FEW ISSUES WHEN MEASURING A HIGH-G-SHOCK

Jan Kunz
Doctoral Degree Programme (3), FEEC BUT
E-mail: xkunzj00@stud.feec.vutbr.cz

Supervised by: Petr Beneš
E-mail: benesp@feec.vutbr.cz

Abstract: This paper deals with effects which cause differences between real and measured mechanical shock, namely a high-pass filtering caused by a piezoelectric sensor and a charge amplifier and a resonance ripple caused by a piezoelectric sensor. The first effect can be suppressed by properly selected filtration which fits the application's requirements. To suppress the second effect the sensor's model needs to be found. In previous work this was done by two-sensor method, now the frequencies are estimated from the electrical parameters of the sensor. A 2-DOF model is used as it suits better for high-g-shocks. The method is able to suppress some ripple effects in the shock shape.

Keywords: Mechanical shock, piezoelectric accelerometer, mechanical resonance, sensor model

1 INTRODUCTION

Mechanical shocks are a part of environmental testing procedure, as every equipment is exposed to shocks during its lifetime. Shock testing procedure is described in [1] where shock parameters are defined for different environments. Shock amplitudes ranging from a few g_n [1] for transportation to several thousand g_n for aerospace testing. Typical shock duration is from tens of milliseconds to tenths of milliseconds. This yields in rich frequency spectrum of the shock. The methods for measuring the shock amplitude and duration were proposed in [2].

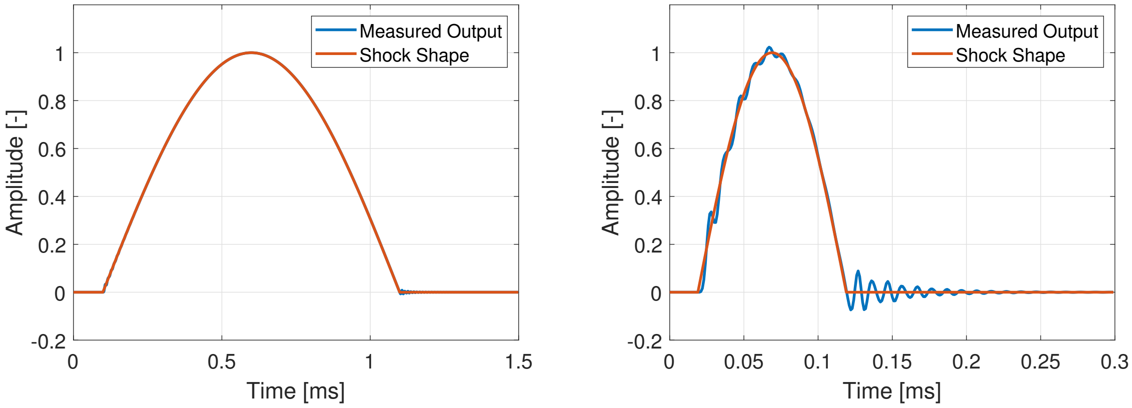
Mechanical shocks are usually measured by piezoelectric accelerometers because of their high frequency range and ability to withstand overloading. Sometimes piezoresistive accelerometers are used, however they have much lower sensitivity and can be damaged by a small overloading [3].

On the other hand, piezoelectric shock accelerometers are naturally an under-damped spring-mass-damper system. Despite the fact that the resonant frequency of such a system is high (>50 kHz), a high-g-shock can excite this structure which affect the measured shock shape. The shorter the shock the more this phenomenon is important as the shock spectrum contains higher frequencies (fig. 1).

Moreover, piezoelectric accelerometers are principally high-pass filters [3] and requires charge amplifiers, which are high-pass filters too. This causes problems especially when signal is integrated to obtain velocity or displacement. This phenomenon is crucial in longer shocks as it contain lower frequencies (fig. 2).

