Fault Diagnosis of the FANUC CNC Lathe Analog Spindle Speed Mismatch

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Abstract: This paper takes the failure of the spindle command speed and the actual output speed mismatch caused by the CK6136 horizontal CNC lathe (FANUC-0i-TD system) produced by Dalian Dalian Machine Tool Plant as an example. The hardware connection and spindle override of the analog spindle control circuit are described. PMC program design, spindle parameter setting, inverter parameter setting and theoretical calculation of main parameters, etc., and successfully debugged on the CNC lathe in the laboratory.

1. Introduction
There are two kinds of spindle control modes for NC machine tools: simulated spindle control and serial spindle control. Analog spindle control means that the drive of machine tool spindle is realized by general Variable-frequency Drive, which drives ordinary three-phase asynchronous motor or special frequency converter to drive special frequency converter motor[2]. Because its speed control is analog (0-10V), which is abbreviated as analog control. The speed adjustment of analog spindle is realized by frequency modulation of frequency converter, which realizes the stepless speed change of motor, and then realizes the output of actual spindle speed through the transmission of mechanical system.

CK6136 horizontal CNC lathe is controlled by fanuc-0 i-td CNC system, spindle motor is YVF100 L2-4 three-phase asynchronous motor, relevant parameters of spindle are shown in table 1. The CNC system uses the "analog spindle" function to control the spindle, the hardware connection is shown in figure 1. The speed of the spindle comes from the JA40 interface, which connect the GND and AI1 Interface of the INVT CHE100 frequency converter. AI1 exports single electrode 0-10V Analog Voltage. The rotation direction is controlled by Y8.0, Y8.1 forward and reverse signals output by PMC in CNC machine, to actuate the corresponding KA3 and KA4 relay coils. The normally open contacts of KA3 and KA4 control the positive and negative ends of the frequency converter through the connection of s1-com or s2-com to realize the positive and negative rotation of the spindle motor[5].

![Analog spindle system structure diagram](Diagram.png)

a) Analog spindle system structure diagram.
b) Analog spindle control electrical schematic.

Figure 1. Analog spindle hardware connection.

Table 1. Parameters of CK6136 NC lathe spindle.

| Components                        | Parameter                      | Note                                                                                   |
|-----------------------------------|--------------------------------|----------------------------------------------------------------------------------------|
| Spindle Drive Module              | Model: INVT CHE100             |                                                                                        |
|                                   | Rated power: 5.5kW             |                                                                                        |
|                                   | Model: YVF100L2 -4             |                                                                                        |
|                                   | Rated power: 3KW               |                                                                                        |
| Spindle motor                      | Rated speed: 1430r/min         |                                                                                        |
|                                   | Frequency: 50Hz-100Hz          |                                                                                        |
| Connection mode of spindle and motor| V belt connection             | The diameter of the belt wheel of spindle and spindle motor are 120 and 80 respectively |
| Connection mode between position encoder and spindle motor | Synchronous belt connection | The number of synchronous belt gear teeth of position encoder and spindle motor are 20 and 40 respectively |
| Lines of position encoder in spindle | 1024                           |                                                                                        |

2. Material and Methods

① According to the spindle speed multiplier switch (as shown in figure 2), the gear X signal (X11.0, X11.2, X11.4, as shown in table 2) is passed into PMC, through G signal and corresponding parameter setting, the relation between CNC and the gear position and speed of mechanical parts is established, as shown in Figure 3.

Table 2. Spindle Ratio Combination Table.

| Ratio value | X11.0 | X11.2 | X11.4 |
|-------------|-------|-------|-------|
| Ratio value |       |       |       |

② Input instructions through the operation panel, CNC instruction decoding and corresponding processing, the speed command signal (actual spindle speed = specified spindle speed * spindle multiplier) is converted into analog voltage (voltage obtained by multiplying spindle multiplier) and transmitted to the frequency converter, frequency converter can convert the output voltage and frequency to motor to realize speed control.

③ The actual output speed of the spindle is fed back to the NC system through the spindle encoder, the matching relationship among instruction speed, actual output speed and screen display speed is realized[1].
3. Results

3.1 The analog spindle parameter

| Parameter | Meaning | Value | Note |
|-----------|---------|-------|------|
| 3706#6    | CWM, TCW: When output spindle speed, the voltage polarity is set to M03 / M04 polarity | 1     | 00: M03 is positive, M04 is positive 01: M03 is negative, M04 is negative 10: M03 is positive, M04 is negative 11: M03 is negative, M04 is positive |
| 3707#7    | Check spindle speed arrival signal (SAR) 0: N, 1: Y | 0     | Analog spindle does not have this signal. If set to 1, the spindle has no output signal |
| 3708#0    | No. 1 spindle amplifier | 1     | Use the spindle motor connected to amplifier # 1 |
| 3717      |         |       |      |
Function of spindle position encoder in NC lathe: To be able to process threads, the spindle motor shall be equipped with a spindle encoder, which rotates synchronously with the spindle as a feedback component of the spindle position signal to measure the speed, displacement and steering of the motor. In threading, the tool can move exactly 1 lead per turn of the spindle. If the spindle is 1024 P/rev, 4096 P/rev after 4 octaves (value of parameter 3720). The encoder sends pulses to the CNC, CNC control Z axis feed ball screw pitch 4096/1 distance, achieve synchronous control, ensure linear and continuous feed. In addition, the encoder also needs to output zero pulse Z per revolution in order to repeat turning the same thread without confusion[3].

