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A new Multi-position calibration method for gyroscope's drift coefficients on centrifuge

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ABSTRACT

In order to accurately calibrate the gyroscope's drift coefficients, the coordinate systems are established on precision centrifuge with counter-rotating platform, and the corresponding error sources of each coordinate system are analyzed. The precise input angular rate along each axis of gyroscope are derived by homogeneous transformation method and also the nominal input specific forces are given. The precise expression of each drift coefficient is provided combining with gyroscope's error model, input specific forces and angular rates of gyroscope at the 16-position. And the compensation for the identification results can be conducted by the expression. It can be shown that through simulation two coefficients are significantly influenced by centrifuge errors when using the 16-position calibration method, and centrifuge errors have no impacts on other coefficients, which proves that the method can effectively eliminate the impacts of centrifuge errors. Only several centrifuge errors should be considered in actual calibration such as the perpendicularity between the counter rotating platform's revolving axis and the working base, the wobbles of counter rotating platform, and the difference between the angular rate of counter rotating platform and the one of the main axis.

1. Introduction

As a necessary inertial device, gyroscope supplies an important angular rate to the inertial navigation system, and the corresponding attitudes can be calculated for aircraft, so the accuracy of the gyro directly affects the inertial navigation system's precision. Limited by low precision of the measurement device and low input specific force of 1g for exciting the gyro, the calibration of gyroscope was also constrained. For low inspiration could not fully excite the high order drift coefficients, the development of navigation system was inhibited [1–6]. Centrifuge could supply high input specific force for gyro by the centripetal acceleration of revolution, making the high order drift coefficients' calibration be more possible [7–16]. However in real calibration, the accuracy of calibration is largely impacted by centrifuge errors, and more consideration should be made in the errors for the high requirement of accuracy of gyro. So how to decrease the influence of the errors should be considered into the calibration method. Few methods were designed on calibration of gyro, a method using centrifuge with counter-rotating platform was given in literature [2], while it was so complex that huge data should be sampled and the testing method was also trivial by introducing 'rate platform'.

In this paper, a simple and practical method with multiple position for calibration of gyro was suggested, and a 'position platform' was introduced. All sorts of possible error sources of the centrifuge with counter-rotating platform were analyzed, and the corresponding coordinate systems were established. Furthermore the precise expressions of the angular rate inputs of gyro were also derived by using homogeneous transformation method, as well as the input specific force of each axis. Combining with the follows (the gyro outputs at special position, the derived angular rates, the input specific force and the static error model of gyroscope), each expression of drift coefficient could be acquired, and the calibration accuracy can be improved by error compensation.

2. Calibration equipment and error sources

In order to eliminate the effect of translational motion, the centrifuge with counter-rotating platform is in choice, shown in Fig. 1.

Fig. 1 is the schematic figure of precision centrifuge with counter-rotating platform, in which 'A' is the main axis of centrifuge, 'B' is the revolving axis of counter-rotating platform. In ideal condition, the angular rate of the main axis equals to the rate of counter rotating platform, while opposite in direction. A positional platform which supplies different positions (0–360°) for calibration is designed on the counter-rotating platform, rotating around axis 'C'.

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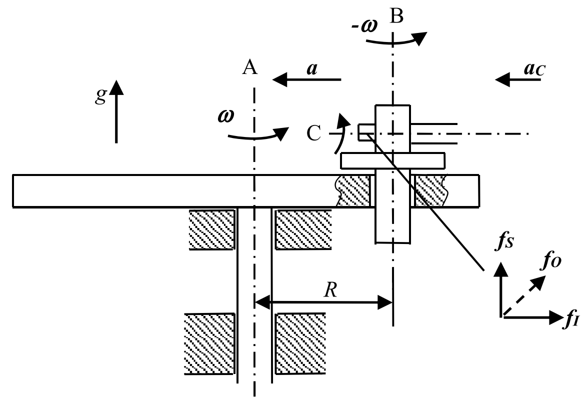

Fig. 1. Schematic figure of precision centrifuge with counter-rotating platform.

The acceleration of the gyro's input axis can be expressed as follows without considering the effect of positional platform, according to direction of input axis in Fig. 1

$$f_I = -R\omega^2 \cos(\omega t + \gamma_0) \tag{1}$$

In which, γ_0 is the starting phase angle between input axis of gyro and the centripetal acceleration a at the beginning of the measurement.

As the calibration accuracy is affected by centrifuge errors, the error sources should be analyzed and corresponding coordinate systems should be established. The attitude errors can be propagated by using homogeneous transformation, and the impact of errors on the calibration accuracy of drift coefficients can be obtained.

The coordinate systems on centrifuge and the corresponding errors as well as the homogeneous transformation expressions are shown in Table 1, in which the errors listed are the same as in literature [2]. It should be pointed out that $\Delta\theta_{x3t}$, $\Delta\theta_{z3t}$ stand for the perpendicularities between the axis of positional platform and the axis of count-rotating platform; $\Delta\theta_{x3}(\omega t)$, $\Delta\theta_{z3}(\omega t)$ are the wobbles of the positional platform.

