VIBRATION AND IMPACT MEASUREMENT FOR COLLISION ANALYSIS

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Abstract: The aim of this work is to analyze a suitable method of High-Velocity Impact detection with space debris for CubeSats. In order to detect and analyze collisions of space debris with nanosatellites, it was necessary to run a series of experimental measurements to verify what types of sensors would be suitable for HVI collisions detection. This article presents some of the sensors examined by experimental testing, its properties, suitability. The article also shows how the testing was performed.

Keywords: CubeSat, collision, space debris, vibrations, piezoelectric actuator

1 INTRODUCTION

With increasing popularity and slightly lower costs of launching satellites into orbit, a CubeSat has become an interesting and relatively available option of exploring from space orbit even for smaller projects. But along with that, the space debris is becoming a frequently discussed topic and rising threat to every space object flying in orbit [1], [2]. This article deals with the design of a suitable detection method of high-velocity impacts (HVI) with space debris for nanosatellites [3]. A major problem with CubeSats is the available space, maximum weight and power consumption available for measuring apparatus, so it is sometimes useful to consider already integrated satellite sensors for HVI detection. An accelerometer is a typical example of standard nanosatellite sensor equipment. A low power consumption of the detection system is achieved by its inactivity, unless a situation requiring analysis occurred. When an adjustable input signal threshold is exceeded, the low-delay circuits are triggered to capture the event and analyze those data such as amplitude, spectral components, event time and potential criticality. In case of hardware damage, the values of known parameters such as a power consumption or temperature might suddenly or gradually change, also communication intermission of any system or complete loss of a communication may occur. Therefore, satellites are often equipped with diagnostic circuits that are capable of system diagnostic even while operating which might be helpful in case of the HVI detection.

2 TESTING APPARATUS

First, a vibration table was examined for the purpose of testing harmonic and long-term vibration exposure to the components. This method showed that the table with its high inertia and mass which also means only low frequency spectrum is not suitable for the purpose of the HVI detection. Therefore, a high frequency speaker was examined for this purpose, but when the tweeter was powered by pulse signal it exhibited an insufficient mechanical response to the signal due to its low membrane mass.

2.1 PIEZOELECTRIC ACTUATOR

Therefore, searching for a suitable vibration source led to usage of piezoelectric actuators which can generate high frequency vibrations and pulses. For this purpose, a 4-layer piezoelectric actuator with silver electrodes was used. Each of the 4 piezoelectric rings has a Cu-foil inserted in-between to connect power supply and as a whole it was pressed together with threaded rod (figure 1). The actuator was powered by a signal generator with maximum output voltage 20 V_{PP}.

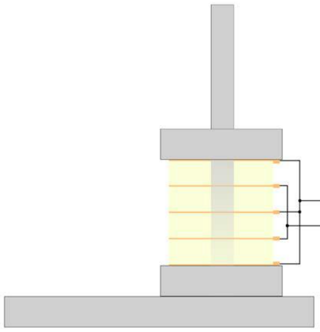

Figure 1: A 4-layer piezoelectric actuator

Figure 2 shows a detailed waveform of the 4-layer piezoelectric actuator with no pressure applied. Main frequency domain components correspond to commonly known frequencies of piezo-ceramic materials with maximal values of 60 kHz and 180 kHz [4]. This wave is also excited inside of a metal beam that is in mechanical contact with the actuator which together makes a source platform for measurement of various types of sensors.

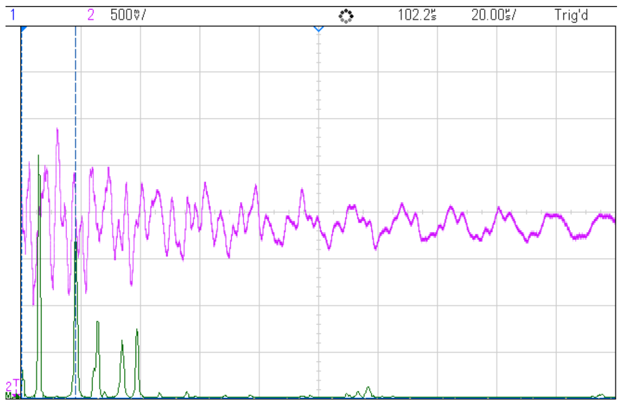

Figure 2: Mechanical response of 4-layer piezoelectric actuator

It was found that the actuator´s response can be measured in case when the piezo-ceramic material is free-mounted. Because the 4-layer piezo actuator has relatively high capacitance and unfavorable mechanical properties (weight, mounting method), it was no longer used. Instead of this a simple disc piezo actuator was used as the main mechanical generator. Before an experimental measurement of various sensors could be performed, it was necessary to explore properties of the disc piezo actuator in terms of vibration amplitudes and frequency bandwidth. It is common to use the Dirac-impulse waveform to determine the system response. When feeding the piezo actuator with very short nanosecond pulses a problem occurred because the piezo material reacts to the both rising and falling edges. The actuator also influences the feeding signal by its own capacitance which results in chaotic waveform. This leads to another mechanical deformation of the piezo material. The resulting behavior can be seen in figure 3. Waveform on channel 1 (blue) shows the piezo-element response and channel 2 (purple) represents the feeding signal. The piezo element reacts almost immediately with logarithmic attenuation as expected, oscillations have frequency at about 18 MHz.

