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Method of suppression of impulse interferences in digital closed loop fiber optic gyro detected signal

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ABSTRACT

Periodic impulse interferences in the detected signal of digital closed loop fiber optic gyro lead to a bias error. In this paper, three kinds of interference sources, D/A converter and phase modulator, light source, and system power supply, are discussed and verified by an open-loop testing approach. A method with an integration of a digital average algorithm and a soft-switching median filter is proposed to suppress the periodic impulse interferences in detected signal. Selection criterions of the parameters used in the method are discussed and verified through simulation. Some considerations for the practical realization of the method within FPGA are given. An experimental verification of the method is presented by applying it to three gyros corrupted by periodic impulse interferences. The results demonstrated that the bias error could be decreased by about 85% with the method proposed.

1. Introduction

Digital closed loop fiber optic gyro (DCL-FOG) is a well-developed, highly stable and sensitive device which has been widely used in the inertial navigation, guidance, and control systems of aircrafts [1,2]. Due to the defections of devices and circuits design of DCL-FOG, its detected signal is apt to get interfered by interferences which deteriorate the accuracy of DCL-FOG. For a better accuracy and the anti-interference performance of DCL-FOG, periodic phase modulation and coherent demodulation, which could effectively suppress random interferences, are introduced into the closed loop [2,3]. However, according to the fundamental principle of coherent demodulation, if there were additional periodic interferences whose frequency are the same or odd-numbered multiple of the modulation signal, a bias error would be induced in the output of DCL-FOG. Impulse interference, interference with short duration, is one of the most frequent occurrence forms of the interferences. Taking the samples at the intervals between the sharp peaks of detected signal where the non-horizontal shelves occur for processing in FPGA or adding an analog switch are most frequently used approaches to suppress periodic impulse interferences. But both of them could only eliminate the interferences in a fixed range. (neighbors of the sharp peaks) Besides, random modulation is also an effective method. However, its application on the one hand depends on high-quality modulator and its related drive circuits, on the other hand probably introduces novel interferences into the closed loop.

In this paper, we proposed a method applied before coherent demodulation to suppress periodic impulse interferences in the detected signal. Firstly, we use a digital average algorithm to improve the signal to noise ratio (SNR) of the detected signal. Then, we use a soft-switching median filter to eliminate impulse interferences detected from detected signal.

The rest of the paper is organized as follows. In Section 2, three major impulse interference sources in DCL-FOG are introduced and verified. In Section 3, a method to suppress impulse interferences is proposed. Its parameter selection criterions are given and verified through simulation. In Section 4, experimental results are given to show the performance of the DCL-FOG with designed method. Finally, conclusions are drawn in Section 5.

2. Analysis of impulse interferences in DCL-FOG

The detected signal of DCL-FOG could be expressed as [2]:

$$I = \frac{I_0}{2}[1 + \cos(\phi_s + \phi_b + \phi_f)] \tag{1}$$

Where I_0 is the peak power of photodetector output, $\phi_s$is the Sagnac phase difference, ϕ_b is the modulating phase, ϕ_f is the feedback phase

If interferences with the same or odd-numbered multiple frequency of the modulation signal is contained in the detected signal, a bias error would be induced in DCL-FOG output.

There are three major sources of periodic impulse interferences in

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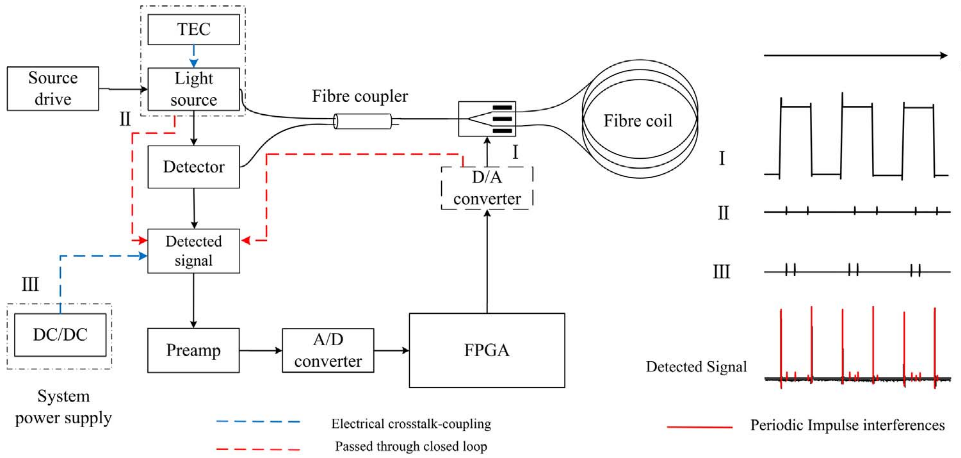

Fig. 1. Typical structure of DCL-FOG and Impulse interference sources.

