Test report

Ellipse performance under vibrations

SBG SYSTEMS

Table content

1. Introduction

Vibrations are common in many real-world applications, such as UAVs and industrial machinery. Since vibrations are unwanted movement -and IMUs are designed to measure movement- Excessive vibrations directly impact can affect sensors and algorithm performance, leading to errors, signal noise and instability in measurements.

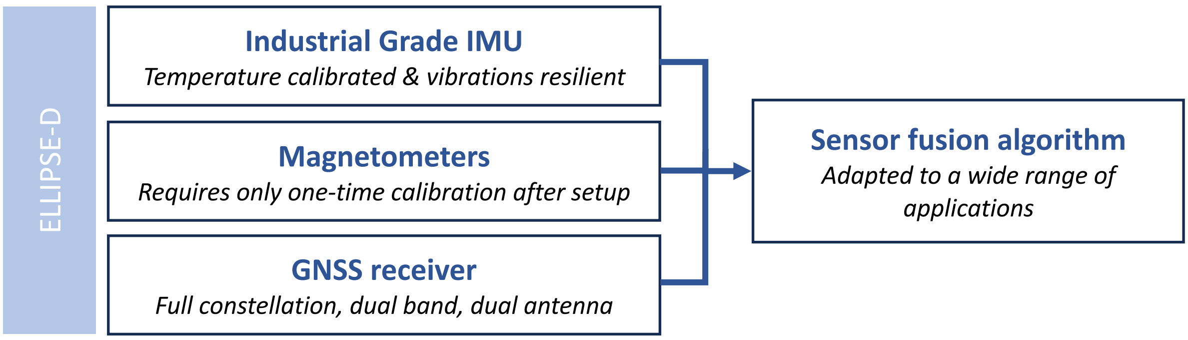
This report aims to evaluate the performance of the Ellipse under various vibration conditions. Extensive testing was conducted by placing the sensor on a shaker and applying different vibration profiles. The goal is to assess the system's ability to maintain stable roll and pitch estimations and determine how well the embedded sensor fusion algorithm compensates for vibrations.

2. Preliminary

2.1. Product presentation

The system under evaluation is the Ellipse, a compact MEMS based product line, ranging from IMUs to GNSS-aided INS. This report focuses specifically on the Vertical Gyro (VG) mode of the Ellipse, where only roll and pitch performance are assessed.

The diagram below illustrates the functional structure of the Ellipse-D.



The environmental specifications of the Ellipse are listed below:

Environmental specifications	
Operating vibration	8 gRMS (20 Hz to 2 kHz per MIL-STD-810G)
Shock limit – survivability	500 g / 0.1 ms
Operation temperature	-40 to +85 °C

2.2. Fundamentals

Vibrations are oscillatory movements that can be categorized based on their frequency, amplitude and source. They can be classified into:

- Sinusoidal vibrations: periodic and predictable, modeled by a sine wave with known frequency and amplitude. They are commonly used in controlled testing environments, particularly to characterize the resonance frequency of IMUs. When the excitation frequency matches the natural frequency of the system, resonance can occur — amplifying the sensor's response. Once this resonance is identified, a dwell can be performed at that specific frequency to further analyze its impact on the IMU's performance.

- Random vibrations: unpredictable and more representative of real-world conditions, such as those experienced during drone flight or in harsh environments. They vary in both frequency and amplitude over time, making them difficult to model precisely. These vibrations are typically analyzed using a Power Spectral Density (PSD) function, which shows how the vibration energy is distributed across frequency bands. The overall vibration level is defined by the gRMS value.

In environments where high reliability is required, such as in aerospace, military, and some industries, it is critical to test sensors under various vibration categories. The MIL-STD-810 standard provides guidelines to test equipment's vibration tolerance in harsh environments, ensuring devices perform reliably in real-world conditions. This standard covers vibration profiles to simulate sinusoidal and random vibrations.

For this test report, the vibration profiles used to evaluate the Ellipse were taken directly from MIL-STD-810, ensuring the system was tested under the same rigorous conditions required for high-performance applications.

3. Test conditions

3.1. Test setup

The test was conducted using a shaker table, which provides a controlled environment to simulate various vibration conditions. The Ellipse was securely mounted on the shaker table, ensuring that it was subject to the full spectrum of vibrations generated by the table's movement.

