Comparative Analysis of Gyro-Parameters in Digital Closed-Loop Interferometric Fibre-Optic-Gyro based on Variations in V2π Ramp and Vπ/2 Bias Voltages

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Abstract: - Fibre-Optic-Gyro (FOG) is an inertial-sensing device, determines the rotation-rate mainly working on the principle of Sagnac-effect. The accomplishment of inertial-grade-performance focused on an Interferometric Fibre-optic-Gyro (IFOG) with the closed-loop operation, but there are several drawbacks exist in analog-IFOG and finally considered the Digital Closed-Loop Interferometric Fibre-Optic-Gyro (DCLIFOG) and it mainly engage with bias-signal frequency and ramp signal (V2π voltage of IOC). The feedback signal uses a digital phase-ramp voltage to neutralize the gyro output. If the slight difference occurred in ramp and bias voltages, then founds the change in performance of gyro. Meanwhile, the dead-band occurs in DCLIFOG at low-rotation-rates, which is a significant phenomenon causes the nonlinearity output and also influences its accuracy. However, dead-band-error elimination is an important problem in DCLIFOG design, and suppresses the effect of dead-zone by a suitable resetting V2π voltage by controlling DAC reference-voltage. Here, different test-methods were proposed and considered for three-cases: (i) V2π (vary) & Vπ/2 (constant), (ii) Vπ/2 (vary) & V2π (constant) (iii) both V2π and Vπ/2 are varying simultaneously. This paper addresses the comparative analysis made on gyro-performance by evaluating its parameters among three-cases: the experimental results showed that the performance of gyro concerning with bias-stability, scale-factor linearity and also tremendously eliminated its dead-band.

Key-Words: - Digital Closed-loop Interferometric Fibre-Optic-Gyro (DCLIFOG); Ramp signal Voltage (V2π); Bias signal Voltage (Vπ/2); Dead-band or Dead-zone and Low-rotation-rates.

1 Introduction

In recent years most of the commercially available Fibre-Optic-Gyros uses Interferometric configuration due to its involvement in reducing the errors to improve the gyro performance by using several techniques including optical reciprocity. With this help of advancement, Interferometric configuration is popular and technology wise it is nature [2]. Based on the principle of interference of light operation, Interferometric Fibre-optic-Gyros (IFOG's) are designed to measure the rotation rate induces optical path difference as measure of phase difference between two counter propagating beams [1, 5]. The main advantage exists in the IFOG technology for inertial systems are smaller size with increased integration of the components, having high reliability and lower cost. In IFOG, the sensitivity depends upon the fiber-coil length, builds a specific mechanism effective in wide range of applications because of having high accuracy and low random noise requirement. However, IFOG's are further arranged as either open loop or closed-loop [6].

A simple arrangement of IFOG is open-loop IFOG obtains the rotation rate by direct estimation but introduces a nonlinearity output for small deviation in phase and causes the instability, limited dynamic range, low accuracy and insensitive for lower rotation rates [4, 6]. But the Closed-Loop IFOG (CLIFOG) was greatly fulfilled for solving most of the above noticed issues. In the operation of CLIFOG the rotation rate was obtained by using a feedback loop which generates a value given to phase-modulator so that the differential phase shift cancels out the rotation induced Sagnac phase shift. Due to this reason, the closed-loop system establishes a very high performance by eliminating the dependency of light intensity and these are very attractive due to increase in scale-factor (SF) stability and linearity.

The different closed-loop approaches primarily differ in the method used to produce the rotation induced non-reciprocal Sagnac phase deviation, which is equal to its significance and sign inversion [12]. The fulfillment of navigation-grade performance mainly focuses on a closed-loop design with IOC, integrated optic chip (sometimes also named as multi- functional integrated optic chip) [14]. So that its operation more feasible with an IOC due to availability of an integrated-optic phase modulators. Such high-speed components are sufficient for yielding the effective phase modulation for calibrating rotation rates in the prescribed dynamic range. However, the feedback loop cannot maintain stability at certain rotation rates due to voltage-dependent errors in the feedback signal, phase servo, or electrical cross-coupling etc.

Two approaches exist in the CLIFOG system is: analog and digital. In analog based CLIFOG system, the interference channel develops a nonlinear response due to sinusoidal biasing signal modulation. But this ACLIFOG system (established with an analog ramp signal with a sinusoidal biasing signal modulation), does not produce a sufficient result on account of unstable output against environment, to conquer this problem by designing a Digital Closed-Loop Interferometric Fiber-Optic-Gyro (DCLIFOG). The DCLIFOG system constructs with the digital feedback ramp signal and with a square-wave biasing signal modulation to eliminate the error close to zero point. This is the main advantage is to operate the DCLIFOG scheme around the zero-point in order to estimate the rotation rate is unsusceptible with the optical power, the electronic-gain, or any other circumstances against environment, especially against vibration. However by maintaining the linear characteristic, scale-factor (SF) stability and good accuracy, obtains a great improvement with this DCLIFOG system [3].

One of the exotic aspects identified within the CLIFOG system is known as the dead-zone. Dead-zone is the region where the Gyro cannot recognize to sense any rotation at low angular rate, thus ignoble sensation in the Gyro. Additionally, noted that dead-band can be affiliated with a number of reasons and extended with the influenced factors based on assembly quality and parameters (optical and electric parameters) of IFOG design is affected on the dead-zone. This dead-band-error leads to extreme impact on inertial-navigation-grade-performance and its precision. By this impact, these are divided into two fundamental sources or groups in accordance with their origin. The primary group is the electronics cross-talk (or cross-coupling) exists in-between the modulated feedback voltage and the photo detector, and in-between the modulated feedback voltage and output of ADC, and also in-between the DAC nonlinearity and the electro-optical phase modulator. Cross coupling is the main factor of a dead-zone and a certain issue to minimize its effect in electronic design. The cross-coupling effect causes due to interfere with each other on the PCB board or through the signal power, or ground. With this interference gyro bias was affected, results a dead-band [7].

