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Direct dither control without external feedback for ring laser gyro

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To avoid the lock-in effect, a body dither is introduced for the ring laser gyro (RLG). A dither feedback signal is necessary to control the dither drive signal. In the current dither control method, a piezoelectric or electromagnetic transducer is often used to obtain the dither feedback. The read-out signal of the RLG contains all dither-related information; hence, dither feedback can be obtained from the read-out signal, and external feedback can be reduced. A novel dither controlling method without external feedback is introduced in the present paper. How to control the dither amplitude and track the resonant frequency of the dither motor is described in detail. A comparative experiment is conducted between the old dither control method and the new one. Results show that the output of RLG using the new method has the same accuracy as that using the old method, aside from having more compact circuit dimensions.

1. Introduction

In the ring laser gyro (RLG), the counter-propagating laser beams tend to lock together to a common frequency because of the lock-in effect [1–4]. A body dither is usually introduced to avoid the lock-in effect. The gyro is rotated alternately in one direction and the opposite, and most of the time the gyro is working far from the lock-in region. The dither is typically provided by a dither motor. Conventionally, a set of piezoelectric elements often serves as an actuator for the dither [5]. In order to improve the dither drive efficiency, the dither drive signal must enable the block of the laser gyro to oscillate at the resonant frequency of the dither motor. If the laser gyro is dithered by a constant angular displacement at a constant frequency, the dynamic lock-in effect occurs [4]. The dynamic lock-in effect can be reduced by injecting random noise in the dither drive signal [6].

The function of the dither control system is to maintain a desired angle displacement and track the resonant frequency of the dither motor. In the traditional dither control method, a piezoelectric transducer (PZT) is commonly used to sense the angular displacement of the gyro block as the dither feedback [7]. But the PZT has hysteresis and switching characteristics [8], and the sensitivity of PZT always changes with time. Therefore, the feedback voltage from the transducer does not reflect the real dither status.

The read-out of the RLG is the beat frequency of the counter-propagating laser beams, which is sensed by two photodiodes in quadrature [1]. The read-out signal is obtained from the quadrature demodulator. The dither component is contained in the RLG output because of the body dither, which is what we want to remove [9–11]. However, the dither component in the output signal has all the information about the dither, such as amplitude and frequency. The dither component in the output can be used as dither feedback, and the external dither pick up using PZT can be reduced.

A new dither control system is developed using the output of RLG as dither feedback. The new dither control system is realized using digital signal processing. Compared with the original dither control system, which mainly uses analog circuits, the new system has a smaller dimension, and it can change work parameters flexibly through programming.

2. Dither bias of the RLG

The lock-in equation of the RLG can be written as

$$\dot{\psi} = a + b\sin\psi, \tag{1}$$

where ψ is the instantaneous phase of the beat frequency signal, a is the input angle rate, and b is the lock-in threshold [4]. With mechanical dither, (1) can be written as

$$\dot{\psi} = a + b\sin\psi + \alpha\cos(\omega_D t), \tag{2}$$

where α is the dither amplitude, and ω_D is the dither frequency. If the rotation rate a is near a multiple of the dither frequency ω_D, it can be written as

$$a = r\omega_D + \tilde{a}, \tag{3}$$

where $|\tilde{a}| \ll \omega_D$, approximately the error of (2) is the same as above

$$\dot{\psi} = r\omega_D + \dot{\psi}', \tag{4}$$

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where

$$\dot{\psi}' = \tilde{a} + bJ_{-r}\left(\frac{\alpha}{\omega_D}\right)\sin\psi', \tag{5}$$

here $j_n(x)$ is the first kind of Bessel function [4]. The above equation indicates that when sin dither is introduced, the lock-in region near the zero angle rate is distributed at the multiple of the dither frequency with a width of $bJ_{-r}(\alpha/\omega_D)$.

Fig. 1 shows the plot of $J_{-1}(x)$,$J_0(x)$,$J_1(x)$. For large values of x, the Bessel function can be written as

$$J_n(x) = \sqrt{\frac{2}{\pi x}}\cos\left(x + (2n-1)\frac{\pi}{4}\right). \tag{6}$$

For a large dither amplitude, with α/ω_D in the order 1000, if the dither amplitude is randomized, we can obtain the following from (4):

$$\dot{\psi} = r\omega_D + \tilde{a} = a. \tag{7}$$

This equation shows that with random noise injection, the dynamic lock-in in the output curve disappears [12].

3. Direct dither control without external feedback

3.1. Introduction to the new method

The original dither control scheme is shown in Fig. 2 [13]. The amplifier in Fig. 2 amplifies the dither drive signal to a proper voltage that will drive the dither motor. The dither pick up is used to pick up the dither feedback signal. It includes PZT to sense the dither of the gyro. It also includes a pre-amplifier, a low pass filter and a signal conditioner for the feedback to have proper amplitude and phase. The system forms a self-excited oscillation loop if the phase is adjusted properly. The dither amplitude is obtained by evaluating the valid value of the feedback signal. The amplitude is compared with the reference amplitude, and an error signal is generated. The amplitude controller adjusts the driving amplitude according to the error signal. Random noise is injected into the dither amplitude every time the driving signal crosses the zero voltage.

