APPLICATION NOTE

Automotive Testing

Nowadays, the automotive industry keeps improving the quality, security and comfort of cars. Although modern vehicles are more reliable, their repair costs are still very high, compared to their initial prices. Cars are long-term assets that are exposed to many problems, as a result of either a component's failure, or vibrations induced by the engine and the road. This document analyses the use of accelerometers for automotive testing applications only.

Automotive designers seek to increase the lifespan of the monitored components, reduce oil consumption and satisfy the passengers' comfort. The tests executed in a laboratory are looking for very precise flaws in components, whereas those performed on a track evaluate overall factors, such as ride quality on specific roads either in summer or in winter.

A good example of an indoor test is the Noise, Vibration and Harshness procedure (NVH). NVH analyses the acoustic propagation from an engine, and tries to improve the driver's comfort not only by isolating parts from one another, but also by optimizing the damping factor of each component. The equipment used consist mainly of shakers that vibrate at various frequencies, Electromagnetic Acoustic Transducers (EMATs) used to generate sound, and electronic analysers to read the sensors' output (vibration sensors, EMAT).

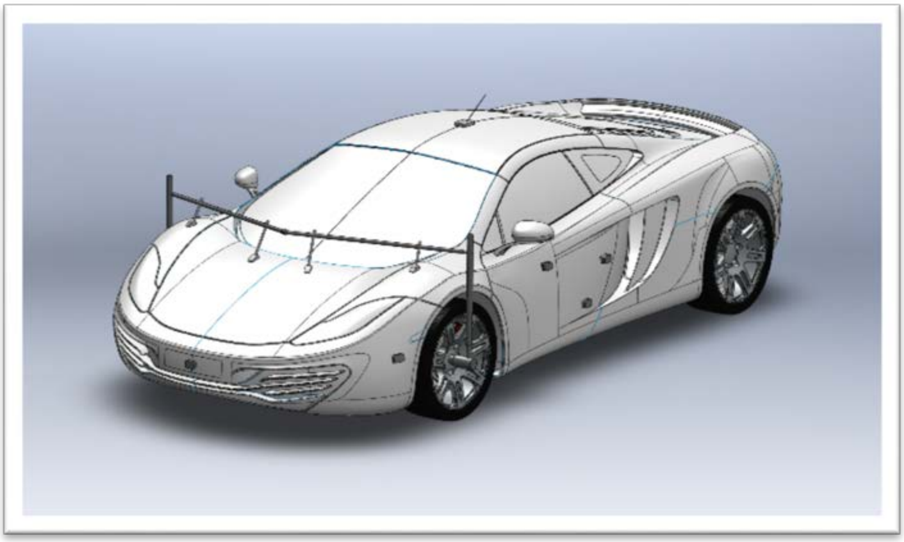

Figure 1: A possible configuration for automotive testing

Figure 1 typically shows where the sensors are placed on the chassis for dynamic outdoor measurements. Accelerometers can be fastened to the bumpers, the hood, the roof and the vehicle doors. Furthermore, torque and vibration sensors can be directly mounted on the car's wheels.

The following table considers the most important applications involving accelerometers:

Parts vs Factors	Durability	Consumption	Comfort
Seat	✓	×	✓
Motors, Pumps	✓	✓	×
Engine and Mounts	✓	✓	×
Radiator, Fan	✓	✓	✓
Transmission and Mounts	✓	✓	×
Suspension	✓	✓	✓
Braking System	✓	✓	✓
Wheel	✓	×	×
Steering System	✓	×	✓
Chassis	✓	✓	×

Explanation of the System

Although many different sensors are attached to a car, the accelerometers play a major role, both for structural analysis and speed tracking.

After placing sensors onto the chassis or mounts, the testing team carries out a modal analysis by applying a forced response simulation. As an effect, biaxial sensors measure the vibration modes and the resonance areas along the structure. A Digital Signal Processing (DSP) unit samples the data and executes a fast Fourier Transform (FFT) in order to obtain the Frequency Response Function (FRF). The purpose of FRFs is to find easily the frequency and amplitude of critical peaks, namely the resonance. Via parametric coordinates, a mapping of these spots can be generated, and compared to the theoretical model. Modal analysis assumes that the structure's properties do not vary over time, and that the output is linearly correlated to the input.