Table 4. Gain adjustment of spindle speed analog output (parameter 3730 setting).

| Step | Content | Note |
|------|---------|------|
| 1    | Set standard Settings 1000. | |
| 2    | Specifies the spindle speed as the maximum speed of the spindle speed analog output (10V). | In MDI mode, enter M03S1500. The voltage between GND and AI1 of the converter terminal is measured and 10.05V is obtained. |
| 3    | Measuring output voltage. | The set value is 995 = \frac{10}{0.05} \times 1000. |
| 4    | Set the value of the following formula in the parameter (No.3730). \( \text{set value} = \frac{10 \times \text{Measure the voltage(V)}}{1000} \) | Reset this value in parameter 3730. In MDI mode, enter M03S1500. The voltage between the converter terminal GND and AI1 was measured to be 10.01V, which met the requirements. |
| 5    | After setting the parameters, specify the spindle speed to simulate the maximum spindle speed output voltage, and confirm that the output voltage is set to 10V. | |

Table 5. Compensation of analog output bias voltage of spindle speed (setting of parameter 3731).

| Step | Content | Note |
|------|---------|------|
| 1    | Set standard Settings 1000. | In MDI mode, enter M03S1500. |
| 2    | Specify the spindle speed as the minimum spindle speed analog output (0V). | |


3. Measuring output voltage. 

Set the value of the following formula in the parameter (No.3731).

The set value = \( -1.817 \times \text{bias voltage} / 12.5 \)

After setting the parameters, specify the spindle speed whose analog output is set to 0, and confirm that the output voltage has been set to 0V.

4. Frequency Converter Parameter Adjustment

Table 6. INVT CHE100 Frequency Converter Related Parameters.

| Parameter | Name                        | Set value | Instructions                                      |
|-----------|-----------------------------|-----------|---------------------------------------------------|
| P0.00     | Speed control mode          | 0         | 0: PG-free vector control; 1: V/F control; 2: Torque control. |
| P0.01     | Run instruction channel     | 1         | 0: Keyboard instruction channel; 1: Terminal instruction channel; 2: Communication instruction channel. |
| P0.03     | Frequency command selection | 1         | 1: Analog AI1 Setting; Analog input. Voltage range: 0-10V. |
| P0.04     | maximum output frequency    | 100       | Setting according to spindle maximum speed parameters and rated parameters of spindle motor. |
| P0.05     | upper limit of Operating frequency | 75 | P0.06-P0.05 ≡ P0.04 |
| P0.06     | Lower limit of operating frequency | 0 | Setting according to spindle minimum speed parameters. |
| P0.10     | Operating direction selection | 0      | 0: Running in the default direction; 1: Running in the opposite direction; 2: No operation. |
| P2.01     | Rated power of motor        | 4.0       | According to the rated current on the nameplate of the spindle motor. |
| P2.02     | Rated frequency of motor    | 50        | According to the rated frequency on the nameplate of the spindle motor. |
| P2.03     | Rated Speed of Motor        | 1430      | According to the rated Speed on the nameplate of the spindle motor. |
| P2.04     | Rated voltage of motor      | 380       | According to the rated voltage on the nameplate of the spindle motor. |
| P2.05     | Rated current of motor      | 7.8       | According to the rated current on the nameplate of the spindle motor. |
| P5.05     | Terminal control operation mode | 0 | 0: Two-wire control; 1: Two-wire control; 2: Three-wire control; 3: Three-wire control 2. |
| P5.07     | Lower limit value of A11    | 0         | According to the NC system output analog minimum value to determine. |
| P5.09     | Upper limit value of A11    | 10.0      | According to the NC system output analog maximum value to determine. |

Calculating the corresponding relation between upper and lower frequencies of frequency converter and Spindle Speed: Assuming that the minimum and maximum rotational speeds of the spindle are respectively \( 0 \) /min and \( 1500 \) r/min, the motor and spindle are driven by diameter 2:3 synchronous belt, the maximum spindle speed convert to the motor side speed is \( 1500 \div 2/3=2250 \) r/min. According the speed formula of three-phase AC asynchronous motor: \( N=(1-S)60F/P (Motor \ pole \ logarithm P = 2, \ slip \ S = 0) \), calculate the lowest frequency and the highest frequency as follows: \( 0\text{HZ} \leq \ 75 \text{HZ}[4] \).

4. Conclusions

Analog spindle frequency conversion control is widely used in economic CNC lathe, economical CNC milling machine, CNC transformation of ordinary lathe. The main control difficulty is the PMC program design of spindle ratio, analog spindle parameter debugging, frequency converter parameters debugging and theoretical calculation of the main parameters. This paper takes the CK6136 horizontal CNC lathe (fanuc-0i-td system),
which is produced by dalian machine tool factory as an example. The realization process of the analog spindle control system is described in detail, the solution to the above difficulties is pointed out, the CNC lathe of the laboratory was adjusted successfully.

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