Correction of Drift by using Thermal Compensation for Ring Laser Gyroscope

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ABSTRACT

Ring Laser Gyroscope (RLG) is the instrument for calculating angular information of the platform on which it is strappedown. The working principle of the Gyroscope is based on Sagnac effect. Behaviour of Gyroscope depends on adjustment of two control loops (Intensity Control Loop and Path Length Control Loop). More precisely tuned control loops will yield accurate results. These control loops are implemented using DSP and FPGA logics.

The output of Gyroscope is rate information and should be independent of temperature. But during testing it is observed that there is drift in output w.r.t temperature. Because of the Gyroscope drift navigational error gets accumulated resulting in large mis-distance of the vehicle where the Gyroscope is strappedown. So a corrective scheme is required to avoid drift w.r.t temperature. This paper explains the development of algorithm and the results before and after the application of compensation scheme.

Key words: RLG, DSP, FPGA, Sagnac Effect

1. INTRODUCTION

Inertial Navigation System (INS) is a vital component for the aircraft & missile applications. The heart of the INS is the set of sensors that are used for the angular rate and linear acceleration measurements. Performances of these inertial sensors will dictate the ultimate strike accuracy of the mission. The inertial sensors comprise of Gyroscopes and Accelerometers which provide the incremental angular displacement and linear velocity at fixed intervals of time. A wide variety of Gyroscopes and Accelerometers are available to cater to the various mission requirements. Broadly the Gyroscopes fall into these technologies and grouped into Mechanical gyros, Laser gyros and Fabric Optic gyros.

2. PRINCIPLE OF OPERATION

The laser Gyroscope works on a physical principle discovered by the French physicist G. Sagnac. Sagnac found that the difference in time that two beams, each traveling in opposite directions, take to travel around a closed path mounted on a rotating platform is directly proportional to the speed at which the platform is rotating.

In the Ring Laser Gyroscope, the laser used is helium- neon type. It produces a beam of wavelength 0.6333 micrometers. A beam splitter is used along with the laser source. It is used to split the laser beam into two beams moving in clockwise and anticlockwise directions. The oscillation frequency of each beam is determined by the optical path length of the cavity. The path length must be an integral multiple of wavelength. As demonstrated by Sagnac, when the cavity is rotated, the oppositely directed beams oscillate at different frequencies and the frequency is proportional to the rotational rate of the cavity. Thus by measuring the frequency difference, the rotation of the laser cavity and any vehicle to which it is mounted can be determined. The oscillation conditions for the Gyroscope are defined in terms of two conditions namely:

1. At frequency of oscillation the loss of the cavity is to be balanced by the gain of the oscillator.

2. The closure condition which demands that there should be an integral number of wavelengths in the total optical path of the cavity.

The optical path length [L] is related to the beam wavelength by

$$L = m\lambda \qquad (1)$$

Where m is a constant, L is optical path length and λ is wavelength of light in vacuum.

$$L = mc / \nu$$

$$\Delta L = - mc\, \Delta\nu / \nu^2$$

or $$|\, \Delta\nu / \nu \,| = |\, \Delta L / L \,|$$

This equation shows that if there is any finite difference in the optical paths of clockwise and anticlockwise beams, there will be finite difference in the clockwise and anticlockwise frequencies.

For simpler calculation a circular cavity is considered. Time difference between clockwise and anticlockwise beams is expressed as following.

$$\Delta t = t\,(\text{clockwise}) - t(\text{anticlockwise})$$

$$\Delta t = 4\, \pi\, R^2\, \omega / c^2$$

$$\Delta t = 4A\, \omega / c^2$$

For a gyroscope radius of 10cms and ω = 10 degree per hr. So time difference is found to be approximately $6.76\text{x } 10^{-23}$ sec, which is too small to be measured.

But when it is calculated in terms of frequency difference

$$|\, \Delta\nu / \nu \,| = |\, \Delta L / L \,| = 4\, A\, \omega / c\, L$$

or $$\Delta\nu = (4A / \lambda L)\, \omega = 15.312 \text{ Hz} \qquad (2)$$

Which is a measurable quantity.

