COMPARISON OF METHODS FOR MEASURING SHOCK DURATION

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Abstract: This paper compares a linear interpolation, an interval and a sine interpolation method for measuring mechanical shock duration. All methods are analysed to find differences and limitations. Then methods are tested on simulated and real shock shapes to confirm analysis results. We discovered that the sine interpolation method is very robust to noise, however is sensitive to shock shape changes. The linear interpolation method accuracy is influenced by noise, however this method works also on high noise level ($SNR = 0\ dB$). The interval method provides consistent results up to some noise level ($SNR > 10\ dB$), where it stops working.

Keywords: mechanical shock, half-sine shock, duration measurement, linear interpolation method, interval method, sine interpolation method

1 INTRODUCTION

Many equipment failures are caused due to mechanical shocks and vibrations. Current trends on one hand forces manufacturers to behave more ecologically. This leads in increasing devices lifetime. On the other hand, devices became more sophisticated and complicated. Then guarantee device lifetime is almost impossible without proper testing.

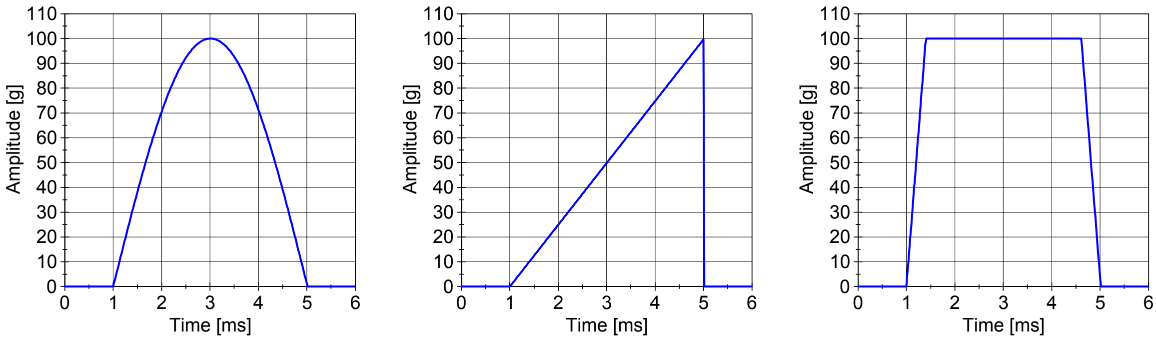
Specification for shock testing is available in [1], where are described shock shapes, parameters and tolerances. There are also requirements for shock measurement and testing evaluation. The norm [1] defines two shock parameters, an amplitude and a duration. For shock duration calculation two methods (linear interpolation and interval) are generally used [2]. We have added for comparison other interpolation method, which interpolates data by ideal shock shape, to see differences in their results. This paper describes pros and cons of all three methods and discuss the differences.

2 SHOCK TYPES

Shock is defined by its shape, a maximal acceleration A_{max} and a duration t_d. There exist also other parameters, which reflects real shapes, such as amplitude tolerances (usually 20 %), an overall velocity change and a shock response spectrum (SRS) [1].

The norm [1] describes three different shock shapes, a half-sine (fig. 1a), a sawtooth (fig. 1b) and a trapezoidal (fig. 1c). However, there are also other similar shock shapes such as a versed sine and a rectangle. There exist also pyroshocks, where no shape is defined [3]. Pyroshocks are mostly used to simulate the effect of pyrotechnic devices (f.e. explosives bolts) in aerospace industry. The half-sine shocks are the most common shock shapes, because it simulates drop or impact [1]. Further in this document will be used only the half-sine shock shape.

Real shocks have different shape than ideal. It is caused by a non-zero mass and usage of a real non-linear materials [4]. In real applications an acceleration profile has a smooth derivation due to inertia.



(a) Half-sine **(b)** Sawtooth **(c)** Trapezoidal

Figure 1: Shock Shapes

Other difference is caused by mechanical resonances which amplifies some frequencies more than others [5]. Rebounds of the tested apparatus also affect the shape. Real shocks have usually different slopes of rising and falling edge because the impact is not perfectly elastic [4]. Finally, noise also changes the shock shape. The noise level in shock measurement can be high (up to $SNR = 0\ dB$).

Typical duration of the shock varies from $0,2\ ms$ to $11\ ms$, however there exist also shocks with duration up to $30\ ms$ [1]. Shock amplitudes are dependent on shock duration, in general shorter shocks have higher amplitudes. Amplitudes vary from $10\ g$ to several thousand g. Pyroshocks can have amplitudes up to $300\,000\ g$ [2, 3].

3 DURATION CALCULATION

For shock evaluation shock parameters has to be calculated from measured data. A calculation of a peak acceleration from data is easy, maximal value is usually used. A shock duration calculation is more complicated due to the non-ideal shock shape. Three methods an interval, a linear interpolation and a sine interpolation for shock duration calculation from the time history and described and compared. For comparison all methods were implemented in LabVIEW.

