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Accuracy analysis of eccentric testing of revolving body based on moment balance principle

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Abstract. The eccentricity test of the rotary body has a wide range of applications in aerospace, precision machinery and other fields, using the principle of torque balance, small-range sensors can be used to test the eccentricity of larger quality products, through a small range of the sensor to feel the changes brought about by the lateral force centroid of the rotary body, thereby improving the sensitivity of the test device to measure the transverse centroid, improve test accuracy, eccentricity measurement error caused by random errors and systematic errors, random error is caused by the measurement error of the weighing sensor, system error is caused by inaccurate measurement and inaccurate quality measurement. Through the analysis of the accuracy of the eccentricity test, the accuracy of the eccentricity test can be controlled within 0.005 mm.

1. Introduction

Eccentric testing is widely used in military and civilian fields [1,2]. Eccentricity test usually adopts the knife edge technique, for the eccentricity test equipment of the rotary body, the structure in which the knife edge and the V groove are matched between the measuring probe and the blade support is called a knife edge structure, taking the symmetry lines of the two edges as the fulcrum, the center of mass perpendicular line with the measured object is spaced as a short lever arm, the distance between the force points of the force sensor pre-arranged with the equipment is a long force arm of the lever, the ratio of two force arms is realized by a mechanical amplification mechanism to achieve a larger magnification, in other words, the sensor with a smaller range can feel the measurement of the imbalance caused by object eccentricity, this technology is the measurement technology of edge eccentricity. The knife edge eccentricity test technique uses the torque balance principle to achieve eccentricity measurement through precise mechanical structure, and obtains high test accuracy [3-6].

2. Principle of Eccentricity Test

The principle of eccentricity measurement of the rotating body is shown in Fig.1, the rotating body is placed in the clamping part of the projectile, the clamping part is placed on the knife edge through the measuring frame and can be adjusted horizontally, one end of the eccentric measuring arm is fixed to the measuring frame, the other end is equipped with an eccentric sensor, the eccentric sensor is connected with the computer for data acquisition and processing. When measuring, the measuring



system is in eccentric state by measuring the position of the mass and eccentricity. When the measuring table drops, the two probes installed in the axis direction of the measuring table fall on the two knife edges of the instrument base. By measuring the data changes on the eccentric sensor and according to the principle of moment balance, the eccentricity of the projectile can be measured [7,8].

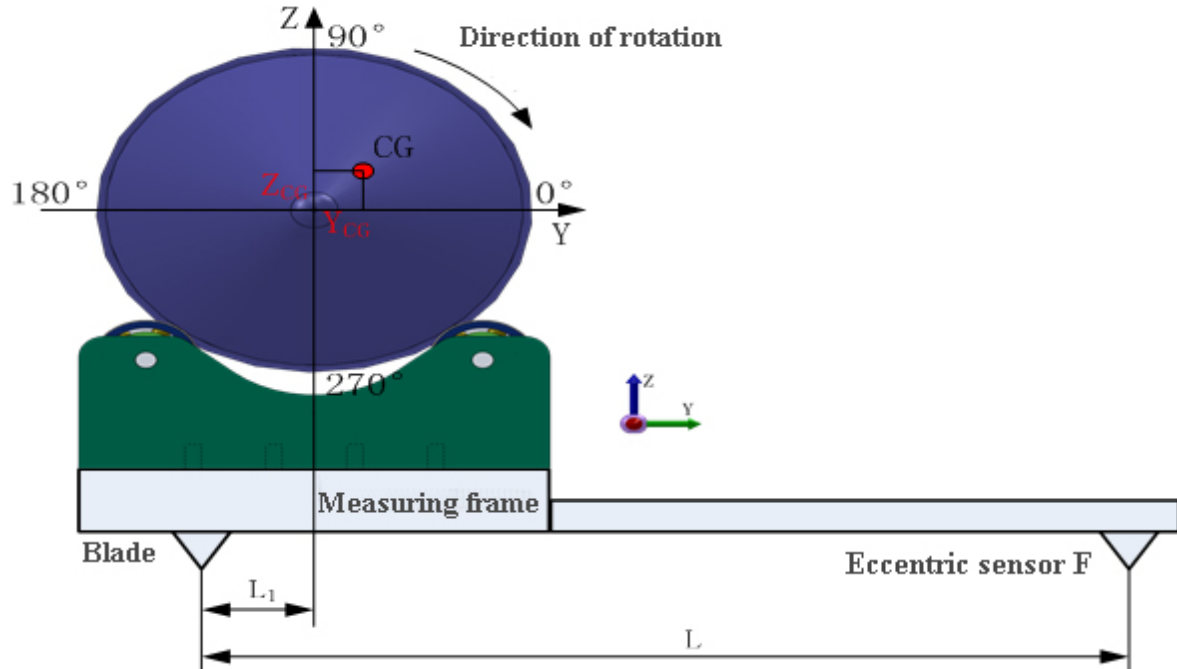


Figure 1. Schematic diagram of eccentricity measurement principle

The rotation of the revolving body is accomplished manually, and the angle control is used to draw the quarter busbar on the rotary body, the completion is determined manually according to the pointer indicating the position of the quarter busbar with fixed relative position.

