Radial Displacement Sensor for Measuring Rotor Axial Displacement

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Abstract: In the magnetic bearings, often used the method of axial displacement of rotor in axial detection, but it can not meet the application requirements of some space constrained occasions. In this paper, to solve this problem, the method of measuring the axial displacement of the rotor with the radial mounting sensor is studied. Experimental results show that this method is feasible.

Keywords: Sensor, Radial mounting, Axial displacement

1 INTRODUCTION
In the magnetic bearings, the axial displacement of rotor is often measured by the eddy current sensor installed on the rotor shaft end face. The axial detective method in axial displacement of the magnetic suspension rotor is suitable for most applications, but it can not meet the application requirements of some space constrained occasions. For this reason, this paper studies the method of measuring the axial displacement of the rotor with the radial mounting sensor.

Fig. 1 shows a measured rotor with a step on the rotary surface. Z axis is the center of rotation of the rotor. The coordinate origin is located at the intersection between the step surface and the Z axis. The eddy current sensor is installed vertically on the rotor surface. The center of the sensor probe and the ladder line projection are located on the X axis. d is the height of sensor installation detection clearance and h is the height of the ladder. When the measured rotor moves along the Z axis, the active area of the sensor and rotor can be changed by the step surface of the rotor. Thus the output voltage of the sensor is changed, the axial displacement of rotor in the Z axis is detected.
FIGURE 1. Schematic diagram of the radial mounting sensor to detect the axial displacement.

As shown in Fig.1, when the rotor moves along the Z direction, if the measured rotor moves in the X direction and in the Z direction, the output voltage of the sensor not only reflects the axial displacement of the measured rotor in the Z direction, but also reflects the radial displacement in the X direction. Formula (1) gives the approximate linear relationship of the three variables (U, z, and d).

\[ U = k_z z + k_x x + U_0 \]  

Where U is the output voltage of sensor, \( k_z \) is the detection sensitivity of the rotor axial displacement, \( k_x \) is the detection sensitivity of the sensor axial displacement, \( x \) is the displacement distance along the axial direction of the sensor, \( z \) is the displacement distance along the axial direction of the rotor, and \( U_0 \) is the constant.

2 Test and Analysis

The displacement of rotor is measured by the three coordinate measuring instruments which are shown in Fig.2. The measuring instrument is composed of three orthogonal linear motion axes, and each axis is provided with a spiral micrometer. The measuring precision is 0.01mm. The measuring instrument is installed on the big table of shock absorption. The sensor is fixed on the small worktable which can move up and down at the front end of the measuring instrument. Accurate positioning of the sensor can be achieved by manually rotating the screw micrometer on each axis. The detection range of eddy current displacement sensor is 2mm, and the linear range is 0.3-2.3mm.
FIGURE 2. Three coordinate measuring instrument.

2.1 In the Case of Constant Ladder Height, the Influence of Sensor Installation Clearance on the Axial Displacement Measurement

When the step height of the rotor is constant, the sensor installation clearance height is gradually changing, then to observe the influence of axial displacement. In this paper, the height of the ladder on the rotor is fixed to 1.1mm. In order to ensure that the rotor surface of the ladder is located in the sensor detection range, the detection range of the sensor installation is 0.3-1.2mm. The height of radial clearances are shown in Table 1. The step 0.01mm micrometer continuous changes the Z axial displacement of rotor, and record the output voltage of the sensor. The test results are shown in Fig.3 and the 8 curves in the figure are the relationship between the output voltage of the sensor and the axial displacement of the rotor.

| Serial number | d₁ | d₂ | d₃ | d₄ | d₅ | d₆ | d₇ | d₈ |
|---------------|----|----|----|----|----|----|----|----|
| Radial mounting clearance (mm) | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |

FIGURE 3. The effect of sensor installation clearance on axial displacement detection.

As can be seen from Fig.4, (1) When the stepped surface is located in the sensor center on both sides of the -0.2 - 1.4mm, the sensor output linearity is
better; (2) In the detection range of the sensor, the change of detection installation clearance has no effect on the axial displacement measurement.

Move the sensor center along the Z direction to the \( z=0.6 \) mm, so that it is in the middle of the linear interval. The test results are shown in Fig.4.