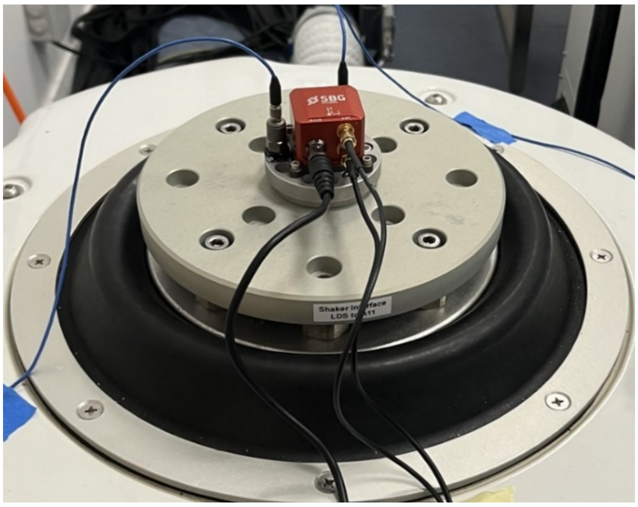


Figure 1: Test setup

3.2. Test description: vibration profiles used

For this test campaign, two main types of vibrations were applied: sinusoidal and random vibrations. Several vibration profiles were selected to represent a wide range of real-world operational conditions. These profiles were progressively intensified to reach the vibration levels specified in the Ellipse's technical documentation.

Each profile's parameters (frequency range, amplitude, duration, etc.) are detailed alongside their respective results in Section 4.

3.3. Test procedure

The Ellipse was kept steady for 5 minutes before each test. Afterward, the designated vibration profile was initiated. Each profile was applied for the specified duration, followed by a 5 minute pause before proceeding to the next test. This process was repeated for each vibration profile.

Euler angles were then extracted and compared to a reference, which is the mean roll and pitch values of the Ellipse in a static position over an extended period of time.

4. Random vibrations test

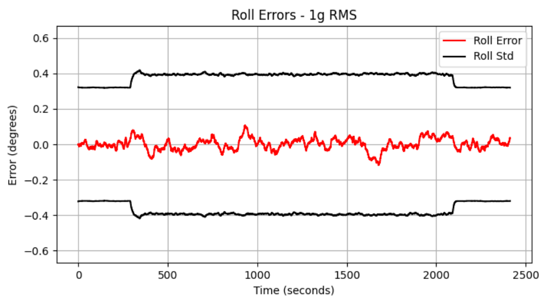
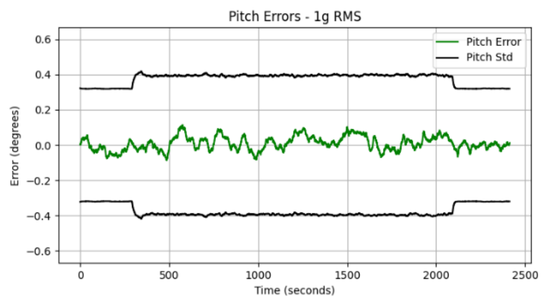
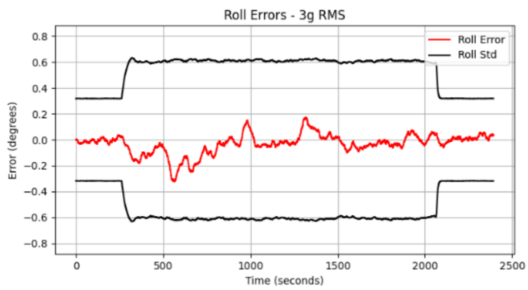
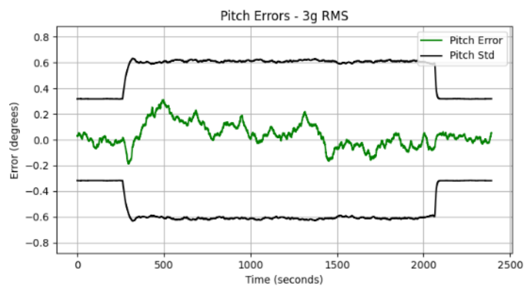
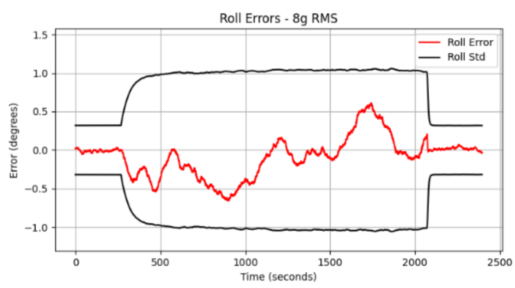
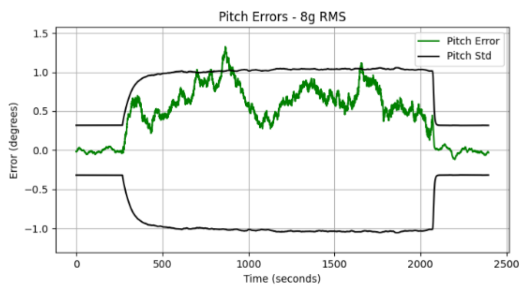
4.1. Test description

The table below summarizes the different vibration profiles used for this test:

Random vibrations "RV": *30 minutes of vibrations following the Power Spectral Density (PSD) as defined in MIL-STD-810G, Method 514.6, Annex E.*		
Test	Amplitude (gRMS)	Duration (min)
RV_1gRMS	1	30
RV_3gRMS	3	30
RV_8gRMS	8	30

4.2. Test results

The graphs below represents the timeseries of the roll and pitch errors. Along with the errors, the real time standard deviation is plotted, which gives insight into the system's confidence and stability.