Thus in Ring Laser Gyroscope a small path length difference is translated into a more readily measurable quantity frequency difference to find out body motion information. To separate the rotational contribution from the high optical frequency, the two beams are first made approximately collinear. By means of retro-reflecting mechanism (using total reflecting prism) two beams are combined. This results in a fringe pattern with the spacing determined by the degree of colinearity. When the frequencies are equal, the fringes are stationary in time. When they differ, the fringes move across the field of view at the beat frequency rate. Thus by measuring the number of fringes moving across the field of view for a fixed time as done in an integrating ring laser gyroscope, angular displacement can be determined.

3. EFFECT OF TEMPERATURE IN OUTPUT OF GYROSCOPE

Drift which is one of the important parameter for characterization of Gyroscope is specified as following.

Drift

(a) Random Walk : $0.003^0 /\sqrt{\text{hr}}$

(b) Bias Instability Coefficient : $0.01\, ^0/ \text{hr}$

But drift may vary w.r.t. temperature beyond the specified value. Hence the Gyroscope performance can be changed from the expected behaviour.

To minimize the variation in drift Thermal Compensation scheme can be implemented as discussed later.

4. THERMAL MODELING SCHEME

Ideally Gyroscope is a rotational sensor whose output is proportional to rotation rate which is measured in terms of number of pulses. The Gyroscope output is constant and independent of temperature as described in following equation.

$$N = (1/SF)*\theta + B \tag{3}$$

Where N is Count, SF is scale factor, B is Bias, θ is the angle of rotation.

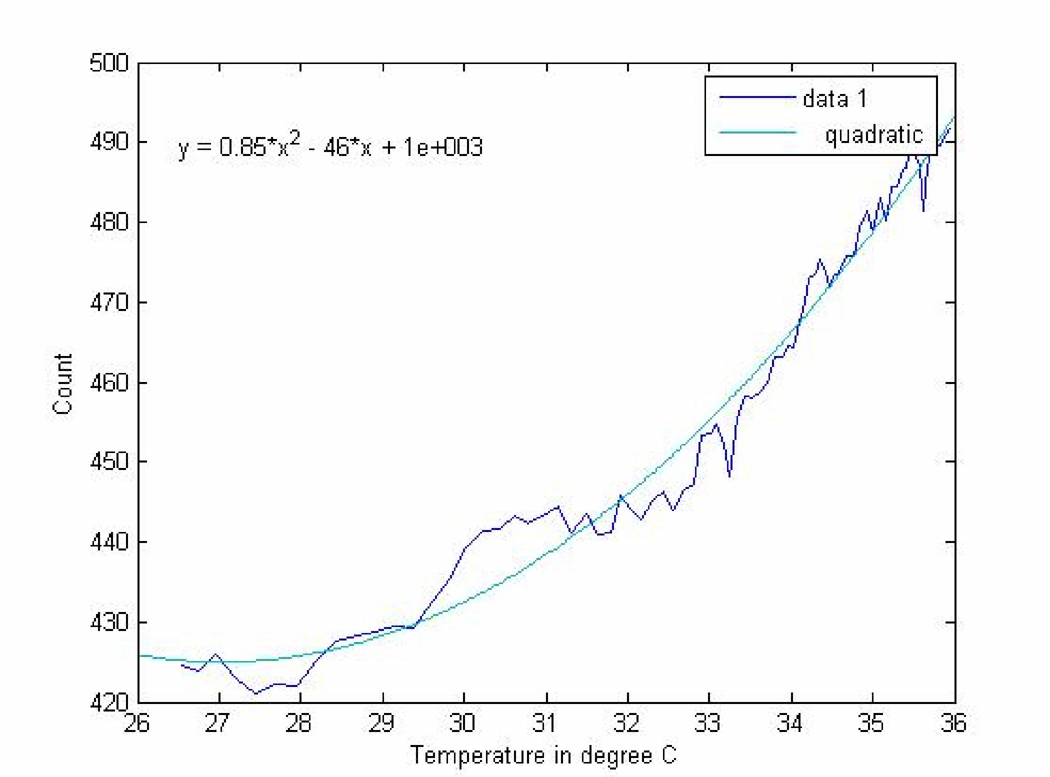
But it is observed that the output of Gyroscope may vary with temperature

$$N = N0 + N1 \tag{4}$$

Where N0 is actual count and that is constant because of fixed rotation rate. And N1 is drift in count due to temperature changes.

