Analysis of the noise generated by variable types of firearms

Magdalena Matys
AGH University of Science and Technology, Poland

Kamil Piotrowski
AGH University of Science and Technology, Poland

Bartłomiej Kukulski
AGH University of Science and Technology, Poland

Wojciech Binek
AGH University of Science and Technology, Poland

Monika Sobolewska
AGH University of Science and Technology, Poland

Summary
The aim of the paper was to analyze impulses generated by various types of firearms and particular stages of the acoustic energy release. Associated measurements were carried out at the sport shooting range in Nowy Targ, Poland, including measurement of the sound pressure level generated by eight different examples of firearms, registered simultaneously close to and far from the source. The paper presents an analysis of spectral and acoustic parameters of the signals of different types of firearms. There has been made an initial attempt to classify the firearms on the basis of frequency domain characteristics and shapes of the impulses waveforms. Further attempt has been made to assess the possible impact of the noise on the shooter and close surroundings, and to estimate how particular features of the firearms (e.g. construction) can affect the waveforms of impulses.

1. Introduction

One of the example of noise that can occur in the environment is noise with impulsive character. Such noise can be characterized by short duration time (usually below 1 s) with simultaneous very high burst of acoustic pressure [1]. Firearm shots are an example of such noise. There is a large group of people exposed to this kind of noise, including, among others, soldiers, hunters and sport shooters (as well as trainers and jury) at shooting ranges.

Impulsive noise is particularly hazardous for people because it exposes them to rapid pressure fluctuations for which human hearing organ is not prepared. Firearms are able to generate impulsive noise with peak levels exceeding 150 dB [2]. Such high values can cause short- or long-term hearing damage and, in extreme cases, damage of organ system or even cardiovascular or respiratory diseases [3]. According to those hazards, for health protection purposes, the use of hearing protection when shooting is very important and strongly recommended.

According to the occupational noise, harmfulness of impulsive noise can be described by selected acoustical parameters. For example, in Poland [4], those parameters are: C-weighted peak sound level (L_{Cpeak}) and A-weighted maximum sound level (L_{Amax}). The limits of those parameters are 135 dB for L_{Cpeak} and 115 dB for L_{Amax}. On the other hand, in the recommendations of the National Institute for Occupational Safety and Health (NIOSH) [5], exposure to impulsive noise shall be not greater than 140 dBA.

Other useful parameters that can be used in the process of characterization of impulsive noise are two time domain parameters that describe two significant parts of impulse generation and decay, respectively, rise time t_{Rise} and release time $t_{Release}$.

Copyright © 2018 | EAA – HELINA | ISSN: 2226-5147
All rights reserved

The time required for the rise of amplitude level from 10 to 90% of the maximum absolute value is called the rise time, whereas the time required for the amplitude level to return to the initial value is called the release time. The last parameter, rapidity of impulse rise V_L can be expressed as theoretical rise of the sound pressure in reference to 1 second and its unit is decibel per second [6]. V_L can be approximated by the tangent of the angle between the sound rise in time (difference between maximum sound level and background level) and the time rise [6]:

$$\Delta L_A = L_{Amax} - L_{Aback} \tag{1}$$

$$V_{LA} \approx \mathrm{tg}\,\alpha \approx \frac{\Delta L_A}{t_{Rise}}, \tag{2}$$

The aim of this paper was to investigate firearm shots impulses in order to extract and subsequently analyze particular stages of firing the firearm as well as examine their spectral and acoustic parameters.

2. Methodology and research material

The measurements of impulsive noise generated by variable types of firearms were carried out at the sport shooting range in Nowy Targ, Poland. It is a two-storey building with 8 shooting windows and 50-meter range. The shots were fired outside the building in front of the shooting window in bladed-off stance. The shooter was aiming a target behind which was a metal bullet trap (inside designed building). Along the bullet path on the left there is a hill with trees and on the right there is a wooden wall. A draft of the area with shooting and measurement spots marked is presented in Figure 1.

The research material consists of 4–5 waveforms obtained for every firearm. The measurements were carried out simultaneously at distance 7 m and 40 m from the source. In order to record the waveforms, Zoom H5 recorder was used and for SPL measurements, SVAN 958 and 959 analyzers with the settings: time weighting F, logger step: 10 ms (at 7 m) and 50 ms (at 40 m). The very short logger step was selected for obtain the better time resolution of the waveforms, and thus for the proper identification of the shoot phases. For the SPL measurements there was 1 class ½'' free field microphone. The firing height was 1,7 m and the measurement points were located at the height of 1,5 m.

