DOI 10.5162/SMSI2020/A4.1

Measuring Considerations for Jitter Characterization on Small Satellite Reaction Wheels

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Summary:

Reaction wheels are used for attitude control of satellites without the need to use thrusters. Characterizing the unwanted vibration or jitter during reaction wheel operation supports balancing operations to optimize the unwanted disturbances. Usage of 6-Component Piezoelectric measurement chains was investigated and optimized to measure low level jitter with the highest precision.

Keywords: Reaction Wheel, Jitter, Microvibration, Piezoelectric Dynamometer

Small satellites, Reaction Wheels and Jitter

Recent years have seen advances in terrestrial observation accompanied by an increase in the need to measure Earth's surface and atmosphere with greater precision. For example, cameras on the latest Earth observation satellites feature resolution on the order of 0.5m.

Reaction wheels are used for attitude control of satellites without the need to use thrusters and propellant, which is in limited supply. The operation of a reaction wheel uses an electrical motor to rotate a flywheel at various rotational speeds, causing the satellite to counterrotate proportionately due to the conservation of angular momentum. As the flywheels rotate there are small fluctuations, called jitter, that are directly coupled into the satellite and can affect imaging precision as illustrated in Figure 1.

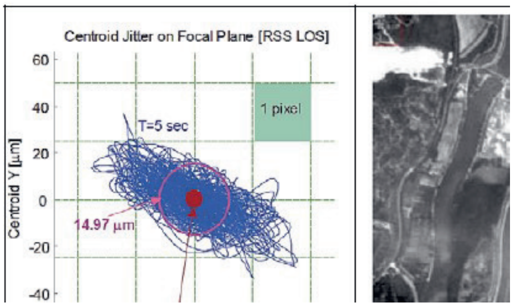

Fig. 1. Satellite Pointing (blue line), which is worse than requirement (red dot), resulting in image distortion (b); image without distortion(c). [1]

Characterizing the unwanted vibration or jitter during reaction wheel operation supports balancing operations to optimize the unwanted disturbances. It is then increasingly common for satellite manufacturers to request jitter characterization.

Satellites with low mass and size, usually under 500kg are becoming more common for cost and convenience reasons. For small satellites, resolution of forces and moments lower than 5mN and 0.5mNm can be significant to the mission.

Piezoelectric Technology for High resolution and High frequency measurement

A 6-component Piezoelectric sensor is ideally suited for jitter characterization of small reaction wheels. Such a solution provides very high measurement resolution as well as direct measurement forces and moments. This makes it possible to measure dynamic force changes greater than 0.5mN, and moments changes greater than 0.02mNm, depending on the signal bandwidth and assuming optimal measuring configurations with optimal charge amplifier. In addition, a static weight can be "eliminated" by resetting the charge amplifier (like a tare function). This allows the measurement range to be based on the magnitude of the dynamic signals of interest – while increasing the signal to noise ratio. Such piezoelectric sensors deliver a rigid measurement platform achieving very high natural frequencies of 6.9kHz in force and 6.3kHz once mounted. Such a 6-component piezoelectric sensor uses 6 pairs of quartz disk, cut in different orientations. The sensor output must be combined to a laboratory grade low noise quasi-static charge amplifier delivering the high

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resolution previously mentioned and converting the signal into voltage.

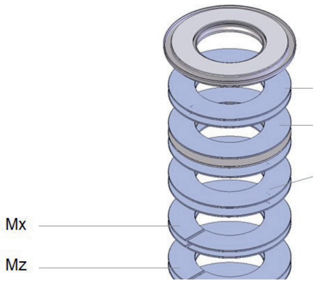

Fig. 2. Internal design of a Piezoelectric 6 Component Force sensor

The voltage output is then input to a 6 Channel DAQ with a noise level that must be at least as good as the charge amplifier in order to allow for the lowest possible measured signal.

Low background Noise

To measure low-level, high-resolution forces and moments, the test environment should be constructed to minimize environmental noise from sources such as airflow and seismic inputs. Typical considerations include a vibration isolation table (see Figure 3) with resonances outside the frequency of interest. This will isolate the force sensor from external vibration sources such as compressors, machinery, people walking and road traffic. Even airflow from an air-conditioning system can create unwanted input to the sensor and may require the use of a box over the test article. Electrical noise from the signal-conditioning system can sometimes be improved by using battery power instead of AC mains power.

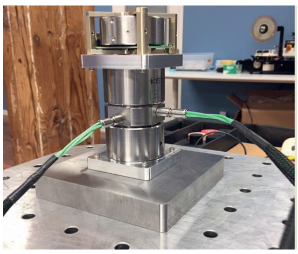

Fig. 3. Small satellite reaction wheel jitter investigations using 9306A 6 Component Force sensor conducted onto a vibration isolation table and using an airflow insulation box.

High Frequency Response

A piezoelectric sensor can be modelled as a lightly damped second order system illustrated in Figure 4. As such the natural frequency can be used to estimate the amplitude response tolerance at different frequencies.

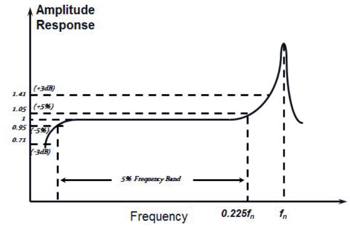

Fig. 4. Lightly damped second order system

Most piezoelectric sensors follow then the high frequency response rule shown in eq (1) :

$$f_{+5\%} = f_n/5;\ f_{+10\%} = f_n/3;\ f_{+3dB} \quad (1)$$

The test engineer should decide on the amplitude response tolerance and the frequency range of interest based on the lightly damped second order approximation. For a natural frequency of 6.9kHz, the 5% amplitude response is up to 6.9kHz/5, or 1.4kHz.
In addition, as mass acting upon the sensor affect natural frequency, a basic tap test, using a very small screwdriver or a small impact hammer can be used to determine the FRF and related f_n of the complete system.

Rangeability and Resolution considerations

Piezoelectric measurement chains permit adjustment of the full-scale measurement range using the charge amplifier. By using a lower full-scale range, the broadband noise can be improved as illustrated in table 1.

	Case 1	Case 2
Full Scale Range	10V = 10N; Therefore 1N/V	10V = 2N Therefore 0.2N/V
Broadband Noise (V)	1mVrms=0.001Vrms	1mVrms=0.001Vrms
Broadband Noise (N)	1N/V*0.0025Vrms =2.5mNrms	0.2N/V*0.0025Vrms =0.5mNrms

Table 1. Broadband noise vs full scale range

Signal Synchronization

It is crucial that measurement signals are synchronized, or results may be interpreted completely incorrectly. Synchronization can be performed in two ways. The classic solution is to have a separate line, where a system clock is routed to each device to ensure that the measured values are recorded at the same time. The other option is to equip each device with a precise clock and periodically adjust it as is used in the precision time protocol (PTP). This last one solution is highly recommended in case of dynamic events such as in Jitter testing.

References

[1] Le, M.P. (2017). Micro-disturbances in reaction wheels Eindhoven, TU Eindhoven