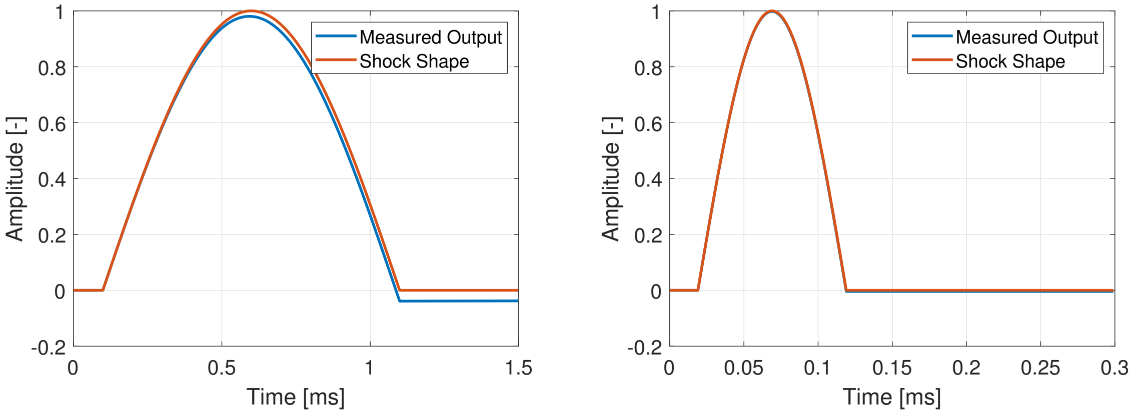
Furthermore, a piezoelectric element under stress load, which can be induced by an intense shock (especially pyroshock), exhibit a zero-shift due to domain switching [3]. All these influences result in differences between actual and measured shock shape, which can have a huge consequences, therefore minimizing these effects is crucial for a proper equipment testing.

[1] In IEC:60068-2-27 is $g_n = 10\ m/s^2$



(a) Shock duration 1 ms **(b)** Shock duration 0,1 ms

Figure 1: Influence of a sensor resonance to shock shape. Sensor resonance frequency 100 kHz, damping 0,05



(a) Shock duration 1 ms **(b)** Shock duration 0,1 ms

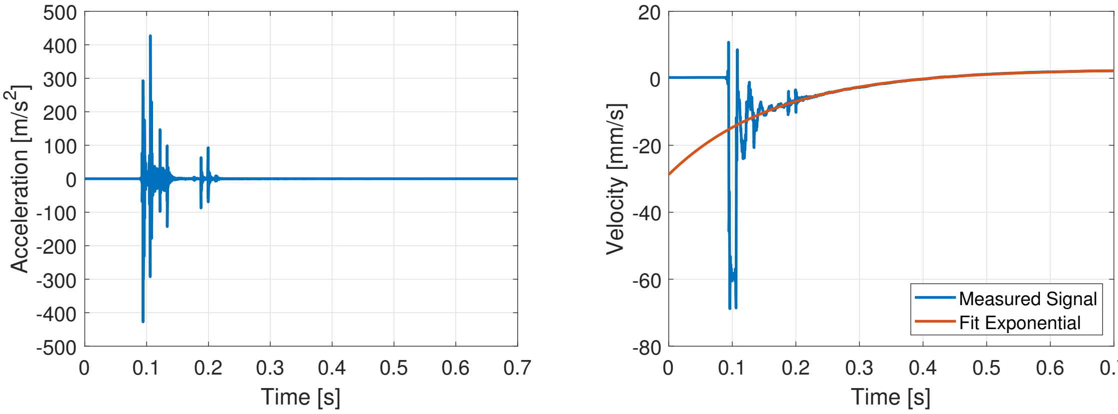
Figure 2: Influence of a sensor/amplifier filtering to shock shape. Filter set to 10 Hz

2 LOW FREQUENCY FILTRATION

The shock is filtered by a high-pass filter in a sensor and in a charge amplifier. This phenomenon can be visible as a drop after the shock (fig. 2), however this effect is significant when the duration of the shock is approximately one tenth (or more) of the filter's time constant [3]. For instance, when the cut-off frequency of the filter is 10 Hz, the time constant is approx. 16 ms. Therefore, if the shock is short enough and the desired quantity is acceleration, the effect does not cause much difficulties. On the other hand, when the shock duration is longer, then the maximal acceleration is smaller, therefore different type of accelerometers, such as capacitance ones, which can measure DC component, can be used.

However, when the shock is short and the desired quantity is velocity (or displacement) the effect is integrated and cause significant differences, therefore it needs to be filtered out. Moreover, a severe shock can cause the domain switch which results in zero-shift. Furthermore, some piezoelectric accelerometers have integrated electronics in the sensor so the mechanical shock can influence it too. Then, it is really complicated to get a correct integrated quantity (fig. 3).

