The common split position feedback device include circular grating and a magnetic grating, as shown in Fig 3. The working principle of integral type and split type is the same, but it is necessary for split type to adjust the distance between the reading head and the dial during installation [3]. During the long time use of the machine, vibration or other factors may cause the loosening of the connection of the position feedback device. Such as the relative displacement between the inner ring of the encoder and the rotating axis, and the loosening of the reading head. Which may cause a slight relative displacement between the measuring part and the fixed part, resulting in the deviation of the zero mark of the rotating axis. While the position feedback system cannot achieve the loosening of its fixed connection inspection, therefore, often causes quality problems of parts. Different encoder combinations can be used for position feedback loop and speed feedback loop. Among them, "incremental - incremental" combination is the most common in machine tool configuration due to its reasonable price and high reliability. Because of the above problems may occur in the rotating axis with this configuration, this paper proposes a design of zero point offset monitoring of rotating axis based on Siemens 840D system.

![Figure 2. Integral type (encoder)](image1)

![Figure 3. Split type (circular grating)](image2)

2. **Analysis of zero mark’s offset of incremental position feedback device of rotating axis**

The working principle of the incremental position feedback device is to convert the relative displacement of a straight line or an angle into a periodic electrical signal, and then convert the electrical
signal into a counting pulse. The number of pulses is used to express the relative displacement, and indirectly calculating the mechanical displacement of machine tool axis [4]. But it is unable to output the absolute position of the rotation angle of the rotating axis, so it is necessary to increase a zero pulse of the encoder, and take the zero pulse as a reference to correct the memory position of the counting device. The machine axis with incremental position feedback system needs to return to the reference point every time when it turns on. There is usually only one zero pulse of the rotating axis position feedback system. In the Siemens 840D system, through the action of returning to the reference point, the system finds the unique mechanical position corresponding to the zero pulse of the rotating axis. And sets the offset value of the position with the parameters MD34080 & MD34090, to ensure the correspondence between the zero mark of the rotating axis and the mechanical zero position. The process is shown in Fig 4.

When the connection of the position feedback device is loose, it may cause the deviation between the zero pulse of the incremental position feedback device and its unique corresponding mechanical position, and the corresponding mechanical position of the zero mark will also change, that is, the zero offset. Because the offset is very small, the system will not give any alarm, and the rotating axis will still find the incorrect zero mark. The offset can’t be found by eyes, but there are great hidden dangers in the processing of parts with high precision requirements.

Take a five axis CNC machine tool with C and A rotating axis with Siemens 840D system as an example. The turning center distance of the machine is 300 mm and the length of machining tool is 100 mm. If the zero point mark of axis A is offset by -0.05 °. When the RTCP function is closed, execute the program A-30C0, and the actual mechanical position of axis A is -30.05 °. The error between the actual value and the theoretical value of the tool tip in the Y direction is $\Delta Y = -0.302 \text{ mm}$, and in the Z direction is $\Delta Z = 0.175 \text{ mm}$, as shown in Figure 5, such errors are unacceptable for aviation structures.

Due to the uncertainty of looseness of the connection, the machine tool state can be divided into two categories when the zero mark of the rotating axis is offset: ① there is a zero mark on the rotating axis; ② there is no zero mark on the rotating axis. In the case of type ①, there are many ways to detect or monitor, such as the comparison function of full closed loop and half closed loop in the safety integration function of Siemens 840D. In the case of type ②, there is no zero mark on the rotating axis
and no reference for the position. At present, such offset cannot be monitored. Through analysis, it is found that in this case, the normal operations that cause the zero mark offset or the operations after the offset are NCK (NC Realtime Kemal) reset, shutdown, JOG move, return reference point or combination of these operations. As shown in Fig 6, the zero mark offset of the rotating axis occurs at a certain point one or more links.

3. Principle of zero mark monitoring
Under the good condition for the mechanical transmission of machine rotating axis, the motor measurement system can reflect the actual mechanical position of axis, so it can be considered to use the motor measurement system to monitor the position in reverse.

Assuming that the zero mark on the rotating axis of the machine does not deviate and returns to zero normally (this assumption must exists). The angle of the actual mechanical position of the last stop is the same as the rotation displacement, which generated by the next time finding the zero mark of the rotating axis. Theoretically, the absolute value of this two angles is the same and the direction is opposite, as shown in Fig 7. If the difference between the two angles is out of the monitoring value, then it is considered that the new zero mark is offset.

4. Zero mark monitoring design
In the SIEMENS 840D system, if the two measuring systems of the rotary axis are incremental + incremental, we need to set the parameter MD30242 ($\text{MA ENC IS INDEPENDENT}[n]$) of rotation axis first. The parameter MD30242 [0] or MD30242 [1] of the motor measurement system is set to 1, making the motor encoder an independent encoder [5]. This means that after the rotating axis completes the zero return operation, the value of the motor measurement system will not be reset to zero when the position measurement system is reset to zero [6].