The secondary group is the phase modulation tendency of the IOC. The IOC consists of phase modulator produces only constrained or inaccurate response at low frequencies like pole-zero filters. If the variation exists in frequency characteristics then the modulated phase signal is further altered in accordance with the phase ramp signal frequency and it is equivalent to the input rotation rate. Sometimes, due to the impact of an artificial interferometer founded by back- scattering and back-reflections, as well as radiation errors in the integrated optic chip (IOC). Due to this reason at lower rotation rate induces the bias instability, spikes produced in the output due to noise, and look-alike dead-zone.

While concentrating the reasons of dead-zones in an IFOG, the aim is to detect the most influenced key factor. According to investigations, the dead-zone is mainly concerned by the second group (in order of significance) of an artificial interferometer signal and other factors have not been identified to show any high impact. Many researchers are concerned to the dead-band compensation by applying an additional phase modulation without eliminating its causes and all these techniques is not to permit the absolute phase value to persist at one fixed value takes place at low rotation rates when the Sagnac phase shift adjusted by the feedback represents to an infinitesimal extra phase. The reason behind this is during the feedback-voltage dependent error exactly cancels the rotation-induced Sagnac phase shift then the lockup takes place and develops a constant feedback loop. To address this lockup issue and to suppress the dead-zone, a bias phase is to adopt larger than the feedback-voltage dependent error and due to this biasing in the phase modulator decreases its dynamic range, needs to perform separation of the additional biased rate [10]. Hence, the dead-zone was also compressed by randomizing the modulation depth, but the bias instability and random noise rises by virtue of optical power sensitivity on the photo detector. Finally, proposed a new modulation scheme is to eliminate the dead-band along with its causes and to produce a sophisticated linear response of the gyro output to any applied rotation rate.

2 Methodology

The basic idea exists in closed-loop approaches by adopting a phase compensating feedback signal generates a proper value to remove the rotation induced Sagnac phase shift from the differential phase shift, thus directly proportional to the detected rotation rate. However, this was not extremely convenient result for maintaining reciprocity. It is not so simple to maintain reciprocity on an adequate range to establish the convenient gyro operation. This device uses the Sagnac effect, which is analogous and reduce the other no desired effects.

If the system is in continuous medium, constant time and away from magnetic fields, the clockwise (CW) and counter clockwise (CCW) optical path lengths are interchangeable then the arrival of two waves to the detector are entirely in phase, except for Sagnac shift [4, 5]. Furthermore, in CLIFOG design the rotation rate grasp by a fed back signal for preventing the turn persuaded Sagnac phase inaccuracy, but it obtains a deviation on account of repeated usage of Sagnac loop. Again, the system inserts the output as feedback to the input, then the phase shift among CW and CCW (clockwise and counter clockwise) paths in entire line, containing direct and feedback lines determines as Sagnac phase deviation.

In Optoelectronics, the CLIFOG suffers from a lockup near low rotation rates or around zero (i.e., due to insensitivity), which results a dead band, dead zone, or an uncertainty region. It is a field of rates where the sensation of the gyro weakens to zero then it is not any more to sense the rotation rate [8]. Moreover, it seems that the noise also increases in addition to this characteristic region. As a result, the feedback-voltage dependent error occurs with the lockup and the increased noise. This error is the source of the dead zone that exists due to electrical cross-coupling between the modulated feedback voltage and the input signal of the photo detector, the back- scattering, and radiation errors inside the IOC of the designed IFOG.

However, the dead band is mainly concentrated with the second group of source and this generates the bias and the feedback phase signal by the phase modulator in the IOC. The system leads to a persuaded modulated feedback voltage in the photo detector output (see dead zone sources in Fig. 1) and directly initiated in the input of ADC. On account of this induced signal the interferometer signal is also increases created an imperfect feedback and occurs the output of gyro signal to lockup at lower rotation rates [7]. This lockup is attributed to the influence of a very small amount of backscatter from the mirror surfaces, and results in a dead band region (below a certain threshold of rotational velocity) for which there is no output signal. Above the lockup threshold, output approaches the ideal linear response curve in a parabolic fashion. Instead of a linear response to an input angular rate, the transfer curve may exhibit a flat zone until it exceeds some undefined threshold. It would therefore be highly desirable to provide a gyro that exhibits a linear response to any applied angular rate [13].

In CLIFOG system, the output of the detector demodulates at the frequency of phase modulation treats as an error signal. This loop offers a contained load of an unequal phase deviation among the two counter propagating optical signals for rectifying the rate-of-turn actuated Sagnac phase deviation. Thus the final phase variation must be within the two interference signals to control the rate-of-turn at zero and recommends the non-reciprocal phase shift as a gyro output and it is nearly relevant to the rate-of-turn i.e., it is return back to the CLIFOG setup and further reproduce feedback phase $\Delta\phi_{fb}$ and that is inverse to Sagnac phase $\Delta\phi_s$. Therefore,

$$\Delta\phi_{fb} = -\Delta\phi_s \qquad (1)$$

3 Digital Closed-Loop Interferometric Fibre-Optic Gyro (DCLIFOG) System

Fig.1 shows the proposed digital closed-loop Interferometric fibre-optic-gyro (DCLIFOG) configuration. A new modulation scheme was proposed by using a dead band compensator in the FPGA board and it was employed by randomized discrete voltage-step to the feedback signal for the dead zone suppression (and also eliminate its causes) to attain the proper V2π reset by controlling DAC reference voltage. The voltage-step is used uncertainly with the time duration considerably smaller than the time earlier to lock the fixed feedback voltage and induces the insensitivity against rotation rate.

The simplest implementation is to remove the voltage-step in the demodulation process while responding by the photo detector signal. But the randomized voltage-step restricts to remain at one consistent level of the feedback signals. Moreover, it equally allocates the modulating feedback voltage signals within the full phase of V2π modulation range, so that the error in this range is moderated and reduces to zero. As a result, this is standard (or real) rotation rate found by the new modulation scheme of IFOG.

In this given digital system constructs the feedback loop with various functional units such as Signal conditioning Amplifier (SCA), DPEC (Digital Phase Estimator card) board and output differential driver. The purpose of the phase modulator adopts the effective biasing, but it needs a laser light emission to hold the reset signal that happens quickly at each cycle, but the replacement of this requirement with the channel waveguide usage in electro-optic phase modulators.