![Sensor Mounting Clearance](image)

**FIGURE 4.** Effect of Sensor Mounting Clearance in the Case Of Step Height \( H=1.1 \text{mm} \) \((Z=0.6\text{mm})\).

As shown in Fig.3 and 4, when the step height is 1.1mm, the linear interval is partially located on the lower surface of the ladder, and the linearity of the sensor is better between \( z=-0.2 \) - 1.4mm.

### 2.2 Influence of Different Step Height on Sensor Detection

The sensor installation mode is shown in Figure 1. When the height of installation clearance is an appropriate value, the height of the ladder has an impact on the sensor's detection sensitivity.

(1) Sensor Installation Clearance \((D=0.3\text{mm})\)

The output voltage of the sensor is measured for different step heights. The height of the ladder has five different heights, namely 0.5mm, 1.2mm, 1.5mm, 1.8mm and 2mm. When the sensor center is located in \( z=0.6 \) mm, the rotor moves along the Z axis. The moving range is \( \pm3.8 \) mm from 3.2mm to 4.4mm. When the height of the installation clearance \((d)\) is 0.3mm, under different step height \((h)\), the measured data curve is shown in Fig.5.

![Sensor Output vs Axial Displacement](image)

**FIGURE 5.** The Relationship between the Output of the Sensor and the Axial Displacement of the Rotor.
(2) Sensor Installation Clearance (D=0.8mm)

There are three different step heights, namely 0.5mm, 1.2mm, 1.5mm. When the ladder is different height, the output of the sensor is measured respectively. When the sensor center is located in z=0.6mm, the rotor moves along the Z axis. The moving range is ±3.8mm from 3.2mm to 4.4mm. When the height of the installation clearance is 0.3mm, under different step height, the measured data curve is shown in Fig.6.

FIGURE 6. The Relationship between the Output of the Sensor and the Axial Displacement of the Rotor.

Comparison of Fig.5 and 6 can be seen: (1) As long as the ladder is within the linear range of the sensor, the change of the sensor installation clearance has no effect on the axial displacement detection. (2) The sensitivity and linearity of sensor are affected by different step height, and it is not related to the height of the installation clearance.

2.3 The Influence of the Radial Displacement of the Measured Axis on the Sensor Detection

The sensor installation mode is shown in Fig.1. The diameter of the rotor is 52mm and the ladder height is constant (h=0.9mm). There are three different height of the installation clearance, namely 0.3mm, 0.5mm, 0.7mm. When the sensor center is located in z=0mm, the rotor moves along the Z axis. The moving range is ± 0.7mm. The corresponding curves are shown in Fig.7.
As can be seen from Fig.7, (1) When the moving distance of the rotor in the Y direction is far less than the diameter of the measured rotor, the change of the sensor output voltage is very small. (2) The influence of sensor mounting clearance on the radial displacement of the measured shaft is not obvious.

2.4 Eliminating the Influence of X Direction Displacement on Axial Displacement Detection

As shown in Fig.8, in order to eliminate the influence of the displacement variation of the X direction on the axial displacement detection, two sensors can be installed on the YOZ plane symmetrically. The two sensors have the same output characteristics. They are installed symmetrically in the Z direction. The distances to the rotor are respectively $d_1$ and $d_2$, and sum of distance is $d_1+d_2$. This does not exceed its linear measurement range. It is assumed that the sum of distance between the two sensors ($d_1+d_2$) is 1.3mm. Figure 3 data can be used to simulate the working state of the two sensors. When $d=d_1+d_6=d_2+d_7=d_3+d_4=1.3$mm, the output voltage is shown in Fig.9. The three group output voltage is almost the same; the results show that when the two sensors are symmetrically arranged and the axial displacement of the rotor is measured, the variation of the rotor radial displacement (i.e., the change of the distance $d$) has little influence on the axial displacement of the rotor.
3 CONCLUSION
The experimental results show that the radial eddy current sensor can accurately measure the axial displacement of the rotor, which verifies the correctness and feasibility of the radial displacement sensor for measuring rotor axial displacement. The results show that it is feasible to use the eddy current sensor to measure the axial displacement of the rotor. This study extends the application of eddy current sensor, which has theoretical and practical significance.

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