Another property of the accelerometer is its ability to measure velocity and displacement, as they are both related to the acceleration by the derivative function. The circuit requires a single or double integration unit to obtain the speed or the relative position of the vehicle, respectively.

Performance Required

A good structure should have low amplitude resonance peaks, so that less energy is lost from vibration. Therefore, it is necessary that the sensors have a very low bias to detect those peaks. Vibrations caused while driving (at fundamental or higher modes) are low frequency, typically between 0 and 1000 Hz. Vibration analysis is possible through the use of mechanical multi-axis shakers that can vibrate up to 2000 Hz[1].

[1] Source from http://www.imv-tec.com/news/

In addition, a sensor must be small and light, so that it can be easily embedded in the automobile. Other factors such as thermal drift and power consumption can be neglected for this application.

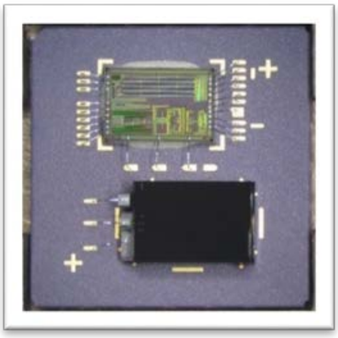

Figure 2: A VC Sensor from Safran Colibrys Top: ASIC. Bottom: MEMS

MEMS Capacitive Accelerometers

MEMS Variable Capacitive (VC) accelerometers work under the principle of electrostatic charges. For this purpose, a cantilever beam is suspended between two fixed electrodes. Whenever a force is applied on the MEMS die, the beam bends towards an electrode. The acceleration is directly linked to a change in capacitance.

Direct competitors of VC sensors are Piezoelectric (PE) and Integrated Electronic Piezoelectric (IEPE) accelerometers. PE sensors use a piezo crystal that responses to acceleration by producing an electrical charge. Despite their large frequency bandwidth, they cannot measure frequencies below 1 Hz. PE sensors have high impedance, meaning that they are exposed to electronic and RF interference. IEPE sensors use a built-in amplifier to counter this weakness. However, they are not interchangeable, unlike standard PE sensors.

In general, VC accelerometers are more linear, and have better bias stability than PE sensors. Nevertheless, the table below shows that different types of sensors can be combined to provide better properties, e.g., a larger frequency bandwidth.

Parts vs Sensors	PE	IEPE	VC
Seat	×	✓	✓
Motors, Pumps	✓	✓	×
Engine and Mounts	✓	✓	✓
Radiator, Fan	✓	✓	✓
Transmission and Mounts	✓	✓	✓
Suspension	×	✓	✓
Braking System	✓	✓	×
Wheel	×	×	✓
Steering System	×	✓	✓
Chassis	×	✓	✓

Safran Colibrys: More than 30 years of experience in MEMS

Safran Colibrys recently commercialized the VS1000 sensor, exclusively designed for vibration applications. If the tests performed on an automobile are not high in amplitude, the VS1002 (±2g), the VS1005 (±5g), or the VS1010 (±10g) are suitable ranges to measure either the vibrations on a static structure, or simply the car's acceleration. The vibration series are specifically designed to have a large bandwidth: they are able to measure frequencies from DC 0 Hz to 2500 Hz at ±5% FS, and up to 7000 Hz at ±3 dB. A linearity of 0.1% FS and a very low spectral density down to 7 µg/√Hz make these sensors extremely accurate. Moreover, these sensors survive shocks up to 6000g.

Figure 3: The VS1000 vibration sensor

All VS1000 sensors are packaged in a hermetic ceramic housing (8.9mm x 8.9mm x 3.2 mm). A self-test function is also available to verify the integrity of the die and the ASIC. Safran Colibrys perfected the bulk-micromachining technique to offer high-performance accelerometers, making them reliable, accurate and durable.

Glossary:

- ASIC: Application specified integrated circuit
- dB: Decibel
- DC: Direct current
- DSP: Digital signal processing
- EMAT: Electromagnetic transducer
- FFT: Fast Fourier transform
- FRF: Frequency response function
- FS: Full scale
- Hz: Hertz
- IEPE: Integrated electronic piezoelectric
- MEMS: Microelectromechanical systems
- NVH: Noise, vibration, harshness
- PE: Piezoelectric