The error in the lock-in amplifier output samples quantizes and retains nearly zero by digitized fed back signal. However, the frequency of sampling signal reciprocates to the emitted transit time τ as the prescribed readjustment of the staircase and biasing signals [14]. Proceedings takeoff against the error signal then guided to the phase modulator by a controller and to reproduce the amplitude of phase steps is adequate to the Sagnac phase deviation and transit time τ.

The DAC systematically generates a staircase reset signal by virtue of its redundancy. The step of the reset signal resembles to a phase shift of 2π radians, constantly to receive proper Sagnac phase shift. The system accomplishes the rotation rate arrangement by the direct measurement of error signal in a digital pattern. Meanwhile, this DCLIFOG system controls the constant phase while retrieving the signal. In FPGA board, if the filtering and amplification development performs the correct regulation then the feedback loop will fine-tune the feedback phase and it is approximately equal with a reverse Sagnac phase by considering entirely with a stable input rate-of-turns.

4 Signal Processing Scheme of DCLIFOG System

The signal-processing design of digital closed-loop Interferometric fiber-optic gyro (DCLIFOG) succeeds through DPEC (Digital Phase Estimator card) board consists of ADC, temperature sensor, FPGA, and DAC etc., which is also shown in Fig 1. Here, the DPEC is a signal-processing board develops for the rate-of-turn measurement in DCLIFOG system. In order to achieve the closed-loop functionality, this DPEC board serves as a signal-processing and data acquisition unit. The suggested way can develop the fed back signal for adjusting the phase deviation of DCLIFOG setup.

The DCLIFOG system tilts with a square-wave biasing signal and its duration is adequate to the transit time τ. However, for light intensity modulation, a square wave biasing signal modulation adapts the raise in sensitiveness and indication of sign to the rate-of-turn. The optic strength of the signal (coming from PINFET photo-detector) converted into electrical signal which is gyro output as a square-wave modulated cosine wave. But, this design receives modulated Sagnac phase deviation through PINFET. The DPEC board consists of 16-bit ADC which (is in parallel interface with FPGA) gets the PINFET data through SCA (Signal Conditioning Amplifier) and transmits this data to FPGA [9].

Then FPGA processes this data to load the digital output with the frequency of sampling signal, which develops into transit gyro frequency. Here, the data samples (1 sample per τ) and demodulates synchronously. Thus, the obtained demodulated signal is familiar with the Sagnac phase deviation exists in the detector result and this error traverse into a moving average (FIR) filter. This outcome amplifies with the gain factor (received through UART). The dead-zone difficulty and whatever the existed spike signals that are compensated by the dead band compensator and this compensation signal also receives through UART. This system integrates the error signals against τ in the phase integral controller to receive the final step height.

Subsequently the integrated error signal from the integrator induces to a digital ramp signal generator, which generates the ramp signal with constant voltage (V2π of MIOC) and that is precisely equivalent to source wavelength. Therefore, the operation of an integral controller with an unpredictable gain revokes the rate-of-turn actuated Sagnac phase deviation of the gyro by virtue of a ramp generator. To accomplish the closed- loop performance of a system, the staircase ramp signal operates as a feedback compensated phase deviation signal to restrict the rate-of-turn actuated phase variation; this approach is well-known as "digital serrodyne modulation technique"[11].

5 Dead-Band Elimination

In this proposed DCLIFOG system, the dead-band error can be eliminated by the addition of a periodic compensation signal, at the input to the step-size integrator. This designed system generates timing