DCL-FOG.

I. D/A converter(DAC)and phase modulator

For the dynamic behavior of DAC, including glitch error and set time, and the finite bandwidth of phase modulator, $\phi_b + \phi_f$ generated by DAC contains periodic impulse interferences and these interferences transmit through the closed loop.

II. Light source

For the fast switching of the pulse width modulation (PWM) circuit in thermos-electric cooler (TEC), placed closed to the light source for the use of cooling, the light power I_0 produced by light source contains periodic impulse interferences. These interferences firstly worsen the light source output by electrical crosstalk-coupling (ECC) and then influence the detecting signal through closed loop.

III. System power supply

The PWM circuit in DC/DC could also produce periodic impulse interferences, which would be directly overlaid on detected signal I and transmit by ECC.

The effects of three impulse interference sources on the DCL-FOG output bias were verified via an open loop testing. The configuration of the testing system is shown in Fig. 1 [2–6], where the three impulse interferences sources and their corresponding propagation paths are depicted by dash lines.

The light power arriving at the detector was about 300 μW. The amplitude of the modulation square was 2 V, while its frequency stood at 250 kHz and the output integration time was 1 s. The experiment scheme and results are demonstrated in Table 1, where the bias error caused by other factors (e.g. electrical crosstalk-coupling between modulation square and detected signal) has been modified.[7].

It can be concluded from above that the bias error caused by TEC is1.33°/h which could be acquired by the differences between the bias error test result A and B. Similarly, the additional bias caused by DC/DC is 1.82°/h and the additional bias caused by DAC is 0.32°/h.

Table 1
Impulse interferences test scheme under square wave modulation.

Connection type of FOG electronic component	Included impulse interference sources	Bias error (°/h)	
Fig. 1	I II III	3.47	A
Replace PWM in TEC with linear circuit	I III	2.14	B
Replace PWM in DC/DC and TEC with linear circuit	I	0.32	C

3. Method to suppress impulse interferences

3.1. Impulse interferences suppression method

3.1.1. Impulse interferences extract algorithm

As a matter of fact, not all the periodic impulse interferences display as distinct as the interferences portrayed in Fig. 2, most of them are buried in stochastic noise of the detected signal. Before we eliminating these interferences, a digital average algorithm based on the weak signal detection theory should be used to extract these interferences from detected signal, whose operational process is shown in Fig. 2.

The i-th storage unit of a cycle after m periods' scanning could be expressed as:

$$A(t_i) = \frac{1}{m}\sum_{k=1}^{m} f(t_i - kT) \quad i = 1, 2, 3, \ldots, M \tag{2}$$

$f(t_i - kT)$ is the i-th sample of the k-th scanning period. $A(t_i)$ is the value of the i-th sample after m periods' scanning. The detected signal with higher Signal Noise Ratio(SNR) could be acquired by arranging $A(t_i)$ in a chronological order.

Assuming the useful signal in detected signal is $s(t)$ and stochastic noise is $n(t)$. The amplitude of stochastic noise isA_n. $A(t_i)$ could be expressed as:

$$A(t_i) = \frac{1}{m}\sum_{k=1}^{m} s(t_i - kT) + \frac{1}{m}\sum_{k=1}^{m} n(t_i - kT) = s(kT) + \frac{1}{\sqrt{m}}A_n \tag{3}$$

The relationship between the input and output signal of the algorithm is:

$$\left(\frac{S}{N}\right)_o = \frac{\sqrt{m}\,S(kT)}{A_n} = \sqrt{m}\left(\frac{S}{N}\right)_i \tag{4}$$

The SNIR (Signal Noise Improvement Ratio) of the algorithm is $\sqrt{m}$

The choice of scanning times m depends on the SNR of the detected signal. Normally, if the SNR of the detected signal approaches 2, we could assume that the impulse interferences have already been extracted from stochastic noise. In practice, we should continuously increase the value of m to meet the requirement.

3.1.2. Impulse Interferences elimination algorithm

Considering the low density and pulse characteristics of the interferences, a median filter could be an ideal choice to eliminate them from detected signal. The main idea of the median filter is to replace each sample of signal with the median of neighboring samples. The pattern of neighbors is called the "window". The output of the standard median filter could be expressed as: