APPLICATION NOTE

True North Finder applications

Date : 28/09/2013
Ref : IN-IR-MPD-73-75, rev. 1.1
Owner: J. BEITIA

Introduction

The INL-CVG-GU200 is a two-axis gyro Unit, CVG based (Coriolis Vibratory Gyros), currently in full series production in Dublin for the stabilisation control market. However, given the short-term bias stability observed on some samples under Lab conditions, the INNALABS' CVG core technology could also be a pertinent candidate for the True North-Finder (TNF) market.

In order to clarify that point, the following test protocol has been carried out on 3 serial products:

- Serial numbers (GU200): SN 126, 179, 180
- Test equipment: Actidyn-Climats with temperature set-point of 25 °C ± 0.5 °C
- Gyro Unit ON over 1 hr. Followed by a Gyro Unit OFF over 5 min.
- Followed by a Gyro Unit power on. Data-collection engaged at that point. Set-up: analogue low-pass filter (0.2 Hz) applied on GU outputs X and Y. Sampling period of 2.5 sec.
- END for data-collection 8 hr later

Based on the data collected and by considering TNF operated through the carouseling method, the second part of this document provides an estimation of the gyro bias errors.

ROUGH RESULTS

At this stage, the scale factor is assumed to be a constant (32 mV/(°/s)). Figures 1, 2 and 3 below show the bias drift observed on each axis over 8 hr after power-on:

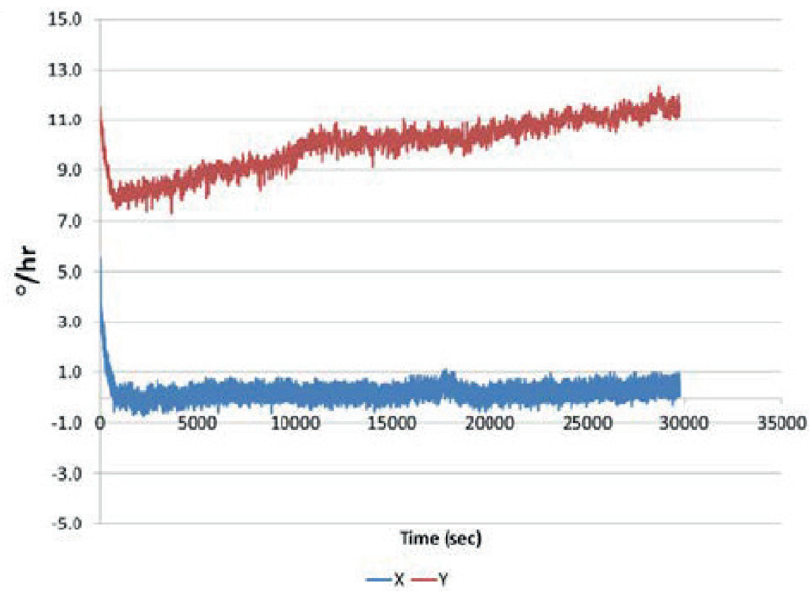

Figure 1
Bias stability over 8 hr after power-on (GU200-126)