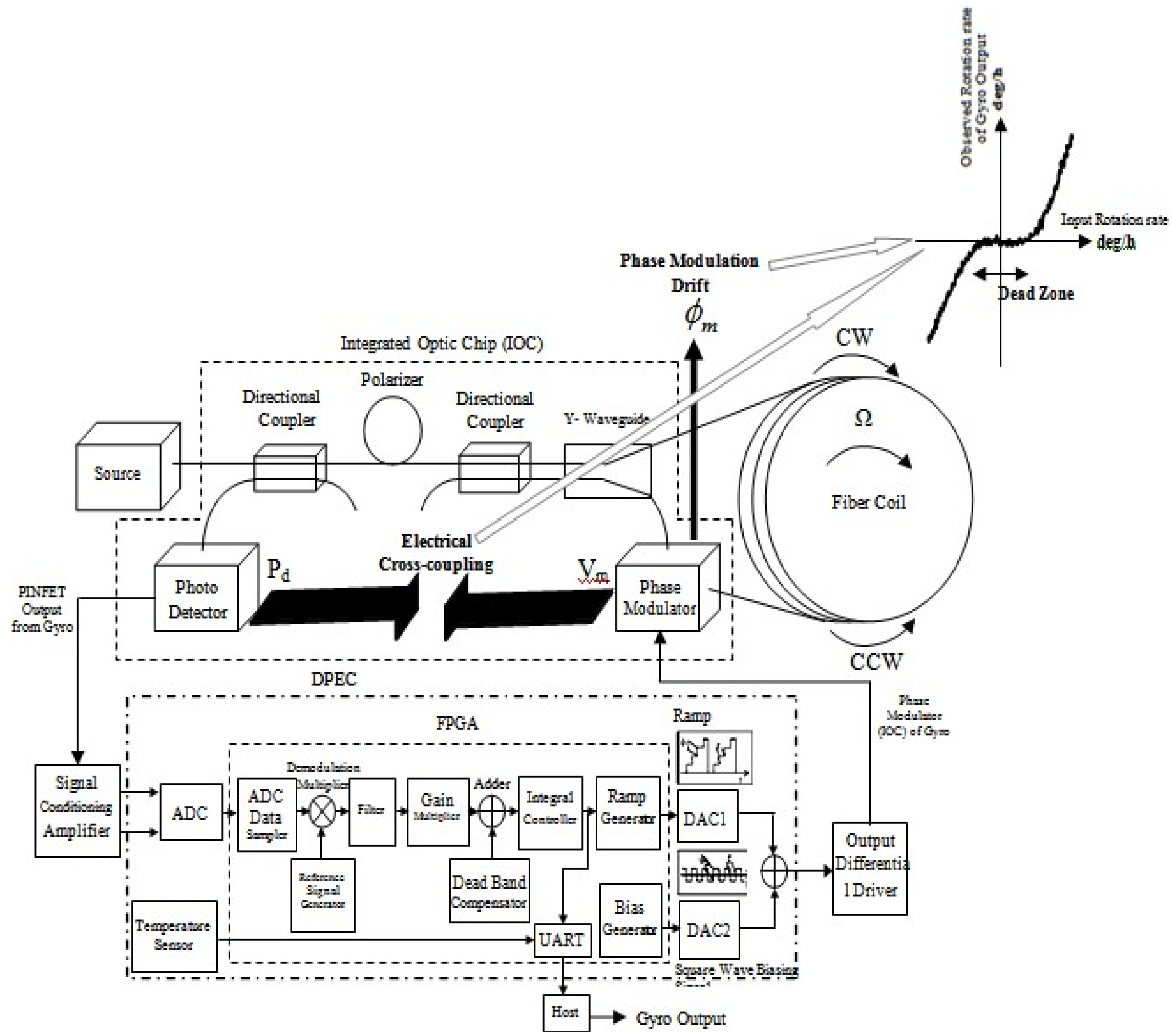


Fig.1 Proposed Configuration of Digital Closed-loop Interferometric Fibre-Optic Gyro (DCLIFOG) and Dead-Zone Sources

control signals used to upload the averaged step size data (i.e. rotational rate information) to PC [2].

Depending on the timing control signals generated, step-size data is accumulated and truncated (power of 2 divisions). Here, the feedback phase compensating signal ($V2\pi$) and the biasing square-wave signal ($V\pi/2$) are used as control signals for DCLIFOG. The peak-to-peak voltage of the biasing signal ($V\pi/2$ is equal to one-fourth of the $V2\pi$, peak-to-peak voltage of the ramp signal) also inclines to IOC for intensity modulation.

Finally, on-board 16-bit DAC receives these control signals and given to the phase modulator of the IOC. In the current design by using these control signals, the DPEC (Digital Phase Estimator card) board substitutes the averaged data output of phase integrator for every 2.5ms and temperature data to the Host/PC by nullifying the temperature-induced-bias-errors in the gyro output at the time of synchronization pulse request. One of these control signals can also be used to generate the compensation square wave signal used in Dead-band compensation [3].

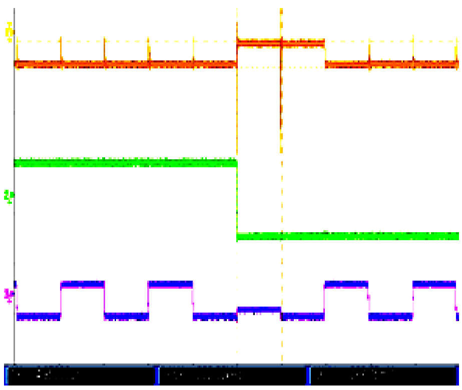
The DCLIFOG system has several parameters like bias-stability, scale-factor, threshold and linearity etc., but while concentrating the lower rotations in the system described by the parameter threshold. So, the system is subjected to various kinds of tests to certain its performance and one of the tests considered here is threshold. Theoretically, the threshold is characterized as the variation in the output is acquired by the given input value and the resolution is specified as a slight increase in input generates the definite variation in output. The threshold sensitivity of a Gyro was related to the rotational velocity of an object is analogous to a degree per second. Thus the proposed system prompts the threshold to be maximum because of dead zone exists in the gyro which is predominantly brought about by the electronic cross-coupling interference in the modulation and demodulation circuit. The threshold should be less than 0.01deg/hr and the resolution should be better than 0.01deg/hr. In general, the working principle of IFOG determines that it has no dead-zone; otherwise if the dead band error exists then it is to be eliminated by addition of periodic compensation signal at the input. But in practice, in order to avoid the dead band error in the gyro output is to increase the dead band value. It was observed that the dead-zone decreases with gyro accuracy increasing.

Based on the definition of the resolution and threshold for FOG, a dead band definition and test method in digital closed- loop IFOG were proposed. The purpose of this threshold test is to measure the threshold and resolution of the gyro and also to determine the dead band as the input range (near zero) over which the output is less than 10% of the input. The data averaging time should be long enough to reduce the gyro noise to less than 25% of the dead band, prior to analyzing data then any bias should be removed.

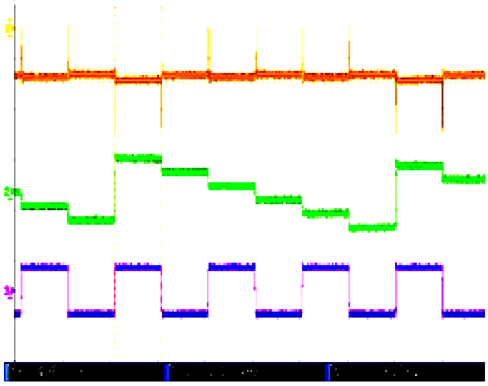
6 Tested Results

In the result analysis, the discussion starts with the closed- loop operation of DCLIFOG system without and with calibrations were seen in the DSO (digital storage oscilloscope) as displayed in the Fig. 2. In these figures (a & b), three waveforms represents with the gyro output, ramp and square wave biasing signals.

After that process performs various tests to measure the DCLIFOG parameters and displays its MATLAB outputs in Fig's 3 to 6.



(a)



(b)