4.1 Algorithm steps:

1. Fit a second order curve by least square error method to test data of Gyroscope output for fixed rotational rate.



2. Find the coefficients (A,B,C) for second order curve as

$$N = A\,T^2 + B\,T + C \tag{5}$$

Where A = 0.85, B = -46, C = 1000

3. At Ambient (25degree C) Count is N0.

4. Variation In Count at different temperatures = N –N0

5. Correction to be applied in different temperature zones = - (N-N0)

6. Theoretically final Gyroscope output is sum of Gyroscope output without correction and correction required.

$$\text{Final Gyroscope output} = N - (N - N0) = N0$$

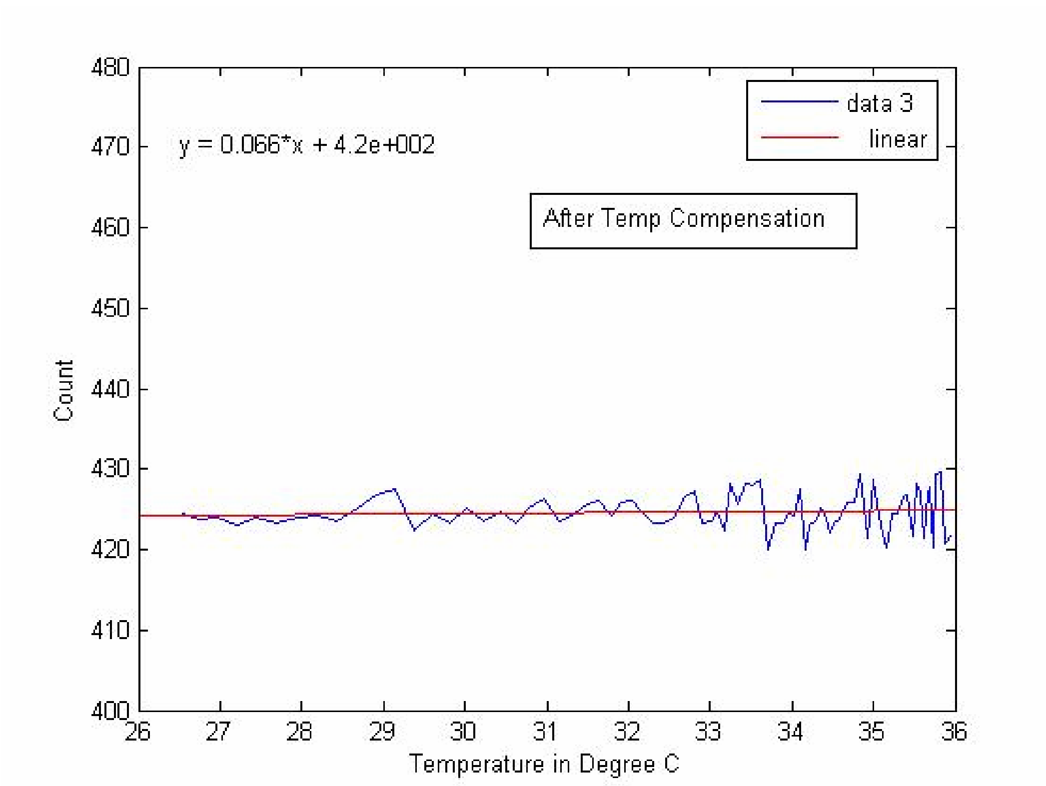
4.2 Implementation:

Without implementation of model, test the Gyroscope for the entire temperature range. Observe the variation in output count. Evaluate the thermal compensation model as described in step 4.1. And calculate the coefficients.

These Coefficients are written in flash memory. DSP executes this correction using these coefficients accessed from flash memory in every100 µSec.

4.3 Results after Implementation of Thermal Compensation:

After implementation of algorithm, Gyroscope has been again tested and following result has been obtained.



5. RESULTS

Results are obtained before and after implementation of algorithm and following observations have been found.

	Minimum Count (100 secs)	Maximum Count (100 secs)	Mean Count (100 secs)	*Error*
Before Compensation	421	491.75	457.85	*70.75*
After Compensation	*420*	*429*	*424.64*	*9.0*

6. FUTURE SCOPE OF WORK

6.1 To get better accuracy, it is necessarily required that Bias and Scale Factor should also be modeled because both vary with temperature. It necessitates the calibration of the RLG under rotational conditions in different temperature environments.

6.2 Implementation of Higher Order Algorithm will yield better accuracy but tradeoff should be in balanced in terms of computational overload and accuracy.

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