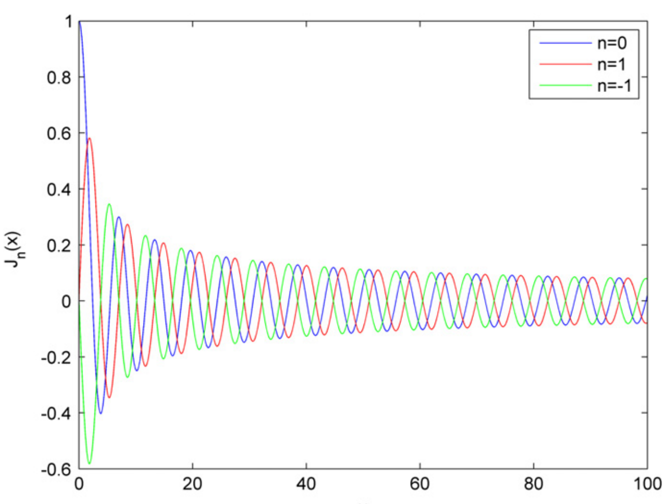

Fig. 1. Plot of $J_{-n}(x)$,$n=-1,0,1$.

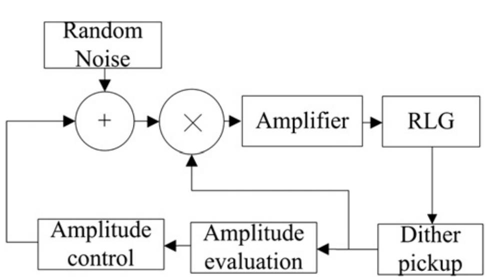

Fig. 2. Original dither control scheme.

If we neglect the lock-in effect, Eq. (2) can be written as

$$\dot{\psi} = a + \alpha\cos(\omega_D t). \tag{8}$$

The dither frequency ω_D is much higher than the frequency distribution of the real input angle rate a. The dither frequency is generally between 300 and 1000 Hz, whereas the spectrum of a is 0–100 Hz. If a high-pass filter is used in $\dot{\psi}$, then we can obtain the dither component $\alpha\cos(\omega_D t)$, and the real input angle rate is removed. The direct dither drive without external feedback is shown in Fig. 3.

In Fig. 3, two photodiodes assembled in the RLG sense the beat frequency signal of the counter-propagating beams. The read-out signal of the gyro, which is the absolute value of ψ, is obtained from the quadrature decoder. The read-out signal is then sampled at 10 kHz. The high pass filter, which is an infinite impulse response (IIR) digital filter, is used to remove the real input signal and obtain the dither component from the read-out signal. The amplitude evaluation section takes the valid value of the dither signal and obtains the dither amplitude. The digital phase shifter is used to adjust the phase delay of the loop and enable the system to track the resonant frequency of the dither motor. The digital-to-analog converter (D/A) is used to convert the digital dither drive signal into analog, which is then amplified to drive the dither motor.

Although Fig. 3 looks similar to Fig. 2, it is quite different. In Fig. 2, all the dither control is managed by analog circuits, whereas in Fig. 3, the control is realized using digital signal processing. The feedback of Fig. 2 form PZT is a voltage signal but not the real dither angle. In contrast, the feedback in Fig. 3 is direct to the real dither angle. All functions in the dashed box in Fig. 3 can be realized in a digital signal processor (DSP), hence the dimension can be more compact. In the implementations of our laboratory, the circuit board dimension of the origin system is 12 cm $\times$ 7 cm, in contrast that of the new one is only 6 cm $\times$ 6 cm. In the applications such as inertial navigation system (INS), the new dither controlling system will reduce the scale of circuit boards.

3.2. Amplitude evaluation and noise injection

Sustaining a relatively steady dither bias for the dither control is necessary; hence, dither amplitude evaluation is very important. Noise injection in the dither amplitude is also crucial in eliminating the dynamic lock-in effect.

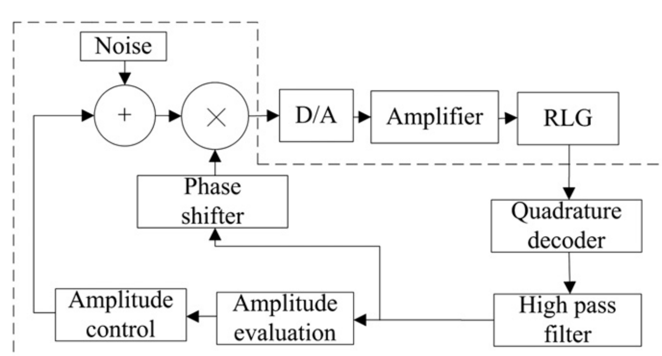

Fig. 3. New dither control scheme.