Fig.2 Closed-Loop Outputs without and with Calibration

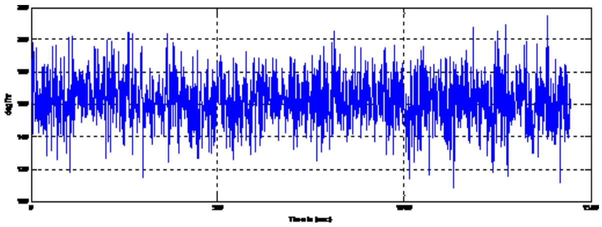


Fig. 3 Bias Test result from the Gyro

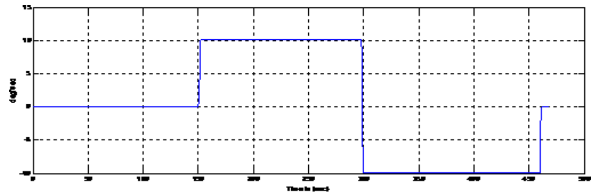


Fig.4 Scale-factor Test result from the Gyro

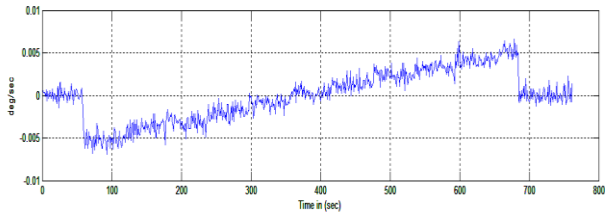


Fig.5 Threshold Test result from the Gyro

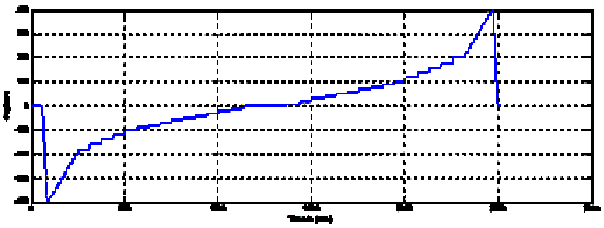


Fig.6 Linearity Test result from the Gyro

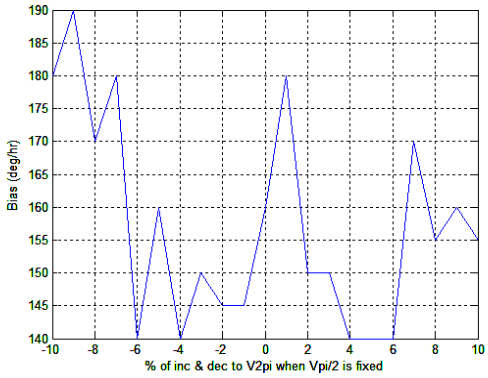
From the view of testing results, the DCLIFOG parameters maintain the stability of bias, scale-factor, linear response and sense for lower rotations by eliminating the dead band error.

7 Comparative Analyses on Gyro Parameters

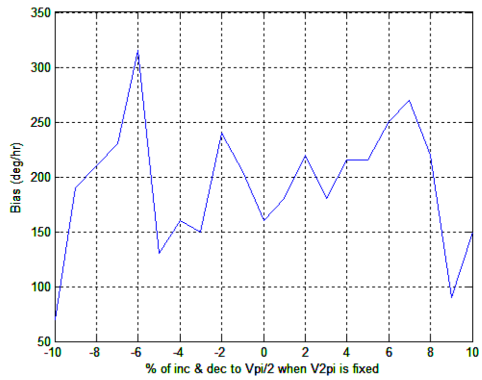
Now the comparison made on DCLIFOG parameters by considering the peak-to-peak voltage of the ramp signal (and/or biasing signal) increases from 1% to 10% and decreases to 10% to 1% and observed the comparative results for three cases as shown below: (i) Vπ/2 kept stable and changes the V2π, (ii) V2π kept stable and changes the Vπ/2, and (iii) Changing both V2π and Vπ/2 at the same time.

7.1 Bias

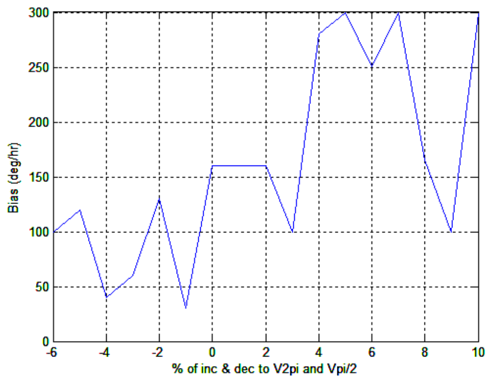
The bias-test performs for all cases; then the comparable bias values for three cases are as displayed in the Fig's. 7 (a), 7 (b) & 7 (c).



(a)



(b)

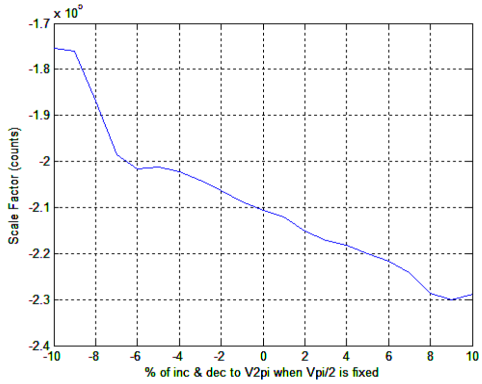


(c)

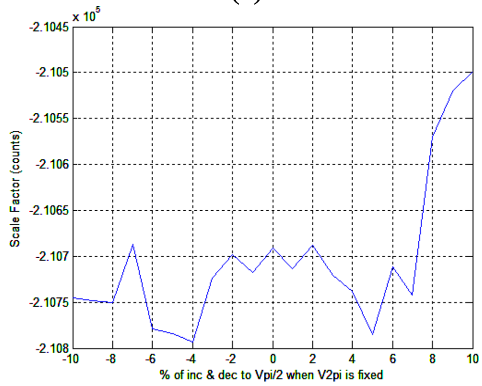
Fig.7 Estimation of Bias values for three-cases

7.2 Scale-Factor

The Scale-Factor-test implements for all cases, and displays its calculated scale-factor (SF) for three cases in Fig's. 8 (a), 8 (b) & 8 (c) in addition to this estimated the interrelated-offset [3].



(a)



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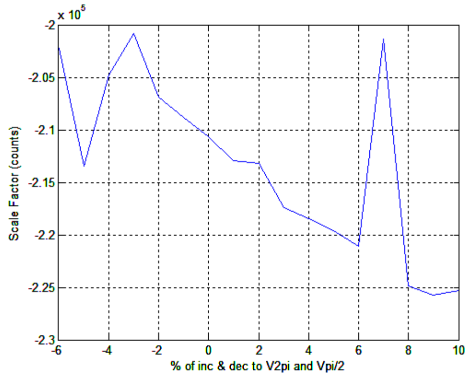


