INERTIAL NAVIGATION SYSTEM DITHER SOUND & VIBRATION TEST

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This is an actual test report, but some potentially proprietary information has been withheld.

Test Objective

Perform a spectral analysis on the sound generated by the dithering of the Inertial Navigation System (INS) Ring Laser Gyros (RLGs). Determine whether dithering could account for the steady 40 Hz signal measured by an INS rotational sensor both before and during the flight of an unnamed suborbital vehicle.

The 40 Hz signal did not affect the mission results, but its source should be identified for a variety of reasons.

Test Equipment

- 1. INS Engineering Development Unit (EDU)
- 2. Power Supply for Inertial Navigation System
- 3. Uncalibrated USB Microphone with Internal Sound Card
- 4. Notebook PC with Audacity v1.2.4 software

Test Description

The test was performed at an unnamed aerospace company on April 9, 2007. The test set-up is shown in Figure 1. The INS was powered such that its Rate Gyros underwent dither oscillations. The resulting sound tones were recorded by a microphone and a PC. The sample rate was 44,100 samples per second.

Assumptions

Assume that the measured sound represents dithering vibration. Also, assume that the ambient noise in the test room was negligible. This noise was mainly due to the air conditioning system.

Results

The sound pressure time history is shown in Figure 1. The spectral magnitude plot is shown in Figure 2. The sound pressure data was then passed through a smoothing and decimation filter which simulated the INS algorithm, as described in Appendix A. The spectral magnitude of the decimated data is shown in Figure 3. Each of the peaks in Figure 3 represents aliasing.

Conclusion

The INS smoothing and decimation filter does not prevent aliasing. The 40 Hz signal referred to in the above Test Objective appears to have resulted from the 2X harmonic of the 620 Hz dithering vibration. This conclusion, however, fails to explain the absence in the flight data of the other dithering frequencies in Figure 3.



Figure 1. Inertial Navigation System EDU Test Configuration

The INS is shown in the foreground. The microphone is shown in the top right hand corner.



Figure 2.

The signal in Figure 2 is composed primarily of components at 526, 573, and 620 Hz.

The beat frequencies are:

620 - 573 Hz = 47 Hz 573 - 526 Hz = 47 Hz 620 - 526 Hz = 94 Hz

The beat frequencies are essentially a psychoacoustic concern. The beat frequencies do not correspond directly to mechanical vibration.



Figure 3.

Table 1. Frequency Results		
Dither Specification Frequency (Hz)	Measured Frequency (Hz)	
521	526	
574	573	
619	620	
-	1194	
-	1239	

The specified dither frequencies are stamped on the RLG housings.

The 1194 Hz component is not an integer harmonic of any of the dither frequencies.

The 1239 Hz component is a 2X harmonic of the 620 Hz dither frequency.



SPECTRAL MAGNITUDE OF DATA PASSED THROUGH SMOOTHING FILTER WITH DECIMATION

Figure 4.

Table 2. Frequency Results for Aliasing via Hand Calculation		
Measured Frequency (Hz)	1200 Samples per Second, Aliasing Frequency (Hz)	100 Samples per Second, Aliasing Frequency (Hz)
526	-	26
573	-	27
620	580	20
1194	6	6
1239	39	39

The frequencies in the third column agree reasonably well with the spectral peaks in Figure 4.

The Hand Calculation formula is given in Appendix C.

APPENDIX A

Reference Email

Excerpt with sensitive information withheld.

I think I understand what the Inertial Navigation Systems is doing:

1) High frequency vibration is filtered by the isolated sensor at 55 Hz for the acceleration and 115 Hz for the rates or rotation. The Q of the isolators is 3.7. This provides about 6.5 dB attenuation at 100 Hz, but amplifies at 50 Hz.

2) The isolated sensor is sampled at 1200 Hz.

3) Two windows of data are captured with 6 sampled points in each.

4) Each window is averaged to give one data point from each window or data at 200 Hz (1200/6)

5) The two data points are averaged further to produce 100 Hz data.

6) I looked at the filter characteristics of averaging six points. The attenuation is not much (a 4 dB attenuation at 100 Hz) and significantly less at 50 Hz.

What does this mean? Aliasing is still a problem between 50 and 100 Hz.