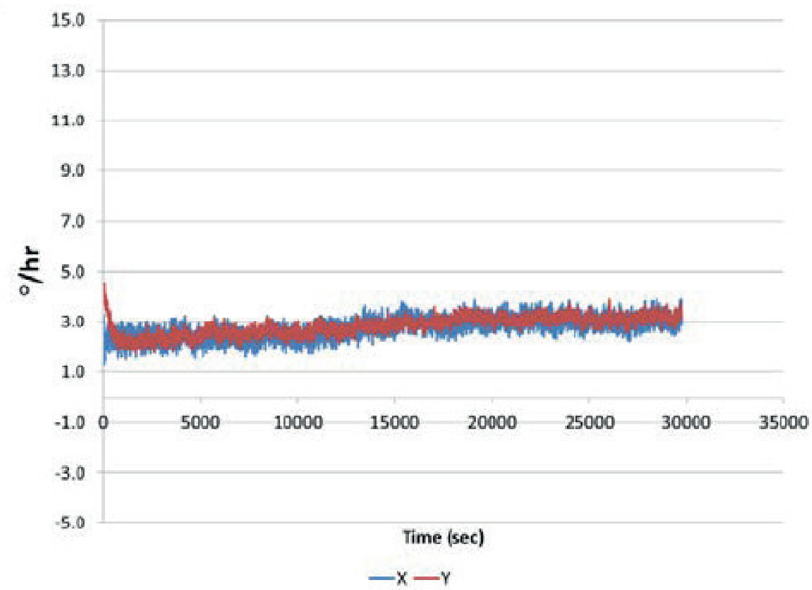

Figure 2
Bias stability over 8 hr after power-on (GU200-179)

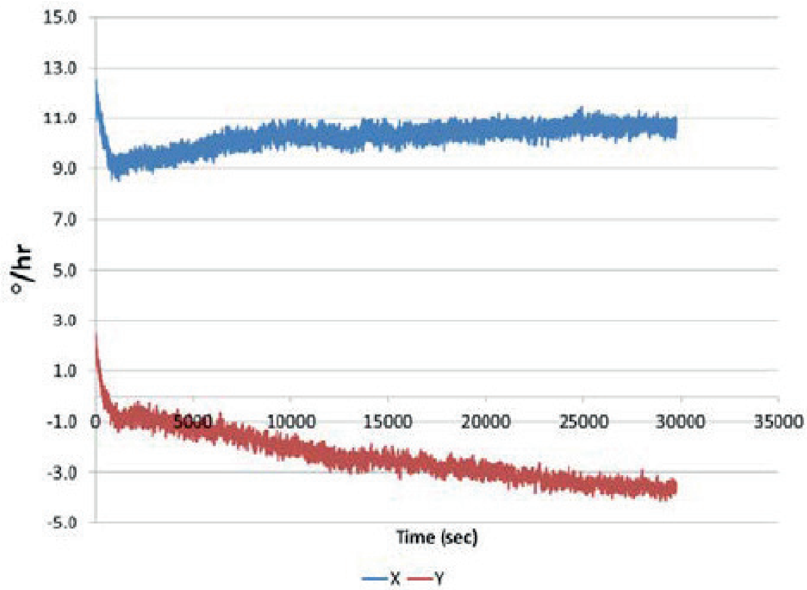

Figure 3
Bias stability over 8 hr after power-on (GU200-180)

Before 900 sec (15 min), the bias drifts by ≈ 1 °/hr (#179, axis X) to 5 °/hr (#126, axis X). Over that period of time, a trend analysis fits an exponential trend model to bias data and provides a time constant of 4 to 5 min which indicates the electronics warm-up is likely the root cause (temperature time constant for the sensitive element is > 15 min). When considering an application such as a TNF, an easy improvement should be achieved by implementing a thermal shortcut between the electronics and the TNF body.

After 900 sec, on average, the bias drift becomes very small with a slope of 0.04 °/hr/hr (#126, axis X) to 0.42 °/hr/hr (#126, axis Y).

An immediate conclusion is the short-term bias stability depends on temperature conditions and, over the warm-up phase after start-up (< 900 sec), as is, the lowest point of the Allan chart can hardly achieve less than 0.1 °/hr (1σ). After the warm-up phase, due to the reduced drift slope, results are far better as shown below.