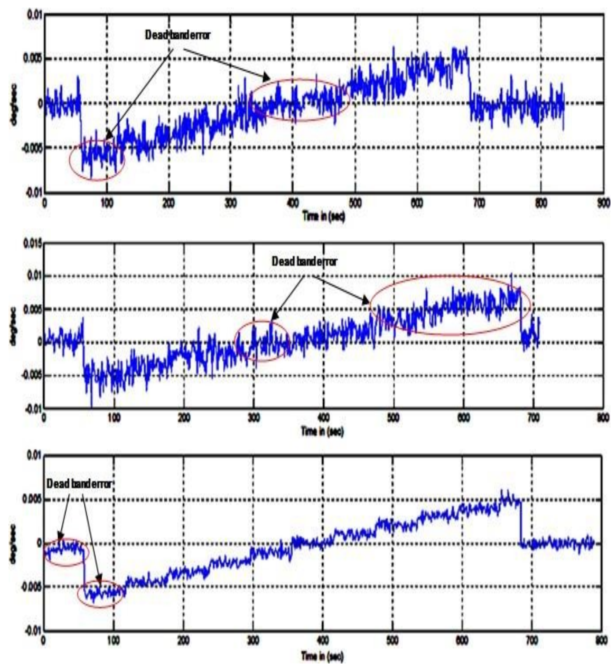
(c)

Fig.8 Estimation of Scale-Factor for three-cases

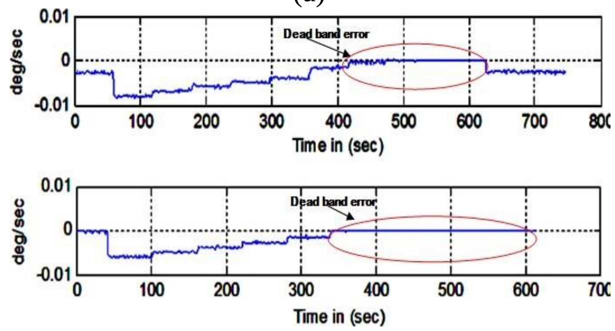
7.3 Threshold

The threshold test executes for all cases as observed in Fig's 9 (a), 9 (b) & 9 (c). The system notices for all of the above three-cases, that there exists a dead zone according to V2π and Vπ/2 voltage variations. In the first case by varying (either increasing or decreasing) the V2π voltage, the DCLIFOG system can sense the lower rotations but cannot obtain the correct rotation rates (regarding the increase in error voltage) even though Vπ/2 kept constant. As a result, the dead band error occurs and this error is also increases in a wide range with increase in V2π, as seen in Fig 9(a), and from this Fig 9(a), it was also observed that the increase in distortion of the DCLIFOG system due to percentage increase (or decrease) of V2π voltage. Hence, the system results with high % error and the output remains non-linear.

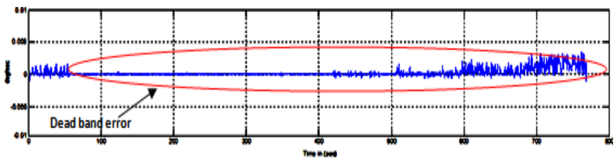
Although, in the second case by varying (either increasing or decreasing) the Vπ/2 and constant V2π voltage, the system can gradually not sense for lower rotations especially in clockwise directions as seen in Fig 9(b). Consequently, the effect of the DCLIFOG system has negligible except for some instances the system cannot sense properly for lower rotations because of having very low % error. Meanwhile, in the third case by varying both V2π and Vπ/2 voltages, the DCLIFOG system cannot respond correctly due to increase in % error and also the threshold range was exceeded and insensitive for all lower rotations either in clockwise or counter-clockwise directions, as displayed in Fig. 9(c).



(a)



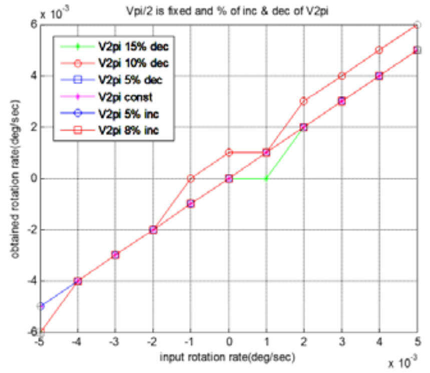
(b)



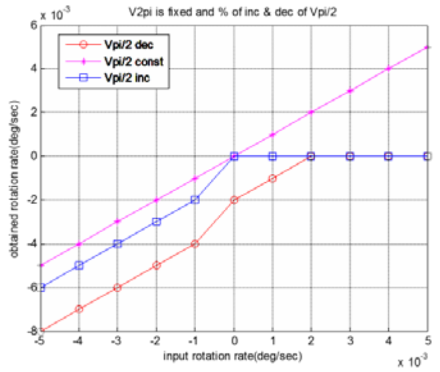
(c)

Fig.9 Threshold Results from Gyro for three-cases

Thus the threshold test executed for all cases, and then observed the linear characteristics of the gyro output by plotting a graph between the obtained rotation rates with actual input rotation rate for first two cases as displayed in the Fig's. 10(a & b) with respect to the tested results of Fig's. 9(a) & 9(b). But for third case cannot plot a graph because of insensitivity of the system for all lower rotations, as seen in Fig 9(c).



(a)



(b)

Fig.10 Estimation of Threshold Output for (a) Vπ/2 kept constant and V2π vary and (b) vice versa.

Finally from all these comparative results of the DCLIFOG system, it was observed that there exists a dead-zone. So that the system needs a correct reset value of V2π voltage to eliminate the dead band thereby reduces the non-linearity and instabilities present in the gyro output. Therefore, the ramp voltage must be exactly fixed with V2π range (which is also equivalent to phase shift range). This limits the range of voltage applied to the modulator for phase controlling in the gyro and need not require threshold testing, otherwise perform the threshold test to find out the dead band error and generate an additional feedback phase voltage according to error and is to be added to the system for dead band elimination.

However to eliminate this dead band error, both the V2π and Vπ/2 voltages are kept constant then only the DCLIFOG system seems to be more stable by effectively removal of dead-band-error and maintains the linear relationship between the measured and actual rotation rates, as displayed in the Fig 11. As a result, V2π "resets" known to those familiar in the art of digital closed-loop Interferometric fiber-optic-gyros (DCLIFOG) occur naturally and automatically then maintain the stability and linearity in the gyro output.