Test	Roll errors	Pitch errors
Random vibration **1g RMS**		
Random vibration **3g RMS**		
Random vibration **8g RMS**		

5. Sine sweep vibrations

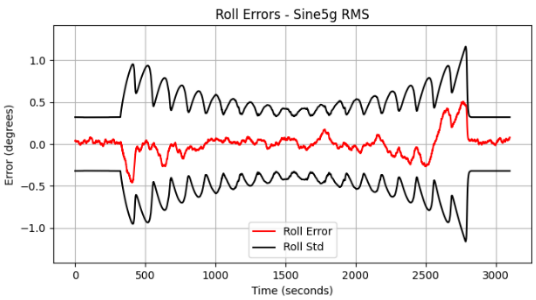
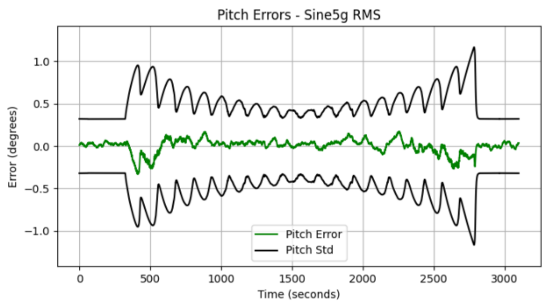
5.1. Test description

The table below summarizes the different vibration profiles used for this test:

Sine sweep "SS": *41 minutes of vibrations in which the frequency gradually increases then decreases over a 10–500 Hz range.*				
Test	Peak (g)	Up-down sweep	Step (Hz/s)	Duration (min)
SS_5g	5	1	0.4	41

5.2. Test results

The graphs below represents the timeseries of the roll and pitch errors. Along with the errors, the real time standard deviation is plotted.

Test	**Roll errors**	**Pitch errors**
Sinus Sweep **5g**		

6. Analysis

Random Vibrations (RV)

As the vibration intensity increases from 1gRMS to 8gRMS, we observe:

- A progressive increase in error amplitude, as expected under more severe vibrations (8g RMS)
- Despite this, the roll and pitch errors consistently remain within the standard deviation envelope, indicating the estimator's robustness and maintained confidence
- Even under 8g RMS, the errors stayed bounded and the Ellipse recovered quickly after vibration exposure, with no drift or bias afterwards

Sine Sweep (SS)

In the sine sweep test at 5g, the system is subjected to controlled vibrations:

- The oscillating pattern in the standard deviation curves reflects the system's response to periodic excitations across a frequency range
- The standard deviation envelope clearly follows the sine wave, indicating the system's sensitivity to frequency content
- Importantly, both roll and pitch errors remained within ±0.5°, with no sign of drift or algorithm instability despite high-frequency inputs

Overall, the Ellipse remained stable and performed reliably across all test conditions. The amplitude and frequency of the vibrations naturally influence the estimation accuracy, yet in all cases, the attitude errors remained within acceptable bounds.

7. Conclusion

This test was designed to rigorously evaluate the Ellipse sensor's performance under high and varied vibration levels, reaching up to 8g RMS and 5g at 500 Hz sinusoidal. The vibration profiles were derived from MIL-STD-810 standards to simulate extreme operational environments and assess both hardware resilience and attitude estimation accuracy.

Across all test scenarios, the Ellipse consistently delivered stable and reliable attitude estimation:

- Roll and pitch accuracy, while expectedly reduced under stress, remained excellent throughout the tests.
- No drift or instability was observed during or after the vibration events.
- The roll and pitch confidence indicators (standard deviation), as reported by the Ellipse, remained consistent and accurate.

These results confirm the robustness of the Ellipse's IMU hardware and the reliability of its Vertical Gyro/AHRS algorithms. The sensor demonstrated its capability to operate effectively in high-vibration and dynamic environments.

Additionally, this test can be considered a worst-case baseline for evaluating the Ellipse in GNSS/INS mode. In such configurations, GNSS aiding provides significant benefits under harsh conditions, enhancing overall system stability by reducing reliance on IMU data alone. Therefore, based on the tested scenarios, an Ellipse operating in GNSS/INS mode would offer reliable and accurate performance even in severe vibration environments.