The following charts are based on an ALLAN variance analysis carried out on the data collected in the range 5 hr to 8 hr. A drift slope correction (linear regression) is applied in order to get a rough estimate of the best performance achievable, as is, in the range of non-carouseling applications (see § 3):

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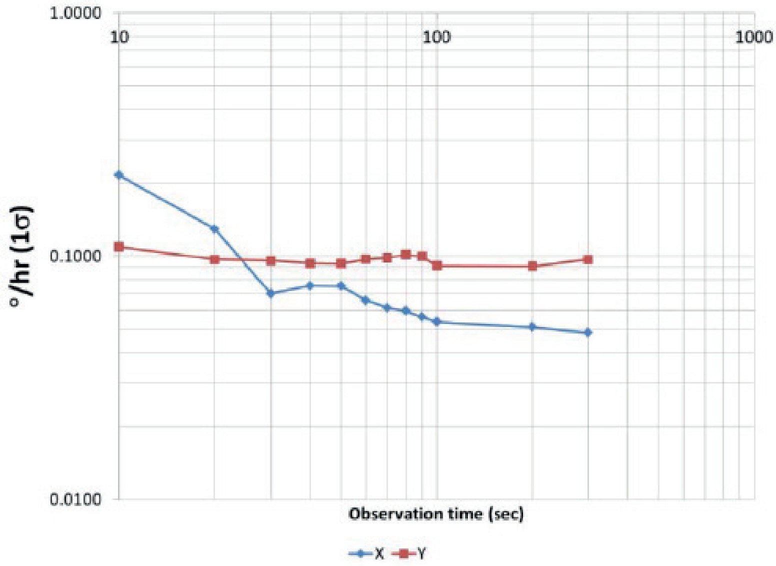

Figure 4
Allan variance analysis (GU200-126)

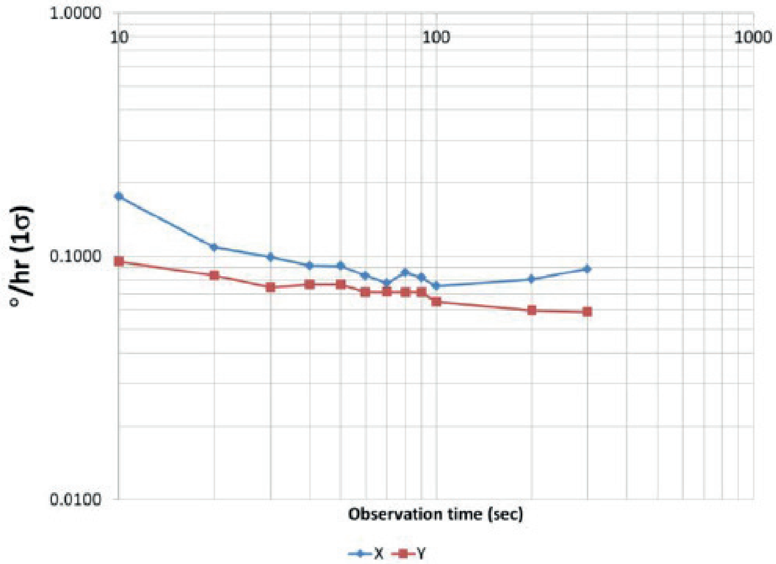

Figure 5
Allan variance analysis (GU200-179)

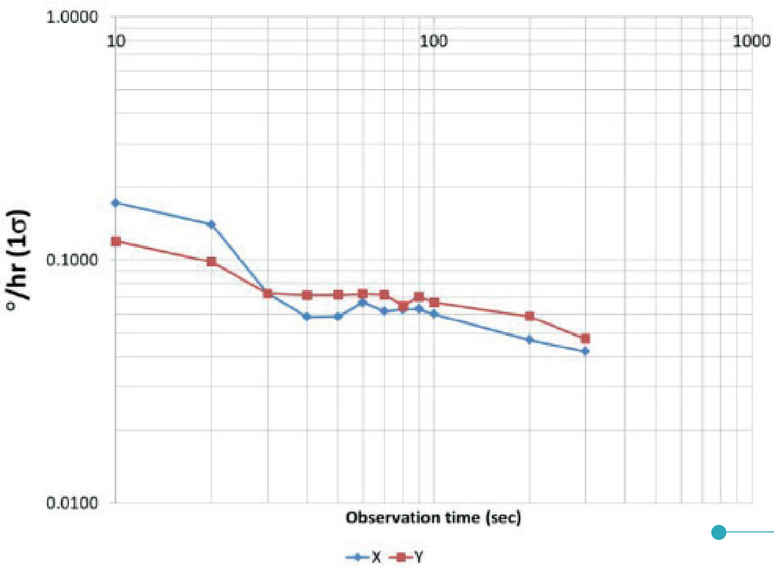

Figure 6
Allan variance analysis (GU200-180)

