Study on control scheme of on-line measurement system for key dimension of spinning head

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Abstract. According to the basic principles of roller measurement and displacement measurement, the on-line measurement system of the outer circumference and roundness tolerance and its control scheme are discussed. To implement automatic and real time measurement of circumference and roundness tolerance, the S7-200 PLC is selected as the controller, the STEP7-Microwin V4.0 is used for programming, the ladder diagram is used as the programming language. The motion simulation test of the measurement system is carried out, and the results show that the control scheme is feasible.

1. introduction

Heads are widely used in technical equipment such as boilers, chemical vessels, oil tanks, nuclear reactors, missiles and satellites[1]. The head is an important pressure bearing component as the end cover of technical equipment. In order to ensure the accuracy and quality of the butt joint between the technical equipment barrel and the head, reduce the amount of wrong sides and avoid the increase of structural stress, the outer circumference becomes the key dimension in the manufacturing process of the head.

When the head is spinning, the operator needs to stop to measure the outer circumference of the head with steel tape for many times, until the measured value meets the design requirement[2]. In this paper, in order to avoid the continuous stop machine to measure during spinning, the principle of on-line measurement and the composition of measurement system about the outer circumference and roundness tolerance of the head are analyzed, the on-line measurement control scheme is studied and the motion simulation test is carried out.

2. Measurement principle for the key dimension of the spinning head

2.1. Measurement principle for the outer circumference of head

The basic principle of the roller measurement method is shown in figure 1. The measuring roller keeps reliably contacting and purely rolling with the measured head. As long as the revolution ratio between the roller and the head is accurately measured, the outer circumference of the head can be obtained:

\[ L = \frac{N}{n} \pi d \]  

(1)

Notes:
L-the outer circumference of the head;
N-the revolutions of the roller;
n-the revolutions of the head;
d-the diameter of the measuring roller.

When the head on the spinning machine is spinning, in order to determine the revolution ratio between the roller and the head, the color marker sensor detects the color marker setting on the measured head end and records the revolutions of the head. The rotary encoder records the angular displacement of roller rotation and produces equidistant pulse signal, when measuring roller is purely rolling along the straight side of the head, because rotary encoder which fixed at the measuring roller bracket rotates coaxially with measuring roller. The pulse number of rotary encoder generated is constant named "equivalent pulse number", when measuring roller rotates a round. The ratio of the total number of pulse generated by the encoder to the equivalent pulse number in a counting cycle is the ratio of the number between the roller and the head if setting one counting cycle for each revolution of the head. Then the circumference can be calculated according to formula (1). The outer circumference value of the head is updated once in each counting cycle. With the spinning process, the outer circumference value of the head is constantly updated until reaching the preset value. Then the spinning and the circumference measurement stop.

2.2. Measurement principle for roundness tolerance of spinning head

If there is roundness tolerance in the straight side of the head, the radial deviation must be generated respected to the "true circle", the roller in contact with the straight side of the head will produce radial runout. In figure 2, the inner circle is the circumscribed circle of minimum radial runout, the outer circle is the circumscribed circle of maximum radial runout[3], and “W” is the difference between the maximum radial runout of the roller and the minimum radial runout of the roller. The radial runout value of the roller is transformed into displacement of the roller’s bearing shaft which is collected by the displacement sensor, roundness tolerance of head is obtained from displacement.

![Figure 1. Measurement principle of roller.](image)

![Figure 2. Measurement principle of roundness.](image)

3. Structure composition of the on-line measurement system

According to the principles of "roller measurement method" and "displacement measurement method", the composition of the on-line measurement system of the outer circumference for the spinning head is shown in figure 3. The measurement system consists of a measuring mechanism, a damping mechanism which prevents the measuring roller sliding, a horizontal and vertical self-adaptive adjustment mechanism, control unit etc. Measuring mechanism is composed of the roller, the rotary encoder, the sensor group and the color marker on the head end.

4. Flow scheme design of the online measurement system

The flow scheme of key dimension on-line measurement system is shown in figure 4. When the color marker on the head end is detected by color marker sensor, the high-speed counter of PLC begins to count the number of rotary encoder pulse, until the color marker sensor detects the color marker again. The pulse number “n” will be transmitted to the numerical calculation counter to calculate the outer circumference. If the circumference does not match the design requirement, the spinning continues and the high-speed counter of PLC counts the pulse number of rotary encoder again until the circumference reaches the design requirement, then the circumference and roundness tolerance are output, and the spinning and the measuring process stop.
5. Hardware selection of the measurement system

The control unit of measurement system adopts Siemens PLC controller named S7-200. The input module of PLC external connection has vertical positioning sensor group, horizontal positioning sensor group, rotary encoder and eddy current displacement sensor, the output module of PLC consists of motor and touch screen.

The rotary encoder records the angular displacement of roller rotation and produces equidistant pulse signal, omron incremental rotary encoder is selected to count the revolutions of the roller in this paper. The model is E6B2-CWZ6C (1000P/R) 0.5M, the supply voltage is DC5-24V, it has load short circuit protection, strong anti-interference ability and high reliability.

The color marker sensor detects the color marker on the head end to measure the revolutions of the head[4]. Panasonic color marker sensor is used and the light input of color code and background color can be confirmed through 4-digit display.