In order to measure the eccentricity, it is necessary to measure four times, that is, at $0^\circ, 90^\circ, 180^\circ, 270^\circ$ position measurement, the pressures $F_1, F_2, F_3,$ and F_4 of the sensors at the four positions are sequentially obtained. According to the torque balance principle, four equations can be obtained:

$$(Y_{CG} + L_1)P = F_1 L \quad (1)$$

$$(Z_{CG} + L_1)P = F_2 L \quad (2)$$

$$(L_1 - Y_{CG})P = F_3 L \quad (3)$$

$$(L_1 - Z_{CG})P = F_4 L \quad (4)$$

Solving this equation is:

$$Y_{CG} = \frac{1}{2P}(F_1 - F_3)L \quad (5)$$

$$Z_{CG} = \frac{1}{2P}(F_2 - F_4)L \quad (6)$$

In the formula:

P — The weight of the revolving body;

Y_{CG} — The Y direction eccentric of the revolving body;

Z_{CG} — The Z direction eccentric of the revolving body;

L_1 — Distance from the edge of the knife to the axis of the rotor;

L — Measuring the distance from the eccentric sensor support point to the knife edge.

Due to the installation of the load cell in the lateral direction and the principle of mechanical amplification, the sensor can be used in a small range. During the rotation of the revolving body, the small sensor is used to feel the change of the force due to the horizontal centroid of the object. This structure increases the sensitivity of the test equipment to measure the lateral centroid while achieving high test accuracy.

The data acquisition system of measurement quality and eccentricity is common, it is responsible for transmitting the electrical signal from the sensor to the computer through A/D conversion, the results are calculated by the program to calculate all the measured data, and output as a certain report as needed.

3. Accuracy Analysis of Eccentricity Test

According to the eccentricity measurement principle in the Y direction, the eccentric Y direction of the tested object can be measured by using formula (5). From the above calculation formula, it can be known that the measurement error of the eccentricity in the Y direction is composed of two parts: random error and systematic error. The random error is introduced by the measurement error of the weighing sensor. The systematic errors are introduced due to inaccurate measurements and quality measurements. The following is to estimate the random error:

$$\sigma Y_{random} = \sqrt{\left(\frac{\partial Y_{CG}}{\partial F_1} \partial F_1\right)^2 + \left(\frac{\partial Y_{CG}}{\partial F_3} \partial F_3\right)^2} \quad (7)$$

Further get:

$$\sigma Y_{random} = \frac{L}{2P} \sqrt{(\partial F_1)^2 + (\partial F_3)^2} \quad (8)$$

Since only the eccentricity measuring sensor is used in the Y-directional eccentricity measurement process, therefore, $\partial F_1 = \partial F_2 = \partial F$, the formula for calculating the Y-direction eccentric random error can be simplified as:

$$\sigma Y_{random} = \frac{L}{\sqrt{2}P} \partial F \quad (9)$$

From the above eccentricity error analysis, it can be seen that the lighter the mass of the object to be measured, the lower the accuracy of the centroid test.

The systematic error is introduced due to the inaccurate measurement of L and the inaccuracy of mass measurement, the systematic error introduced by them can be estimated by the following formula.

$$e Y_{system} = \sqrt{\left(\frac{(F_1 - F_3)}{2P} eL\right)^2 + \left(\frac{(F_1 - F_3)}{2P^2} L eP\right)^2} \quad (10)$$

Since the force of the eccentricity sensor is basically the same when testing the Y-direction eccentricity, the comprehensive system error of the Y-direction eccentricity test can be approximated to 0:

$$e Y_{system} \approx 0.0 \quad (11)$$

Combining all the above errors, the comprehensive error of the Y-direction eccentricity test is:

$$\sigma Y_{CG} = \sqrt{(\sigma Y_{random})^2 + (e Y_{system})^2} \quad (12)$$

The Z-direction eccentricity test error analysis method is exactly the same as the Y-direction eccentricity error analysis method, and the size is the same as the Y-direction eccentricity comprehensive test error, the comprehensive error of the Z-direction eccentricity test is:

$$\sigma Z_{CG} = \sqrt{(\sigma Z_{random})^2 + (e Z_{system})^2} \quad (13)$$

4. Eccentricity calculation

It can be seen from the eccentricity error analysis of equation (9) that the lighter the mass of the object to be measured, the lower the accuracy of the eccentricity measurement. Therefore, we take a lighter test object $P=8\text{kg}$ and substitute it into the random error calculation formula for analysis. According to the foregoing, the weight of the load cell is $0.05P=0.4\text{kg}$. Therefore, the range of the eccentric test sensor is 1kg , and the accuracy is 0.02% , the length of the eccentric arm is $L=12.5/0.05=250\text{mm}$, then

$$\sigma Y_{CG} = \sqrt{(\sigma Y_{\text{random}})^2 + (\sigma Y_{\text{system}})^2} = \frac{L}{\sqrt{2}P} \sigma F = 0.0044\text{mm}, eY_{\text{system}} = 0 \quad (14)$$

therefore,

$$\sigma Z_{CG} = \sigma Y_{CG} = 0.0044\text{mm} \quad (15)$$

5. Conclusion

Using the torque balance principle, the sensor with a smaller range can feel the imbalance brought by the object's eccentricity, get higher test accuracy. By testing the pressure on the sensors at the four locations, then, the eccentricity of the rotating body in both the Y-axis and the Z-axis is obtained by the torque balance principle. The systematic errors of eccentricity testing include random errors and systematic errors, the random error of the eccentricity test can be ignored, and the systematic errors need to be estimated. Through calculation and analysis, the integrated system error in Y axis direction is 0, and that in Z axis direction needs to be calculated. Through the analysis of the accuracy of the eccentricity test, it can be known that the eccentricity test accuracy can be controlled within 0.005 mm , which can provide theoretical and technical support for the test of the eccentricity of the rotator.

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