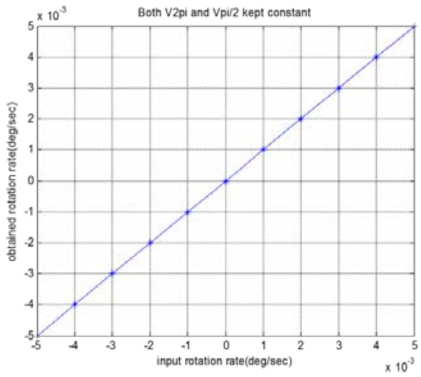
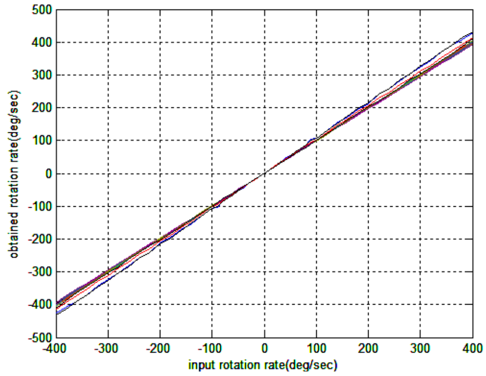


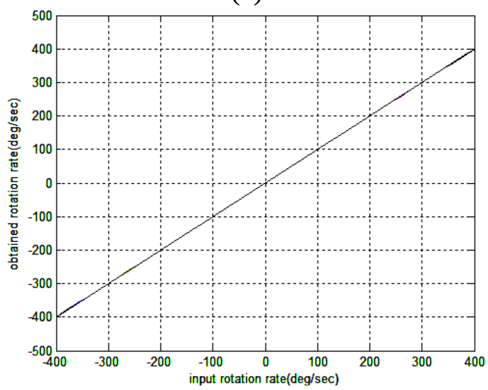
Fig.11 Estimation of Threshold Output for both V2π and Vπ/2 kept constant

7.4 Linearity

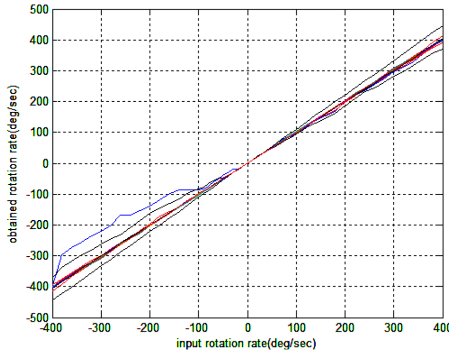
The linearity test executes for all cases, and then observed the linear characteristics of substantial rotation rate for an inclined rotation rate of input for three cases as displayed in the Fig's. 12 (a), (b) & (c). From the Figure 12 (b), it seems that the removal of dead band error and results a more stable and linear relationship between the measured and actual rotation rates, but in remaining two figures (Fig's 12 (a) & 12 (c)) there exists dead-zone due to variation in V2π voltage [2]. Therefore, the system observes that the ramp voltage must be exactly fixed with V2π range (which is also equivalent to phase shift range). This limits the range of voltage applied to the modulator for phase controlling in the gyro and need not require threshold testing.



(a)

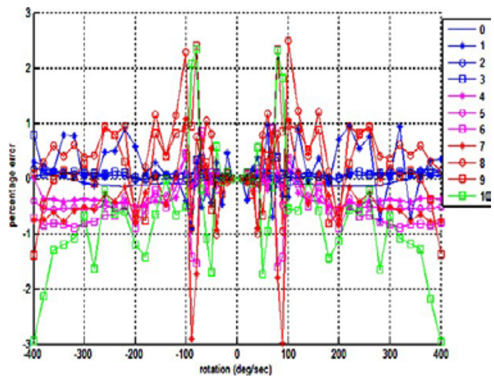


(b)

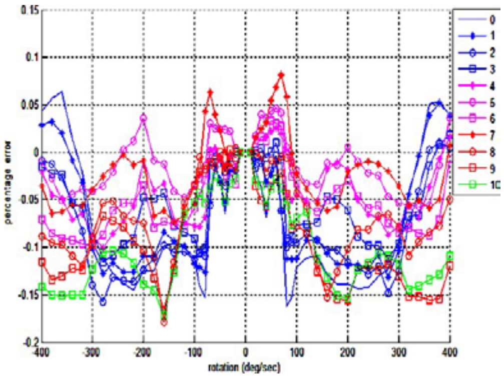


(c)

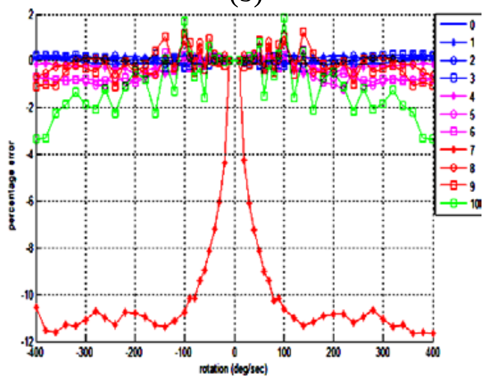
Fig.12 Estimation of Linearity for three-cases



(a)

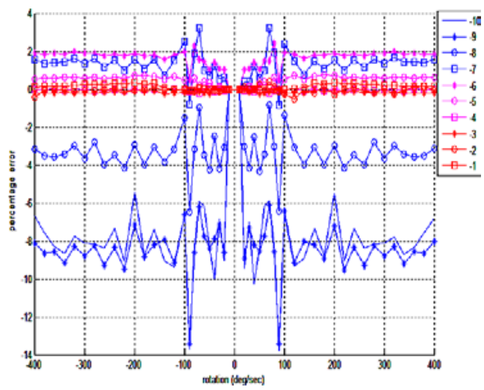


(b)

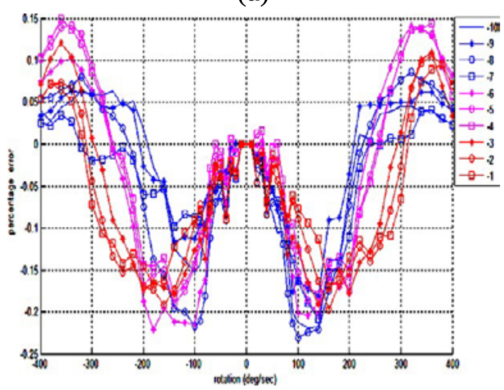


(c)

