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Accelerometers for Shock and Vibrational Testing

Introduction

Testing response to shock and vibration is critical in determining the life cycle and failure rate of a product. The accelerometer works as a key measurement sensor, able to detect and measure both acceleration due to shock and frequencies of vibration experienced by objects onto which it is mounted. This paper examines the various testing environments in which accelerometers are used, tradeoffs between different accelerometers, how they generate data, and how this data is processed.

Commercial Applications

An accelerometer allows for the measurement of vibrations, which are signs of unbalance, misalignment, mechanical looseness, and structural resonance that could cause failures in a product [1]. Bridges, for instance, are susceptible to the excitation of their natural frequencies during their lifetimes due to vehicles and wind. This leads to high-amplitude oscillations at the natural frequency of a bridge, damaging its structure. An example of this phenomena, known as "flutter," is the Tacoma Narrows Bridge collapsing due to a lack of damping this frequency in 1940 [2]. This structural testing also applies to structures exposed to much higher frequencies such as airplane fins. The issue of flutter can shorten the lifespan of fin structures and limit the length of time a plane can fly in the air [3]. Testing with accelerometers attached to these surfaces allow designers to ensure natural frequencies are damped appropriately, precluding these high-amplitude oscillations. Inspecting a stationary structure like a bridge favors low-acceleration, high-sensitivity accelerometers such as the Silicon Design Model 2012-002 which has a ± 2 g input range, a frequency bandwidth of 0 to 300 Hz, and a differential sensitivity of 2000 mV/g [4]. Aircraft structures that are exposed to higher frequency vibrations require a higher frequency bandwidth at the cost of sensitivity. An example is the Omega ACC103 which has a ± 500 g input range and a frequency bandwidth of 2 Hz to 10 kHz, but a differential sensitivity of only 10 mV/g [5].

Another use is shock testing. Crash test dummies are fitted with multiple accelerometers to examine the shock applied to the human body at different locations in the event of a vehicle crash. Such high-G impact events require an rugged accelerometer with a high measurement range. The PCB Series 3651 fits this description with a ± 2000 g input range and ruggedized casing, but a differential sensitivity of only 0.2 mV/g [6].

Various reporting and testing activities of accelerometer characteristics are governed by the IEEE and SAE International. Linear, Single-Axis, Non-Gyroscopic Accelerometers, which describe the relevant accelerometers for lab shock and vibration testing, have IEEE Standard 1293-1998 [7]. High-G shock testing accelerometers must follow SAE J211 which outlines the instrumentation requirements for valid impact tests [8]. Crash testing in particular must also follow SAE J2570 which outlines requirements for anthropomorphic testing, as the test activities must be applicable to human characteristics [9].

Underlying Technology

The primary components of an accelerometer are a mass and a piezoelectric material. When a force is exerted on an accelerometer by vibrations or a change in motion, the mass moves. This presses against the piezoelectric material, generating an electric charge which is proportional to the force exerted [10]. As the mass is constant, the acceleration is also proportional to the electric charge generated according to Newton's Second Law of Motion. An accelerometer can be single or multi-axis depending on its intended use [10].

There are two types of accelerometers: high and low impedance charge output. The high impedance version has the electric charge generated by the piezoelectric crystal connected directly to the measurement instruments and work in high temperature environments >120°C, but must be connected to special instrumentation to acquire data [10]. The low impedance version adds a micro-circuit and FET transistor built into it that converts the charge into a low impedance voltage that can interface easily with standard instrumentation, but cannot work in high-temperature environments [10].

Implementation of Accelerometers

For shock, an accelerometer outputs a spike in voltage proportional to the force. The accelerometer chosen must have both the measurement range to support the shock event as well as a high enough sampling rate to pick up pulses as short as 10 µs [11]. The output voltage is proportional to the force experienced, meaning it can be tied to how much force an object instrumented with an accelerometer experiences.

For vibration, the accelerometer measures the force the object it is mounted on experiences. Given the accelerations along an axis in the time domain, this data can be Fourier transformed to find out the natural frequency of an object, characterized by a distinctly large amplitude in the frequency domain [12]. The Fast Fourier Transform (FFT) algorithm is now the primary tool used for this analysis which can be implemented through MS Excel or MATLAB [12].

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