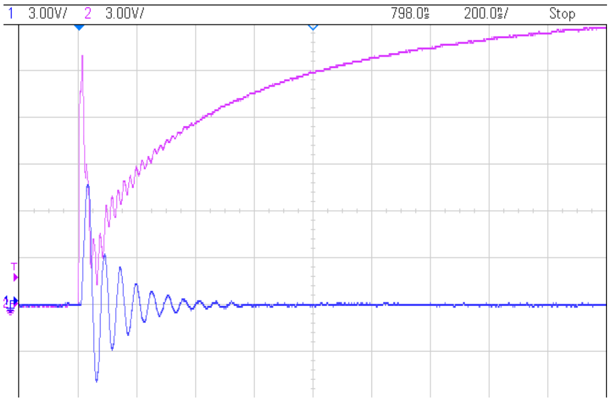

Figure 3: Piezo element oscillations when rising edge signal applied

Based on the measurements, following waveform was set for further sensor measurements. The pulse width was determined to 35 ms with falling time 30 ms, rising time 120 ns with amplitude of 20 V. The figure 4 shows the final waveform that was used to drive the piezo actuator. The most significant advantage of this solution is the repeatability of the measurement.

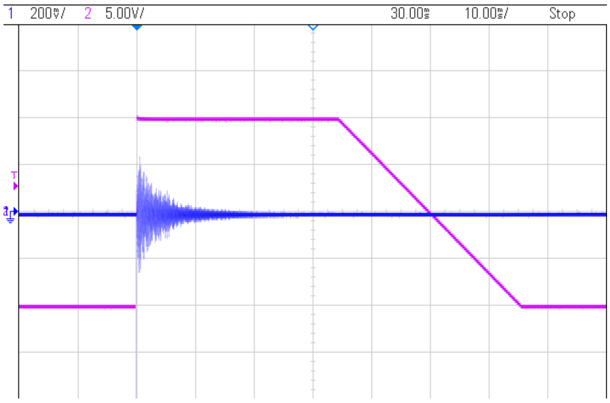

Figure 4: Final feeding waveform for piezo actuator

3 VIBRATION SENSORS

Accelerometers were excluded from the experiments after several measurements and considerations because they are designed to measure vibrations and oscillations with high amplitudes and they are not able to detect weak high-frequency surface waves caused by small dust particles. Because of very low-level output signal coming from sensors the signal had to be amplified. The amplifier consists of low-noise opamp OPA2134PA [5] used as a simple inverting amplifier with gain -10.

3.1 PIEZO SENSING FILM PVDF

In this experiment, piezo sensing foils Parallax Vibra Tab and Pro-Wave Electronics FS-2513P were used. The piezoelectric material was applied to a substrate of excessively rigid material during manufacture process. The sensing foil when measuring surface vibrations generated a significantly weak signal compared to the other sensors and also insufficient frequency range, i.e. the sensor filtered higher frequency components probably by attenuating properties of the substrate.

3.2 MEMS MICROPHONES

For the purpose of this measurement strictly analog condenser types of microphones were used, i.e. TDK InvenSense ICS-40730, TDK ICS-40212, Knowles SPH-0611LR5H-1, Vesper Technologies

VM1000R and their new model VM1010 [6]. This type of microphones was able to capture the frequency spectrum generated by mechanical pulses that was in area of ultrasound.

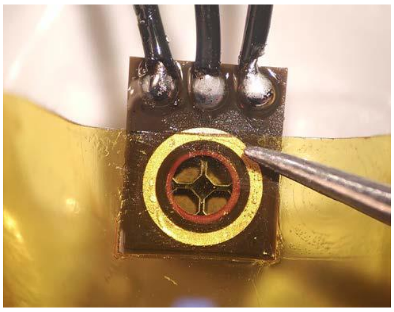

Figure 5: MEMS microphone TDK ICS-40730

The apparent success was rebutted by changing the pressure of the sensor attached to the beam. Increased contact resulted in closing the access to the MEMS hole for sound waves and so the mechanically transmitted vibrations did not produce a sufficient sensor response. Thus, the sensor output signal is significantly low and its level is around a noise level.

