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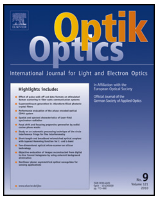

Original research article

Detection method for the singular angular velocity intervals of the interferometric fiber optic gyroscope scale factor

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ABSTRACT

The scale factor is an important parameter used to characterize a fiber optic gyroscope. A scale factor test was performed on the B-215 closed-loop interferometric fiber optic gyroscope and the scale factor was observed to change considerably in some angular velocity intervals, which are defined as singular angular velocity intervals. To determine the singular angular velocity intervals accurately, we implemented the free-pendulum experiment and proposed a new method based on the Daubechies wavelet transform to detect the intervals. The results show that the method can calculate the singular angular velocity intervals efficiently and accurately, and the detection results are consistent with the scale factor test results at discrete angular velocity points. Moreover, the free-pendulum signal reflects the changes of the scale factor in detail. Therefore, this study further improves the scale factor test method by using the following approach: in addition to the scale factor test at discrete angular velocity points, it is necessary to implement the free-pendulum experiment to determine whether singular angular velocity intervals exist.

1. Introduction

The fiber optic gyroscope (FOG) is an angular velocity sensor based on the Sagnac effect [1], which was first proposed by V.Vali and R.W.Shorthill in 1976 [2]. It can be classified into three main types: the interferometric fiber optic gyroscope (IFOG), the resonant fiber optic gyroscope, and the Brillouin fiber optic gyroscope [3]. The FOG has been widely used in inertial navigation systems owing to its unique advantages, such as high-speed resolution, good stability, high reliability and short preheating time [4].

Generally, to establish the mathematical model that describes the relationship between the input and output of the FOG, the following method is employed. Firstly, choose a series of discrete angular velocity points. Secondly, measure the output value of the FOG at each angular velocity. Thirdly, calculate the first-order linear fit by the least-squares method; the scale factor is the slope of this line. However, the relationship between the output and input of the FOG is not completely linear [5–8], which results in the nonlinear error in the scale factor.

In an inertial navigation system, the FOG is required to have high measurement accuracy in the entire angular velocity range; therefore, it is necessary to compensate for the nonlinear error. Widely used calibration techniques include segmented and polynomial curve fitting methods [9–12], which have been proposed for the modeling and compensation of the scale

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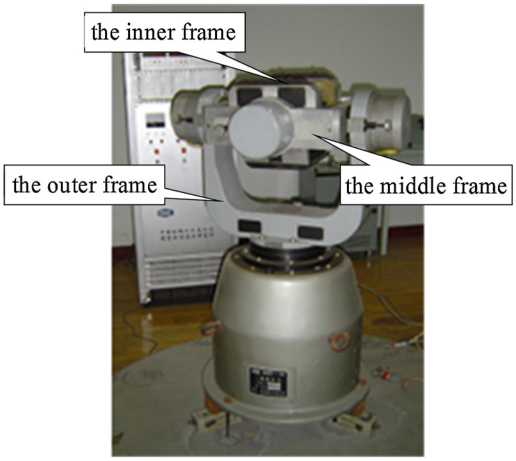

Fig. 1. SMT-I type three-axis simulation table. The inner frame, middle frame and outer frame are indicated in the figure.

factor nonlinear error. Meanwhile, the compensation method based on neural networks is more effective in reducing the nonlinear error [13–17].

However, these methods are only applied to compensate for the nonlinear error in a wide angular velocity range and it is difficult to compensate for the drastically changing scale factor in a narrow angular velocity range. The scale factor test was performed on the B-215 closed-loop IFOG and the nonlinear error was observed to change significantly when the angular velocity was approximately −20°/s and +20°/s. Owing to the large amplitude and random direction of the drastic change, it is difficult to be compensated. To interpret the characteristics of the IFOG correctly, the singular angular velocity intervals cannot be ignored and must be determined accurately. Considering the importance of this issue, the free-pendulum experiment was implemented in this study. Thus, the output signal of the IFOG was obtained when the input angular velocity changed continuously. Additionally, we propose a new method based on the wavelet transform and demonstrate that it can detect the singular angular velocity intervals efficiently and accurately. The singular angular velocity intervals were determined to be [−21.18°/s, −18.65°/s] and [18.82°/s, 21.11°/s], which are consistent with scale factor test results obtained at discrete angular velocity points.

2. Methods

2.1. *The free-pendulum experiment*

The gyroscope used in this study was a B-215 digital closed-loop IFOG with a measurement range of −100°/s to +100°/s, a scale factor of 498.4774/(°/s), a bias of 5.3494°/h and a maximum sampling frequency of 2000 Hz. The simulation table for the experiment was a SMT-I type three-axis simulation table installed on an independent base, which is shown in Fig. 1.

The following experimental method was applied:

1. The IFOG was fixed on the simulation table with the input reference axis of the IFOG perpendicular to the inner frame axis. The outer and inner frame were adjusted to make the input reference axis of the IFOG point to the east; this orientation can reduce the influence of the Earth's rotation on the IFOG. The middle frame was adjusted to make the inner frame axis parallel to the plumb line. The outer and inner frame were locked and the middle frame was not locked.
2. The IFOG was powered on and preheated for a certain time to reduce the effect of the temperature on the IFOG.
3. The test software was executed and the data were recorded.
4. The angular velocity range for dynamic testing was determined. According to the measurement requirements in the application of the attitude and heading reference system, the angular velocity range from −35°/s to +35°/s was selected. The boundary values $S_{-\max}$ and $S_{+\max}$ of the IFOG output signal were calculated in this angular velocity range using the measured scale factor K.
5. The simulation table was powered off. The middle frame was vertical when the inner frame axis was parallel to the plumb line. By pushing the north side of the middle frame lightly, the middle frame was allowed a forward free swing under the action of gravity. The maximum angular velocity of the forward swing was obtained at $T_{w\max}$. The output value of the IFOG is denoted as $|S'_{+\max}|$.
6. If $|S'_{+\max}|$ was smaller than $|S_{+\max}|$, the thrust was increased. Steps 5 and 6 were repeated until $|S'_{+\max}|$ was greater than $|S_{+\max}|$.