In the figure (3) is visible, that the acceleration data (fig. 3a) looks normally, however the velocity data, after integration, (fig.3b) shows a significant high-pass filter response. This response can be

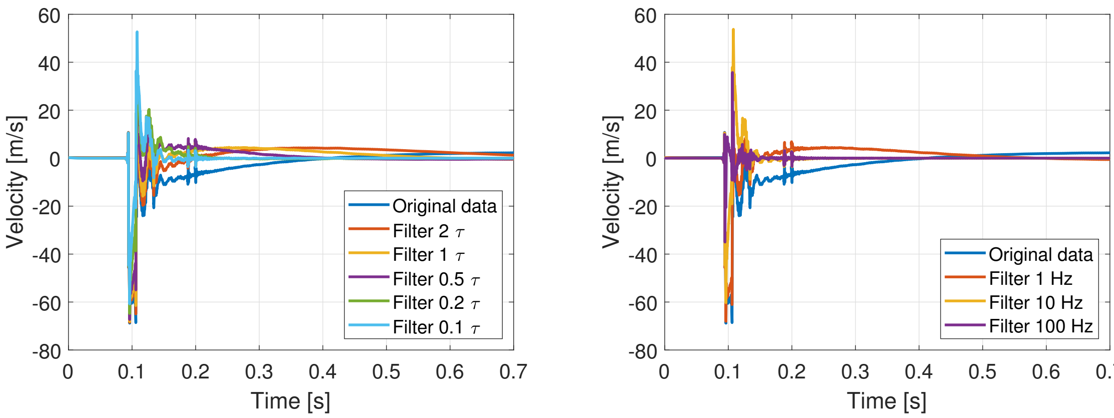


(a) Acceleration **(b)** Velocity with fitted exponential function

Figure 3: The effect of integration to measured acceleration data. Velocity and displacement before and after the shock was the same (0). Data measured by accelerometer PCB 356A03 with integrated electronics.

easily fitted by an exponential, so the time constant can be estimated. In our case (fig. 3b) the time constant is estimated from the exponential decay after the shock, the result is $\tau = 0.168$ s. Having known the time constant the effect can be filtered out.

The effect can be easily filtered only when the shock and the high-pass filter spectrum do not overlap. If both spectra do overlap, then filtering the filter response changes the amplitude of the signal which is undesired. In that case, it is possible to suppress the filter effect but the shock signal will change too. Then, selecting a proper cut-off frequency is challenging and is dependent on specific criteria. The effect of different filter cut-off frequencies is visible in the figure (4). From the filtered data (fig. 4) it is visible that the higher the cut-off frequency (lower time constant τ) the better filter effect suppression but the higher the shock amplitude is affected.



(a) Velocity data filtered by filter with different time constants, $\tau = 0.168$ s **(b)** Velocity data filtered by filter with different cut-off frequencies

Figure 4: The effect of filtration on velocity data where shock and high-pass filter spectra do overlap.

3 RESONANCE FILTRATION

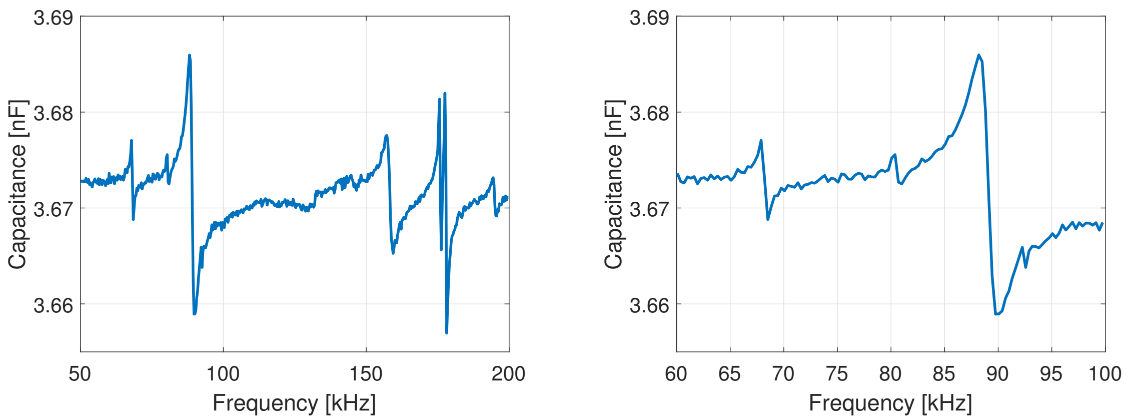
To filter the effect of a sensor's resonance it is crucial to find the resonance. However, the resonance usually lies at very high frequency range from mechanical point of view, therefore to measure it is almost impossible. The author tried to find the resonance frequencies of two accelerometers by processing the measured data from the same event [4]. The method is working quite well on longer (> 1 ms) and smaller (< 500 g_n) shock, however it fails on high-g-shocks due to noise which cannot be filtered out.