Following Table Provides the results at 60 sec

AXIS	GU126	GU179	GU180
X	0.07 °/hr (1σ)	0.08 °/hr (1σ)	0.07 °/hr (1σ)
Y	0.10 °/hr (1σ)	0.07 °/hr (1σ)	0.07 °/hr (1σ)

On average (6 axes), 0.075 °/hr (1σ) @ 60 sec is achieved. The best case is 0.066 °/hr (1σ) (#126, axis X), very close to results previously observed under laboratory conditions on the #12 (0.035 °/hr (1σ) over 1 month).

Although those results are 10 times better than results achieved by most of the MEMS gyros available on the market, a ratio of 3 improvement is still required to satisfy the needs of the TNF market.

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THE CAROUSELING METHOD

In case of strapdown TNF systems, it has been shown that the carouseling method significantly helps reduce gyros errors. In this case, the gyroscope is rigidly fixed on a rotating platform which axis is parallel to the local Earth's vertical. When the gyro input axis is oriented horizontally and the platform rotates continuously, assuming the gyro bias errors stable enough within a lap, the gyro output signal varies as a harmonic sine function. The amplitude of the sine is a reading of the Earth's rate angular rotation and its phase is a measure of the heading to the Earth's True North.

A variant of the method is obtained when the rotating platform moves back and forth between two 180° angular positions. In that specific case, the complexity of the overall mechanical system architecture gets simplified since there is no need for an accurate control of the platform. Assuming the gyro axis is perfectly horizontal, the gyro output measured along position 1 and position 2 (180° from 1) takes the form:

$$Output_1 = \Omega_T.\cos(\psi_1).cos\lambda + b_1 + noise \quad \textbf{(1)}$$

$$Output_2 = -\Omega_T.\cos(\psi_1).cos\lambda + b_2 + noise \quad \textbf{(2)}$$

Where:

Ω_T: The Earth's rate rotation (≈ 15.04 °/hr)

ψ_1: The azimuth angle at start (toward the True North)

λ: The Latitude angle

B_1 and B_2: The gyro bias errors along position 1 and position 2

Since a TNF has no specific requirement in terms of phase lag, given the shape of the Allan charts above (Fig. 4, 5, 6), a Low Pass Filter (LPF) with a high order and a cutting frequency less than 0.1 Hz can be implemented in order to cut off the gyro output noise. After filtering, equations (1) and (2) take the form:

$$Output_1 = \Omega_T.\cos(\psi_1).cos\lambda + b_1 \quad \textbf{(3)}$$

$$Output_2 = -\Omega_T.\cos(\psi_1).cos\lambda + b_2 \quad \textbf{(4)}$$

Consequently:

$$\frac{Output_1 - Output_2}{2.\Omega_T.cos\lambda} = \cos(\psi_1) - \frac{b_2 - b_1}{2.\Omega_T.cos\lambda} \qquad (5)$$

When $B_2 = B_1$, the above equation (5) gives an accurate estimation of the azimuth angle ψ_1. But in reality, as shown by Figure 1, 2 or 3, the bias is time-dependent and drifts over the time period required for filtering and/or for the platform to rotate from position 1 to position 2.