Ideally we would provide bending modes data to 100 Hz, where we have a total of 10.5 dB attenuation due to the isolators and averaging. Of course modes in this range are unknown.

I believe we must rely on flight data from (Name Withheld). We see no indication of aliasing. The bending modes below 50 Hz have been identified on past missions and match the model very well. The only thing I can conclude is modes between 50 and 100 Hz are either well damped or not excited.

I recommend we continue keeping modes only to 50 Hz.

(Name Withheld)

APPENDIX B

Background References for Generic Ring Laser Gyro Systems

Reference 1 (Excerpt)

http://www.airpower.maxwell.af.mil/airchronicles/aureview/1985/may-jun/siuru.html

Air University Review, May-June 1985

Science and Technology Perspectives Laser Gyroscopes—The Revolution in Guidance and Control

Colonel William D. Siuru, Jr., USAF (Ret) and Major Gerald L. Shaw

One of the inherent difficulties of the laser gyro is the problem of frequency "lock-in." As previously mentioned, the laser gyro measures turning rate by sensing frequency differences. When the rate of turn is very small and thus the frequency difference between the two beams is also small, there is a tendency for the two frequencies to couple together, or "lock-in," and a zero turning rate is indicated. Lock-in limits the accuracy of the laser gyro at important low turn rates. Fortunately, there are several ways to overcome the problem of lock-in. The approach currently used in production devices is to "dither," or vibrate, the gyroscope, either mechanically or electromagnetically. This dithering of the laser gyroscope adds to the complexity, weight, and size of the device, and, in the case of mechanical dithering, adds moving mechanical parts.

Reference 2 (Excerpt)

http://en.wikipedia.org/wiki/Ring_laser_gyroscope

Ring laser gyroscope From Wikipedia, the free encyclopedia

A **ring laser gyroscope** uses interference of laser light within a bulk optic ring to detect changes in orientation and spin. It is an application of a Sagnac interferometer.

Ring laser gyros (RLG) can be used as the stable elements (for one degree of freedom each) in an inertial reference system. The advantage of using a RLG is that there are no moving parts. Compared to the conventional spinning gyro, this means there is no friction, which in turn means there will be no inherent drift terms. Additionally, the entire unit is compact, lightweight and virtually indestructible, meaning it can be used in aircraft. Unlike a mechanical gyroscope, the device does not resist changes to its orientation. Physically, an RLG is composed of segments of transmission paths configured as either a square or a triangle and connected with mirrors. One of the mirrors will be partially silvered, allowing light through to the detectors. A laser is launched into the transmission path in both directions, establishing a standing wave resonant with the length of the path. As the apparatus rotates, light in one branch travels a different distance than the other branch, changing its phase and resonant frequency with respect to the light traveling in the other direction, resulting in the interference pattern beating at the detector. The angular position is measured by counting the interference fringes.

RLGs, while more accurate than mechanical gyros, suffer from an effect known as "lockin" at very slow rotation rates. When the ring laser is rotating very slowly, the frequencies of the counter-rotating lasers become very close (within the laser bandwidth). At this low rotation, the nulls in the standing wave tend to "get stuck" on the mirrors, locking the frequency of each beam to the same value, and the interference fringes no longer move relative to the detector; in this scenario, the device will not accurately track its angular position over time.

Dithering can compensate for lock-in. The entire apparatus is twisted and untwisted about its axis at a rate convenient to the mechanical resonance of the system, thus ensuring that the angular velocity of the system is usually far from the lock-in threshold. Typical rates are 400Hz, with a peak dither velocity of 1 arc-second per second.

APPENDIX C

Aliasing Equation

The alias frequency is summarized in equation (C-1).

$$\text{Alias frequency} = \begin{cases} S_{f} - E_{f}, & \text{if } \frac{1}{2}S_{f} < E_{f} < S_{f} \\ E_{f} - mS_{f}, & \text{if } mS_{f} < E_{f} < \left(m + \frac{1}{2}\right)S_{f} \\ (m+1)S_{f} - E_{f}, & \text{if } \left(m + \frac{1}{2}\right)S_{f} < E_{f} < (m+1) \\ m = 1, 2, 3, 4, \dots \end{cases}$$

where

- S_f is the sample rate
- E_f is the energy frequency

(C-1)