The limit position of the cross slide table in the horizontal and vertical directions is mainly controlled by the limit sensor[5]. Considering the spinning processing technology and the processing environment, omron inductance proximity switch (E2E-X7D1-N) is selected, and the DK960 eddy-current is selected as displacement sensor which has strong anti-interference ability.

6. Software design and main program description

6.1. Control scheme of the measurement system

As shown in figure 5, the measuring mechanism (including compression and vibration reduction mechanism) and the vertical adjustment mechanism can be accurately positioned in the X direction under the control of the X-axis stepping motor and the inductive proximity switch. Vertical adjustment mechanism and measuring mechanism can be accurately positioned in the Z direction under the Z-axis stepping motor and the control of induction proximity switch. The high-speed counter of PLC counts the number of pulse sent by the rotary encoder which is rotating coaxially with the roller. The color marker sensor on the roller bracket detects the color marker on the head end and transmits it to the PLC controller. When the PLC controller receives the head color marker again, the circumference value is updated once. Two eddy current displacement sensors detect the displacement of the sliding shaft, and they respectively control the spring’s pre-compression amount and detect the head’s roundness information. If the circumference value of the head meets the design requirement, the value of the outer circumference and roundness tolerance are displayed on the touch screen. Then the PLC controller sends out the instruction, the spinning and the measuring process stop.

6.2. Main procedures of the measurement system

6.2.1. High-speed counter instruction. The pulse generated by the rotary encoder is automatically counted to obtain rotating revolutions of measuring roller with the high-speed counter of PLC named “HSC0”. Its working mode is single channel pulse input, and controls the third bit of byte which is
used for adding count. 10.0 input terminal is used as pulse input terminal, ladder diagram is shown in figure 6.

6.2.2. **Interrupt instruction.** When the color marker sensor detects the color marker at the head end, the control system executes a short interrupt and generates an impulse signal, the system automatically executes the high-speed counter instruction after processing. When the color marker sensor detects the color marker again, the control system executes a short interrupt instruction again, and generates the pulse signal. The interval between the two pulse signals represents one revolution of the head. Ladder diagram of interrupt instruction is shown in figure 7. This system includes timer interruption which number is “0”, and the event number is “10”. The sampling period 250ms in the main program is written to special memory “SMB34”, and break time “10” is connected with INT_0, so the model is open global disruptions.

6.2.3. **Calculation for the outer circumference of head.** Analog signal “AIW2” which is produced by high-speed counter is transformed into digital signal “VW22” through mobile word instruction “MOV_W”. As shown in figure 8, when “VW22” is greater than 80, the head has rotated a circle. The data is screened to determine whether the outer circumference conforms to the design requirement with the interrupt command, and the instantaneous circumference value “VD120” is output in real time. Until the outer circumference conforms to the design requirement, the circumference value “VD108” is output.

6.2.4. **Roundness tolerance measurement.** Analog signal “AIW0” which is produced by displacement is transformed into digital signal “VW20” through the mobile word instruction “MOV_W”, then digital signal “VW20” is transformed into the double word “VD312” to get the radial instantaneous runout by the arithmetic operation instructions. In the process of measurement, the data of radial instantaneous runout can be displayed on the touch screen in real time, because the PLC is connected with the touch screen by PPI protocol. As shown in figure 9, the maximum runout “VD330” and the minimum runout “VD320” can be obtained by the comparison instruction in every revolution of the head. The contact will be closed when the comparison instruction is established, otherwise it will be disconnected. Finally, as shown in figure 10, the calculation instruction “SUB_R” is used to calculate
the maximum runout “VD330” and the minimum runout “VD320” to obtain the roundness tolerance value “VD340”. After the measurement is completed, the roundness tolerance value can be cleared by reset button.

![Figure 9. Ladder diagram of roundness tolerance.](image)

Figure 9. Ladder diagram of roundness tolerance.

![Figure 10. Ladder diagram of clearing value.](image)

Figure 10. Ladder diagram of clearing value.

7. Simulation test
As shown in figure 11, the control system sends out instructions to control the motor rotation when the head is spinning, and the horizontal adjustment mechanism moves to the preset position(The preset value is related to the head size and obtained by the test), then the vertical adjustment mechanism starts to move. When the sensor detects the color marker which is on the head end, the vertical adjustment mechanism stops moving. After the system detects the roller which starts to rotate, the horizontal mechanism still needs to move 3mm to position “5”. Then the spring provides the compression force to avoid slipping between the roller and the straight side of head. The rotary encoder sends out pulses continuously during measurement. When the sensor detects the color marker on the head end for the first time, the high-speed counter of PLC starts to record the number of encoder pulse as “n”. Each time the sensor detects the color marker, “n” is sent to the numerical calculation program, until the color marker is detected again, the “n” is sent into the calculation program again. The head turns round and the circumference information is updated once, and it is displayed on the touch screen.

As shown in figure 12, color marker on the head end has just been identified, the circumference value of the head whose diameter is 1000mm is shown in the digital tube.

![Figure 11. Motion sequence.](image)

Figure 11. Motion sequence.

![Figure 12. Effect diagram of motion simulation.](image)

Figure 12. Effect diagram of motion simulation.

8. Summary
The measuring principle and method for outer circumference and roundness tolerance of the head are analyzed in this paper. Based on the online measuring structure for key dimension of the spinning head, the control process and control scheme based on the Siemens PLC controller are designed, the hardware selection and software programming of the control scheme are completed, and the motion simulation test is finished. The test result shows that the control scheme is feasible.

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