Assuming $\frac{B_2 - B_1}{2.\Omega_T.\cos\lambda} \ll 1$, equation (5) shows the angle ψ_1 will be identified with an error ε as follows:

$$\varepsilon = \frac{B_2 - B_1}{2.\Omega_T.\cos\lambda.\sin(\psi_1)} \qquad (6)$$

Since:

$$\cos(\psi_1 + \varepsilon) \approx \cos(\psi_1) - \sin(\psi_1).\,\varepsilon \qquad (7)$$

Comment:

An easy way to minimize the angular error ε is to orientate position 1 toward East or West so that $\sin(\psi_1) \approx 1$. For the next, we assume $\psi_1 \approx 90°$. The worst case happens when B_2 and B_1 are not time-correlated.

Assuming an error of 1 mrad (1σ) and 45° angle latitude, the bias stability requirement is then:

$$B_2 - B_1 = \varepsilon.2.\Omega_T.\cos\lambda \leq 0.02°/hr\ (1\sigma) \qquad (8)$$

But in fact, the observation time allocated for the estimation of the azimuth angle ψ_1 is generally ranging from 2 to 5 minutes, and, as shown by Figure 1, 2 or 3, a component of the bias drift is then clearly time-correlated. As a consequence, over the overall observation time:

$$B_2 = B_1 + \Delta B + \delta \qquad (9)$$

Where:

ΔB: bias deviation, time-correlated
δ: short-term bias deviation, no time-correlation

From a system point of view it becomes realistic to set-up a recursive math model aiming at estimating ΔB based on the previous known state (including the latest output sample picked-up). Equation (6) becomes:

$$\varepsilon = \frac{\delta}{2.\Omega T.\cos\lambda} \qquad \textbf{(10)}$$

POTENTIAL PERFORMANCE OF INNALABS'S TECHNOLOGY

Based on above considerations, a rough estimation of the potential performance is achieved when post-processing the previous data as follows:

+ A digital second order LPF with 20 sec characteristic-time to cut-off the gyro output noise after sampling (2.5 sec)
+ A linear regression using the least squares method to estimate ΔB over 120 sec, every 120 sec, and to elaborate a discrete signal consistent with δ
+ An ALLAN variance analysis carried out on signal δ, right from start-up

Following Figures 7, 8 and 9 show the ALLAN charts achieved.
At 60 sec, results are:

AXIS	GU126	GU179	GU180
X	0.014 °/hr (1σ)	0.020 °/hr (1σ)	0.012 °/hr (1σ)
Y	0.023 °/hr (1σ)	0.016 °/hr (1σ)	0.014 °/hr (1σ)

On average (6 axes), 0.016 °/hr (1σ) @ 60 sec is achieved.

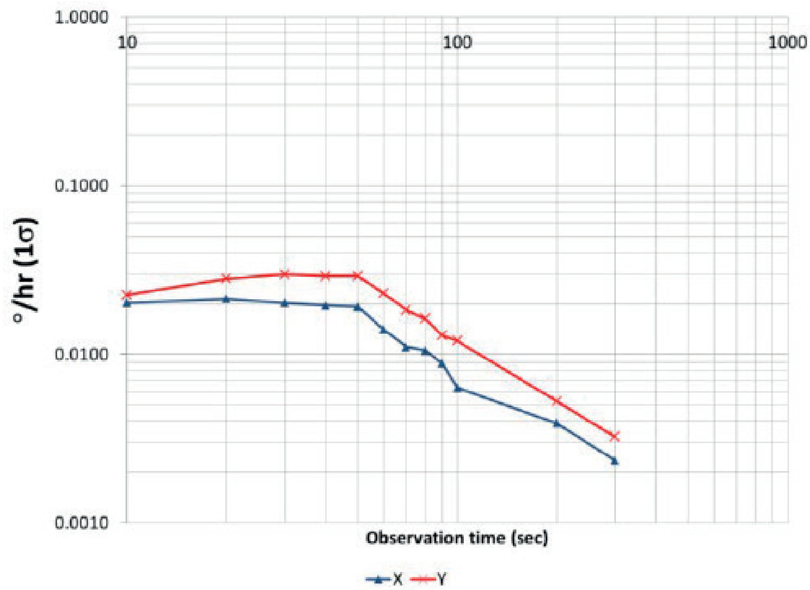

Figure 7
Allan variance analysis (GU200-126)