3. Correspondence between centrifuge errors and the input angular rate or input specific force

The accuracy of gyro calibration is determined by the precision degree of input angular rate, for the gyro is sensitive to the angular rate which is relative to the inertial space on the carrier. So the input angular rate ω_I of gyro relative to inertial space is largely impacted by attitude errors of centrifuge when gyro is calibrating on centrifuge. For the translational motion can be eliminated by counter-rotating platform, separating the input angular rate in ideal condition, the input angular rate can still be impacted by the difference between the main axis's rate and the counter-rotating platform's rate, thus the input angular rate can be expressed as:

$$\begin{aligned}\omega_I &= \left[(k_1\cos\gamma - k_2\sin\gamma)\omega + \omega_e\cos\varphi\right]\cos\beta \\ &\quad + (\Delta\omega + \omega_e\sin\varphi)\sin\beta\end{aligned} \tag{2}$$

in which:

$$k_1 = \Delta\theta_{y2t} + \Delta\theta_{y2}(-\omega)$$

$$k_2 = \Delta\theta_{x2t} + \Delta\theta_{x2}(-\omega)$$

$$\gamma = \omega t + \gamma_0, \qquad \beta = \omega t.$$

$\Delta\omega$ is the difference between the main axis rate and the and the counter-rotating platform rate, ω_e is the rotational angular rate of the earth, φ is the latitude of the local place.

Although the input specific force of each axis of gyro is influenced by centrifuge errors, the input of gyro is only described as nominal value, for the drift coefficients themselves are quite little in value, thus the input specific force of each axis considering the Coriolis acceleration can be expressed as:

$$a_I = (-A - A_k)\cos\gamma\cos\beta + \sin\beta \tag{3}$$

$$a_O = -A\sin\gamma \tag{4}$$

$$a_S = (A + A_k)\cos\gamma\sin\beta + \cos\beta \tag{5}$$

in which $A = \omega^2 R_0/g$; $A_k = -2\omega R_0\omega_e\sin\varphi/g$, R_0 is the nominal value of the centrifuge radius.

4. Static model error of gyro

The general form of static error model of gyro is shown as follows:

$$\begin{aligned}\omega_d &= \omega_I + d_F + d_I a_I + d_O a_O + d_S a_S + d_{II} a_I^2 \\ &\quad + d_{OO} a_O^2 + d_{SS} a_S^2 + d_{IO} a_I a_O + d_{IS} a_I a_S \\ &\quad + d_{OS} a_O a_S + \sigma_\omega\end{aligned} \tag{6}$$

In expression (6), ω_d is the equivalent output of gyro's angular rate, the unit is °/h; a_I, a_O, a_S are components of input specific force along input axis IA, output axis OA and spiral axis SA respectively; d_F is the zero bias, the unit of which is °/h; and ω_I is the angular rate along the input axis; d_I, d_O, d_S are first order drift coefficients, the unit of which is °/h /g; d_{II}, d_{OO}, d_{SS} are second order drift coefficients, the unit of which is °/h/g^2; d_{IO}, d_{IS}, d_{OS} are cross drift coefficients, the unit of which is °/h/g^2; σ_ω is residual error.

5. Calibration method of gyro on centrifuge

8 positions are often adopted for calibrating d_F, d_I, d_O, d_S when the calibration of the drift coefficients are in the 1g gravity field, while the premise is the ignorance of high order drift coefficients. As the calibration of each gyro's drift coefficient conducted under the condition shown in Fig. 1, not all the drift coefficients could be calibrated in the traditional 8 positions, so a 16-position method appears which is more advanced. The 16 positions are generated by giving γ and β four special angles respectively, and the combination of γ and β contribute 16 state. Though memorizing the output of gyro at every position, each drift coefficient can be expressed by solving the 16 equations which formed by Equations (2), (3), (4), (5) and (6) (Fig. 2).

Taking the input specific force and the input angular rate along each axis of gyro listed in Table 2 into the expression (2), 16 equations including drift coefficients could be obtained, and the solutions of the equations can be expressed as:

$$\begin{aligned}d_I &= \frac{(\omega_{11}+\omega_{12}) - (\omega_{15}+\omega_{16}) - 4(\Delta\omega + \omega_e\sin\varphi)}{4} \\ &= \frac{(\omega_1-\omega_2) - (\omega_5-\omega_6) - 4k_1\omega}{4(-A-A_k)}\end{aligned} \tag{7}$$

$$\begin{aligned}d_O &= -\frac{\omega_{11}+\omega_{15} - (\omega_{12}+\omega_{16})}{4A} \\ &= -\frac{(\omega_3-\omega_4) + (\omega_7-\omega_8)}{4A}\end{aligned} \tag{8}$$

$$\begin{aligned}d_S &= \frac{(\omega_1+\omega_2) - (\omega_5+\omega_6) - 4\omega_e\cos\varphi}{4} \\ &= \frac{(\omega_9-\omega_{10}) - (\omega_{13}-\omega_{14})}{4(A+A_k)}\end{aligned} \tag{9}$$