The other method how to find out the sensor's resonance was presented by Volkers [5]. He has found out that the mechanical resonances are the same as the first electrical resonances. Therefore, we can measure the frequencies of the electrical resonances and use it for suppression of the mechanical ones. The problem is that the electrical resonance can be measured only in piezoelectric accelerometers without integrated electronics.

Moreover, piezoelectric accelerometer is usually modelled as a 1-DOF spring-mass-damper system. However, in case of high-g-shock the rigid part od the sensor starts resonate too, therefore the system should be modelled as a 2-DOF system [6].

For these reasons, we have decided to measure the electrical resonances of high-g piezoelectric accelerometer without integrated electronics Kistler 8044 using Agilent 4294A impedance analyser and then filter out the effect of its mechanical resonance.

The capacity changes of the accelerometer were measured (fig. 5). From the figure (5a) it is visible that there are three resonances. However, the mechanical system should be 2-DOF [5]. Fortunately, one resonance is very small and close to the next one, therefore we have decided to merge the two resonances together. The resonance frequencies were estimated as follows 68,25 kHz and 89 kHz. Damping ratios were estimated from the width of the resonance peaks.



(a) First resonances **(b)** Detail near 80 kHz

Figure 5: Capacity dependence on frequency of the Kistler 8044 accelerometer measured by Agilent 4294A impedance analyser

Measured data were filtered in frequency domain only around the resonances as the inverse function would amplify noise. The filtration was performed in area where the gain is more than 1.1. The filtered signal together with the original one is shown in the figure (6), where it is visible that the filtration helps to suppress the resonance ripple. However, some ripple remain as it can be from other sources such as a mounting resonance.

4 CONCLUSION

In this paper, we describe a few issues which cause differences between actual and measured shock shapes. The first was the effect a of high-pass filtering performed by a piezoelectric sensor and a charge amplifier. This effect is more significant in shocks with longer duration. It can be easily filtered out if spectra do not overlap, if they do then the filtration is a compromise between suppressing the effect and changing the shock shape, so the filter parameters are dependent on application.

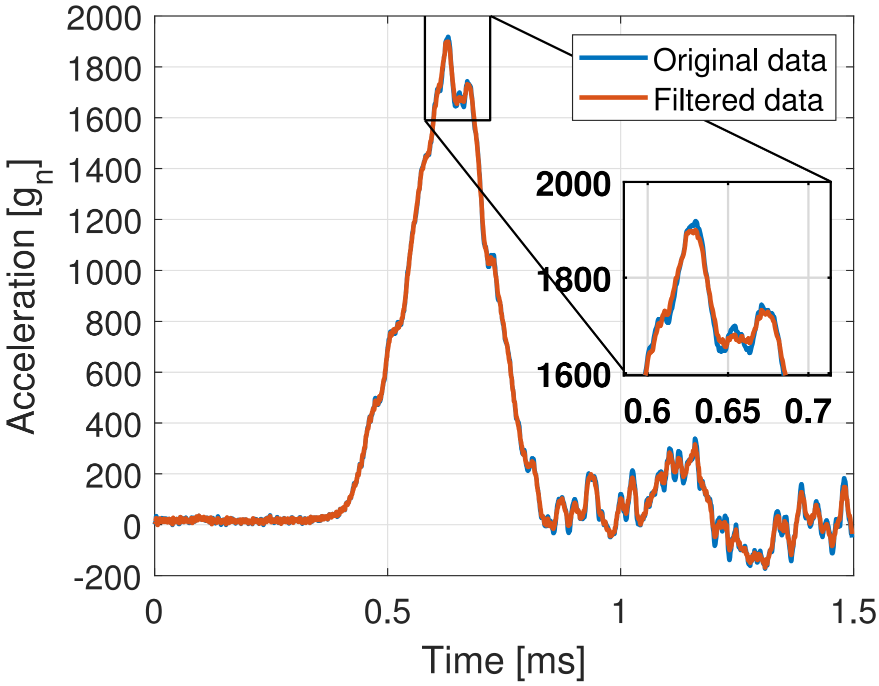


Figure 6: The effect of filtering the resonance ripple

Then the effect of sensor's resonance on the shock shape was discussed. New method of suppressing this effect by measuring sensor electrical resonances, which correspond with the mechanical ones, was tested. Moreover, the method uses a 2-DOF sensor model, which should be more accurate for a high-g-shock. The method suppress some resonance ripple in the shock shape, however there are other effects which are influencing the shock shape, such as a mounting resonance, which still causes some differences between real and measured mechanical shock.

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