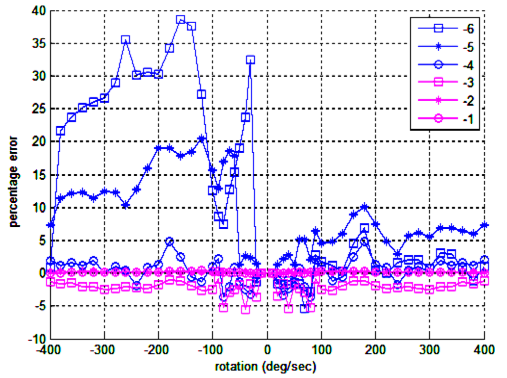
Fig.13 Estimation of % error increases from 1% to 10% for three-cases



(a)



(b)



(c)

Fig.14 Estimation of % error decreases from 10% to 1% for three-cases

The % error also detects for all cases, within a inclined rate-of-turn for three cases as displayed in Fig. 13 (a), 13 (b) & 13 (c) and Fig. 14 (a), 14 (b) & 14 (c).

In DCLIFOG system, the comparison is made on three cases, and the parameter values are finally tabulated as shown in the Table 1.

Table 1 Calibrated Values of DCLIFOG Parameters

DCLIFOG Parameters	Gyro Output
Ramp Voltage $V2\pi$	8.75V, 200 KHz
Square-Wave Bias Voltage $V\pi/2$	2.18V, 100 KHz
Bias	160 deg/hr
Scale-factor	-210683 counts
Offset	0.045 counts
Threshold Range	± 0.005 deg/sec
Linearity Range	± 400 deg/sec
Max. Non-Linearity	1313.60 counts
Min. Non-Linearity	-1290.10 counts
Percentage Error	± 10 %

8 Conclusion

In this paper, the rotation rate measurement in DCLIFOG system was studied theoretically and observes its performance by evaluating the gyro parameters. By changing these parameter values, different tests are done for three cases. All these obtained results comparison made in terms of bias, scale-factor, threshold and linearity. The performance of the DCLIFOG system was observed at lower rotation rates by adequate elimination of the dead band error. Otherwise, the system required to perform the threshold test in order to know the dead band error value for suppression. The comparative analysis made on gyro parameter among three cases: the obtained results shows that the system performance is susceptible against the change in ramp V2π voltage and results a dead band error in gyro output is of 10%, but has no severe effect in the system due to change in Vπ/2 square-wave biasing signal voltage when V2π voltage kept stable i.e., system is precise. Finally, concluded that the DCLIFOG system performance is very sensitive with respect to ramp voltage (V2π) variations. To eliminate the dead-band error, a proper resetting of V2π voltage is required. The experimental results shows that this adopted method can tremendously eliminate the dead-band error, nonlinearities and instabilities, produces an accurate output at the rate of ±0.005 deg/sec, and has no severe effect on other static FOG performance. As a result, V2π "resets" known to those familiar in the art of digital closed-loop Interferometric fiber-optic-gyros (DCLIFOG) occur naturally and automatically then maintain the stability and linearity in the gyro output.

References:

[1] Ruffin Paul, "Fiber-Optic Gyro Sensors", *Optical Science and Engineering*, 2008.

[2] T.Sireesha and K.Krishna Murthy, "Comparative Assessment on Linearity Test based V2π and Vπ/2 Voltage Variations of Closed-Loop IFOG", *International Journal of Electrical and Computer Engineering*, Vol.2, No.1, April 2016, 11 pages.

[3] T.Sireesha and K.Sreenivasa Ravi, "Comparative Assessment on Ramp and Bias Voltage Variations of Closed-Loop Interferometric Fiber-Optic Gyro", *Indian Journal of Science and Technology*, Vol 8(18), 67723, August 2015, pp 1-11.

[4] G. Krishna Prasad and Jagannath Nayak, "Design, Fabrication and Testing of Digital Signal Processing Scheme for Inertial Grade Fiber-Optic Gyro", *Inertial System Group*, RCI, Hyderabad, 2011, 10 pages.

[5] Jagannath Nayak, "Fiber-Optic Gyros: From Design to Production", *Applied Optics*, 09/01/2011, volume 50, Issue 25, E152-E161.

[6] Nasiri-Avanaki et al., "Comparative Assessment on the Performance of Open-Loop and Closed-Loop IFOGS", *Optics and Photonics Journal*, March 2012, 2, Issue. 1, pp 17-29.

[7] D. A. Egorov et al., "Study on Dead Zones of Fiber-Optic-Gyros", *Gyroscopy and Navigation*, 2011, ISSN 20751087, Vol. 2, No. 4, pp. 197–207.

[8] Rohollah Mazrae Khoshki and Prof. Submarian Ganesan, "Investigation on Closed-Loop Fiber-Optic Gyro Structure and Operation", *International Journal of Hybrid Information Technology*, Vol.7, No.5 (2014), pp.23-32.

[9] Q. D. Sun et al., "FPGA-Based Hardware Design of Closed-Loop Control for Fiber-Optic Gyro", *Journal of Theoretical and Applied Information Technology*, 10th May 2013. Vol. 51 No.1, pp 121-128.

[10] Hong Gu et al., "Real-Time Dynamic Simulation of Angular Velocity and Suppression of Dead Zone in IFOG", *Optical Review*, 2015, vol. 22, Issue 1, pp 39-45.

[11] A V Anuhya et al., "Suppression of Thermal Effect on Closed Loop Fiber Optic Gyroscope", *Indian Journal of Science and Technology*, Vol 8(15), 69571, July 2015, pp 1-7.

[12] G. Harish Babu, et al., "Digital Signal Processing Scheme for Open Loop and Closed Loop IFOG using MATLAB/SIMULINK", *Indian Journal of Science and Technology*, Vol 9(11), March 2016, pp 1-10.

[13] Chung-Jen Chen, "Interferometric Fiber Optic Gyroscope Dead Band Suppression", *Applied Physics Express*, Vol. 1, No.7, 27 June 2008.

[14] Shitao Ji, et al., "Research on small 3-Axes Integrated Fiber-optic gyro", 2010 3rd International Symposium on Systems and Control in Aeronautics and Astronautics, http://dx.doi.org/10.1109/ISSCAA.2010.5632217, pp 784-787.