In case of zero mark on the rotating axis, the data of the motor measurement system is collected and stored in real time and recorded as $\alpha$. When the zero point is lost and before it return to the reference point, $\alpha_1$ is triggered by conditions to read $\alpha$, so $\alpha_1$ is the last actual mechanical position before the zero point is lost. After returning to the reference point, the data of the motor measurement system $\alpha_2$ is read ($\alpha_1 = \alpha$ at this time), that is, the rotation displacement when the zero mark is found again. Set the alarm threshold value, so that the value of $|\alpha_1 + \alpha_2| < $ threshold value is established, so as to achieve the purpose of monitoring. However, the experiment shows that $|\alpha_1 + \alpha_2| < $ threshold value is not established after multiple operations. There are two reasons:

① The incremental measurement system is powered on again after NCK reset / shutdown, and the
measurement system will clear the position value. After multiple times shutdown without zero mark, α₁ cannot correctly reflect the actual mechanical position when the zero point is lost, so it is necessary to record the last normal state of the rotating axis when returning to the reference point, the position value β of the motor measurement system, which can be read by α₃, and the triggering condition is the same as α₁. ②The rotation axis moves without zero mark, and the rotation displacement is recorded as Δₓ, and then NCK resets/shuts down. This operation can be performed multiple times, and there may have Δₓ₁, Δₓ₂ … Δₓₙ. Therefore, it is necessary to modify the above relationship. When the zero point of the next rotation axis does not offset, there is such a relationship between them

\[ |α₁+α₂-α₃+(Δₓ₁+Δₓ₂+… Δₓₙ) | < \text{threshold value} \]  

The number and value of Δₓ₁, Δₓ₂, … Δₓₙ are uncertain, and it is difficult to collect and store the data. However, if the operation of NCK reset/shutdown is performed every time when the rotating axis has zero mark, these data will be zero. And this operation is easy to achieve for normal machine operation. If a false alarm is caused by ②, we just need to reset the α₁, α₂, α₃ to zero through the NCK operation, and check the zero accuracy of the rotating axis. Based on this, the relationship can be simplified as:

\[ |α₁+α₂-α₃| < \text{threshold value} \]  

According to the relationship formula, α₁ and α₃ are both collected under the normal state of the rotation axis, and triggered by the condition when there is no zero mark, α₂ is collected by returning the rotation axis to the reference point when the zero point offset may occur. If the relationship does not hold, it means that the zero mark has offset after the rotation axis returns to zero. Based on SIEMENS 840D system, PLC is used to realize α₁, α₂, α₃ data collection. The specific process is shown in Fig 8.

Figure 8. Flow chart of monitoring design
5. Verification application of zero mark monitoring design

This design is applied in a five axis machining center with good mechanical transmission. In the case where the rotation axis is normally returned to zero, the following operations were carried out: NCK reset / shutdown at any angle within the allowable range → JOG moving after power on → return to reference point → moving → NCK reset / shutdown → JOG moving after power on → return to reference point. The specific values are shown in Table 1.

| Link | NCK reset at 10° | Move to 20° | Return to reference point | Move to 25° | NCK reset | Move to -35° | Return to reference point |
|------|-----------------|-------------|---------------------------|-------------|-----------|-------------|---------------------------|
| α    | 10.002          | 10.002      | -10.005                   | 14.998      | 14.998    | 14.998      | -25.001                   |
| α₁   | 0               | 0           | 10.002                    | 10.002      | 10.002    | -10.005     | 14.998                    |
| α₂   | 0               | 0           | -10.005                   | -10.005     | -10.005   | 10.002      | -25.001                   |
| α₃   | 0               | 0           | 0                         | 0           | 0         | 0           | -10.005                   |
| α₁+α₂-α₃ | 0       | 0           | -0.003                    | -0.003      | -0.003   | -0.003      | 0.002                     |
| threshold value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

Return to the reference point at any angle within the allowable range → NCK reset / shutdown → JOG moving after power on → Return to reference point → NCK reset / shutdown → Return to reference point, as shown in Table 2.

| Link | Move to -40° | Return to reference point | NCK reset | Move to 15° | Return to reference point | NCK reset | Return to reference point |
|------|-------------|---------------------------|-----------|-------------|---------------------------|-----------|---------------------------|
| α    | -39.997     | -0.002                    | -0.002    | -0.002      | -0.001                    | -0.001    | -0.002                    |
| α₁   | 0           | 0                         | 0         | 0           | -0.002                    | -0.002    | -0.001                    |
| α₂   | 0           | 0                         | 0         | 0           | -0.002                    | -0.002    | -0.001                    |
| α₃   | 0           | 0                         | 0         | 0           | -0.002                    | -0.002    | -0.001                    |
| α₁+α₂-α₃ | 0       | -0.002                    | -0.002    | -0.002      | -0.001                    | -0.001    | -0.002                    |
| threshold value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

It can be seen from the two tables that no matter what operation was performed, as long as the zero mark of the rotation axis is not offset, the value of $|α₁+α₂-α₃|$ will be stable in a small interval, so it can be monitored. In June 2019, when a five-axis machining center returned to the reference point, relative displacement occurred between the C-axis encoder inner ring and the mechanical rotation axis due to the loosening of the locking screw, which caused the C-axis zero mark to offset by 0.4°. The monitoring function successfully triggers an alarm to avoid parts accidents.

6. Conclusion

In this paper, aiming at the problem of zero point offset of rotating axis, a method of zero point offset detection of rotating axis based on Siemens 840D is proposed. The feasibility is verified by the experimental results, and it has been implemented and applied in several five axis CNC machines. It has the advantages of simple principle, strong operability, high sensitivity, strong reliability and easy maintenance. And it can effectively monitor the zero offset of the rotating axis. In the process of practical application, two problems of zero offset caused by loose measuring parts of rotating axis are found in time. Through this method, the accidents of parts are effectively prevented, and it provides a strong guarantee for the quality control of parts processing.
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