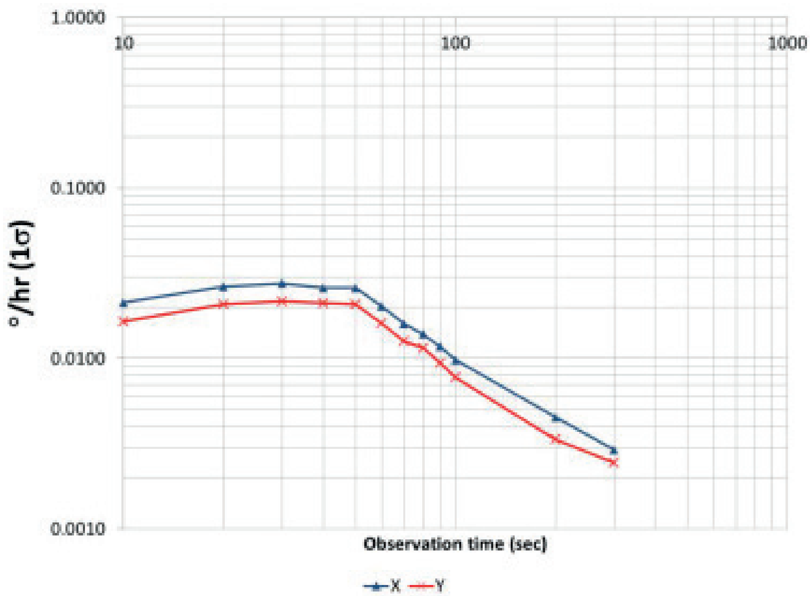

Figure 8
Allan variance analysis (GU200-179)

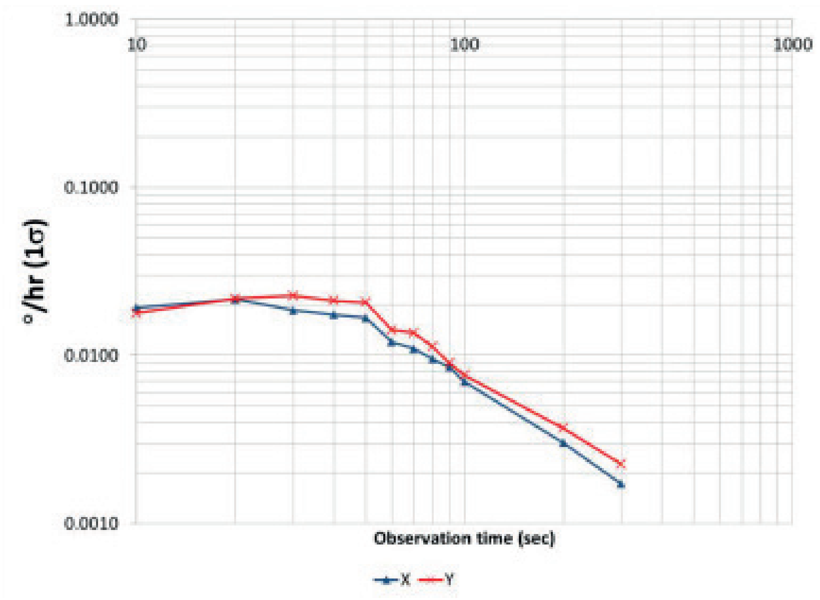

Figure 9
Allan variance analysis (GU200-180)

CONCLUSION

INNALABS Ltd has developed a low cost tactical-grade Coriolis Vibratory Gyroscope with very low output noise and excellent short term bias stability.

When considering the specific operating conditions delivered by strapdown carouseling TNF, some advantageous achievements (recursive math model) can be implemented leading to less than 0.02 °/hr (1σ) @ 60 sec.

Given those performance parameters, INNALABS Ltd CVG technology appears to be a realistic technology for terrestrial low cost North-finders.

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