3.1 Interval method

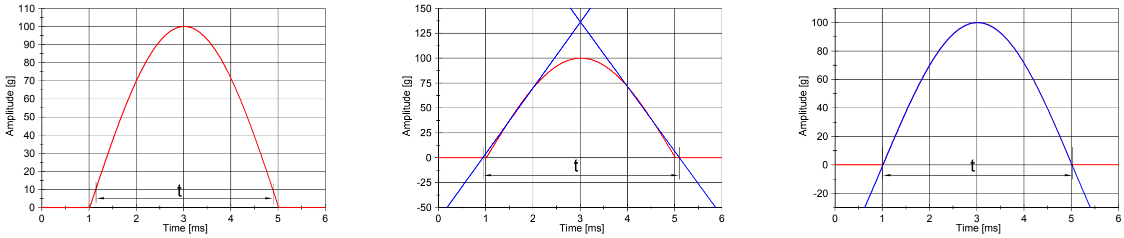
This method measures a time interval in 10 % level of the peak amplitude (fig. 2a) [2]. The 10 % level is compromise between method accuracy and noise robustness. At this level the effect of smooth shock edges is minimal, however at this level method is sensitive to noise. The method is measuring shorter duration, however the error is less than 7 %. For $SNR = 10\ dB$ is probability (confidence interval $99,9$ %), that white noise peaks exceed the 10 % level, $0,1$ % and for $SNR = 0\ dB$ is $3,6$ %.

In ideal case (without noise) is detection when the shock exceeds 10 % level of the peak amplitude simple. In case with noise the detection is more complicated, however averaging can be used. A linear interpolation for noise suppression is also possible, however then is easier to use the linear interpolation method.

3.2 Linear Interpolation method

This method linearly interpolates rising and falling edges (fig.2b). Then calculates time (f.e. t_1 for rising and t_2 for falling edges) when interpolation line crosses zero. Finally, duration of the shock t is calculated as a difference $t = t_2 - t_1$ [2].

It is important to select which part of the slope to interpolate. An ideal shock shape is possible to interpolate from zero. Because of shock smooth edges the interpolation can start from 10 % of the



(a) Interval method **(b)** Line interpolation method **(c)** Sine interpolation method

Figure 2: Principle of duration calculation methods

peak value. At this level method is sensitive to noise (see 3.1). To minimize the sensitivity, the start level can be increased. For 20 % of the peak value as a starting point and $SNR = 0\ dB$ is the probability, of exceeding the level by noise, $0,02$ %. In my implementation I interpolate from 20 % of the peak amplitude.

The highest point for interpolation should be as low as possible. However, in real application is necessary to have enough samples for interpolation to suppress noise. The highest limit should not exceed 80 % of the peak amplitude, because the error between ideal and actual slope increases polynomially. For 80 % of the peak amplitude is the error 4 %. In my implementation I interpolate to 80 % of the peak amplitude.

3.3 SINE INTERPOLATION METHOD

This method interpolates the half-sine shock shape by a sine wave (see fig. 2c), then from the period T calculates the shock duration $t_{SI} = \frac{T}{2}$. Similar to the interpolation method (sec. 3.2) it is important to select which part of the shock to interpolate. This method needs only lower limit, due to smooth edges. My implementation uses same lower limit as the linear interpolation method (20 % of the peak amplitude). For non-linear interpolation Levenberg-Marquardt algorithm is used because this is the only general non-linear fitting algorithm available in LabVIEW.

This method should be the most accurate from all methods mentioned above. However, it is sensitive to different slopes of shock edges, which is limitation for usage on real signals.

4 COMPARISON

Methods for measuring a shock time duration were compared on a simulated shock shape with known duration and added noise. Then methods were used to measure a duration of a real shock.

4.1 SIMULATED SHOCK

The shock used for simulation was half-sine shape with duration $t_d = 4\ ms$ and peak acceleration $A_{MAX} = 100\ g$. Firstly was measured a duration by all three methods without noise. Then white noise with different SNR was added to the shock and the duration was measured again. For each SNR value were performed thousand measurements by each method.

From results is for every method calculated an average value (t_{IP} for linear interpolation, t_{IV} for interval method and t_{SI} for sine interpolation), a standard deviation (σ_{IP}, σ_{IV} and σ_{SI}) and a relative error (δ_{IP}, δ_{IV} and δ_{SI}). Calculated values from simulation are shown in (tab. 1).

In the first line is visible, that the linear interpolation method is measuring longer duration, the interval method shorter and the sine interpolation exact. This corresponding with theory mentioned above. In following lines are results from noisy data with different SNR. Actual white noise standard deviation was calculated from the shock amplitude with 99.9 % confidence interval.