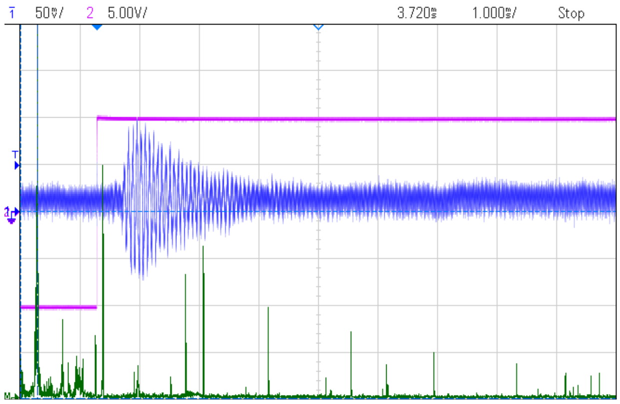

Figure 6: Waveform measurement of Vesper VM1010 along with spectral noise component

3.3 PIEZOELECTRIC DISCS

Piezoelectric disc shown in figure 7 has become the main reference sensor for any further experiments because of its high sensitivity and especially wide frequency range in comparison to the other samples. In figure 8 can be seen the piezoelectric disc response to the vibrations generated by the piezo actuator. The measured waveforms were slightly changing during the experiment due to changing the individual sensor and attaching them to the metal beam.

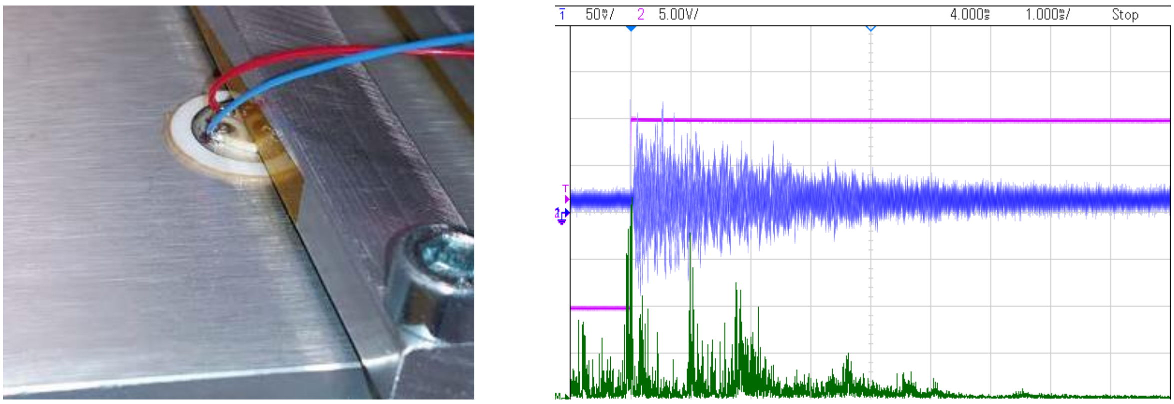

Figure 7: Piezoelectric disc and its response using piezo actuator as vibration source

4 CONCLUSION

This work is focused on exploring the possibilities of mechanical vibrations detection caused by HVI collisions with space debris. First, it was necessary to develop a suitable source of vibrations that might imitate real collisions. For this purpose, the vibrations table, high frequency speakers or any other electro-mechanic generator proved to be unusable. Further testing showed that the piezoelectric actuator meets the requirements, specifically the piezoelectric disc attached to metal beam proved to be an excellent option for upcoming experiments. The only drawback of this solution occurred when swapping between other types of sensors, therefore, changes in the attachment position and gripping force which significantly influenced amplitude and frequency spectrum of outcoming signal. The potentially new approach could be a usage of Vesper Technologies' s new piezoelectric MEMS microphones which were tested as well. Unfortunately, after series of experiments these failed to prove their usefulness for sensing vibrations or acoustic emissions in their original housing. In theory, piezoelectric microphone plates could achieve an enough sensibility if placed directly on a substrate. Piezoelectric films proved to be a potentially usable as a surface wave sensor if a suitable type is chosen. The main disadvantage is the low temperature resistance, the piezoelectric properties of PVDF sensors drop significantly at 70 °C or higher. As the best choice proved to be the piezoelectric disk. Appropriate combination of dimensions, substrate materials and other aspects of piezo element manufacturing can provide reliable HVI detection. After examining the appropriate piezo element mounting solutions on the CubeSat structure, deploying one or more sensors to a given configuration and after the final calibration, the amplitude of each satellite impact can be measured by reference. However, this approach requires calibration of the sensing apparatus of each CubeSat separately, as it was found that the measured values were significantly influenced by changes in the pressure and contact area of the sensor with the beam.

ACKNOWLEDGEMENT

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