Table 1: Table of measured durations (t_{IP}, t_{IV} and t_{SI}), standard deviations (σ_{IP}, σ_{IV} and σ_{SI}) from ($N = 1000$) samples and relative errors (δ_{IP}, δ_{IV} and δ_{SI}) for linear interpolation, interval and sine interpolation method on half-sine shock with duration $t_d = 4\ ms$ and peak acceleration $A_{MAX} = 100\ g$ with different noise levels

SNR	Linear interpolation			Interval			Sine interpolation		
[dB]	t_{IP}[ms]	$\sigma_{t_{IP}}$[ms]	$\delta_{t_{IP}}$[%]	t_{IV}[ms]	$\sigma_{t_{IV}}$[ms]	$\delta_{t_{IV}}$[%]	t_{SI}[ms]	$\sigma_{t_{SI}}$[ms]	$\delta_{t_{SI}}$[%]
–	4,16	0,000	4,00	3,73	0,000	-6,80	4,00	0,000	0,00
30	4,17	0,013	4,37	3,74	0,019	-6,46	4,00	0,005	0,01
25	4,18	0,017	4,51	3,74	0,024	-6,51	4,00	0,007	0,02
20	4,19	0,023	4,70	3,74	0,031	-6,57	4,00	0,009	0,02
15	4,20	0,032	5,02	3,80	0,060	-4,87	4,00	0,012	0,02
10	4,22	0,047	5,58	5,48	2,800	33,62	4,00	0,017	0,04
5	4,26	0,089	6,68	–	–	–	4,00	0,037	0,07
0	4,43	0,550	10,50	–	–	–	4,06	0,482	1,46

In case of the linear interpolation method increasing noise level cause the result and the error slightly increased. This method is able to measure shock duration even if noise level is high ($SNR = 0\ dB$). The interval method measures almost the same values with increasing noise level, however at some level (in this case $SNR = 10\ dB$) are the noise peaks higher than 10 % level of the peak amplitude, that causes the measured value inapplicable. The sine interpolation method is the most accurate and stable from all tested methods. With increasing noise level, the method becomes slightly inaccurate. However, some difference is visible only at $SNR = 0\ dB$.

A difference between sine interpolation and linear interpolation (interval) method is 4 % (6,7 % respectively). While the difference between linear interpolation and interval method is approx. 10 %.

4.2 Real shock

For testing methods on a real shock was used half-sine shock generated by a shock machine AVEX SM110-MP and measured using a piezoelectric accelerometer PCB J352C04. Data was sampled using a NI card 9234 with sampling frequency $f_s = 51.2\ kSa/s$.

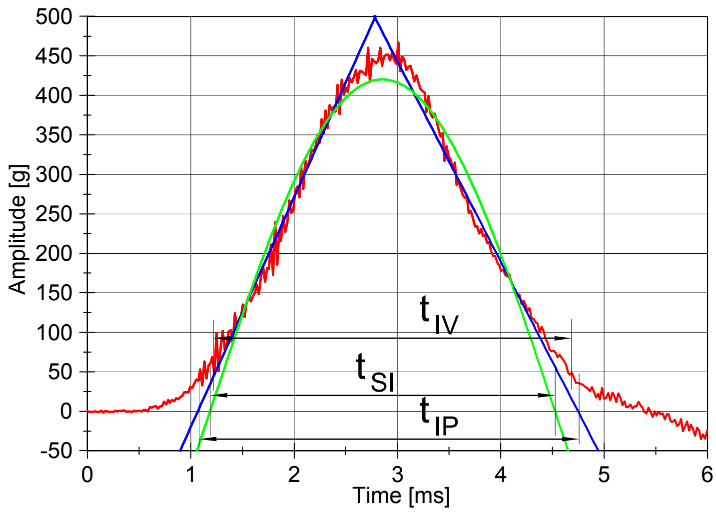


Figure 3: Methods results on real shock data

On figure (fig. 3) is visible real shock shape with time intervals measured by all three methods. The linear interpolation method measures shock duration $t_{IP} = 3,68\ ms$, the interval method $t_{IV} = 3,44\ ms$ and the sine interpolation method $t_{SI} = 3,33\ ms$.

Difference between the sine interpolation and the linear interpolation (interval) method is -10 % ($-3,3$ % respectively) and for the linear interpolation and the interval method approx. 6,5 %. Changes in differences between real and simulated data are in the same order 14 %, 10 % and 3,5 %.

The smallest difference is between the linear interpolation and the interval method, so these methods behave similarly on simulated and real data. The differences between the sine interpolation and other methods are 14 % and 10 %, which is significant difference. This difference is caused by the sine interpolation method because the other methods behave similarly. While the sine interpolation method behaves perfectly on simulated data, on real data it produces significant error.

5 CONCLUSION

In this paper we compare three methods for measuring shock duration, the linear interpolation, the interval and the sine interpolation method. All methods were analysed to find their limitations (sec. 3) and tested on simulated (tab. 1) and real (fig. 3) data.

The simulated results confirmed that the sine interpolation method is the most accurate and robust from all tested methods. The interval method can't be used on noisy signals ($SNR < 15\ dB$), however on signal with higher SNR provides consistent results. The linear interpolation method can be used on noisy signals, however the results are influenced by low noise levels.

Testing methods on real shock signal reveals, that the error between the linear interpolation and the interval method remains almost the same like in simulated testing (difference 3,3 %). Both methods can be used to measure duration of real shock with respect to their limitations. In contrast the sine interpolation method has differences with the linear interpolation (interval) method 14 % (10 %). These differences reveals that the sine interpolation method is sensitive to the non-ideal shape, so this method is inappropriate for real applications.

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