In the research, 8 types of firearms were examined. The used firearms differ significantly in such parameters as caliber, barrel length or muzzle velocity. Full list of used firearms and their specification is presented in Table I and their pictures in Figure 2.

Figure 1. The draft of the area with shooting and measurement points. (Source: maps.google.com)

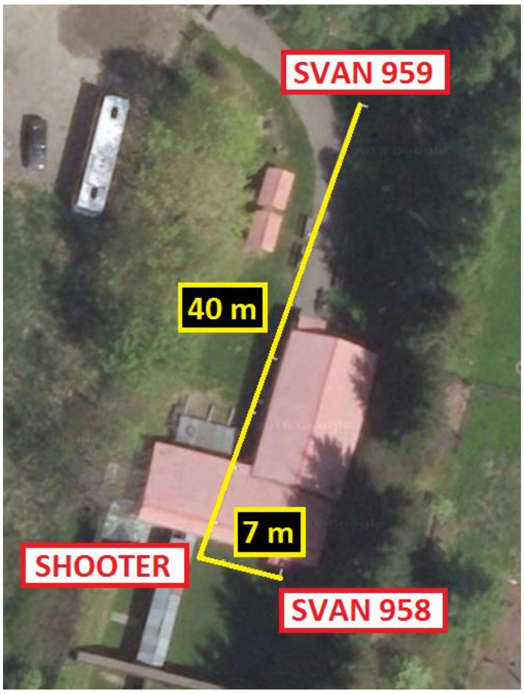

Figure 2. Firearms used in the research.

Table I. List of used firearms with their specification.

No.	Firearm name	Caliber [mm]	Barrel length [mm]	Muzzle velocity [m/s]	Propellant mass [g]
1	AKMS	7.62x39	415	715	1.6 – 1.8
2	Emperor	12/76*	470	405	1.9 – 2.1
3	FEG FP9	9x19	118	390	0.32 – 0.36
4	Galil SAR	5.56x45	332	948	1.62
5	Mauser 1942 model 24	8x57IS	600	755	3.05
6	Margolin	5.56 (.22LR)**	150	216	0.105
7	TT model 33	7.62x25	116	502	0.5
8	Vostok CM-2	5.56 (.22LR)**	660	216	0.105

* 12 - number of balls with diameter of the barrel, which can be cast off a pound of lead, 76 – length of cartridge ** in inches

3. Results

3.1. Ranges of obtained results

During analysis, the following parameters taken into account: L_{Cpeak}, L_{AFmax}, L_{AE}, V_{LA}. Table II contains obtained ranges of values of mentioned parameters, respectively for measurements close and far from the source.

Analysis of the acoustical parameters provide the information that all of the firearms provide noise with impulsive character, regardless the distance and influence of shooting range building at the propagation path. Even at the distance of 40 m from the source, values of peak values as well as rapidity of impulse rise seems to be higher than e.g. continuous noise measured at the same location.

Because of impulsive character of the firearms as sound sources, the process of adjusting the noise must be carried out when assessing its impact on total environmental noise. Also selected logger step is significant when assessing parameters such as rapidity of impulse rise, V_L.

3.2. Analysis of the firing process

From the human point of view, firearm shot is received as a single short-term acoustical event. In fact, the process of releasing energy during a shot is way more complicated. The shooter presses the trigger in a controlled manner until the gun fires. During the firing process, striker hits the primer on the cartridge which causes the ignition of the gun powder. As a result of the explosion there occurs a rapid chemical reaction which consists in expansion of gases inside a small case. These gases exert a huge pressure on the case's wall and the bottom of the bullet pushing it out of the case towards the muzzle. After leaving the muzzle, the bullet flies with muzzle velocity towards the paper target and in 50 meters it hits the target and the metal bullet trap. After the firing, shooter remains in their position for about 0.5 – 1 s preparing to perform another shot [7].

Due to the non-ideal measurement conditions, waveforms of the shots are significantly different for each firearm. Due to high acoustic pressure levels and a clipping problems, the measurement was made at the closest possible distance from the shooter. Unfortunately, the distance was too big to register processes taking place inside the weapon. However, sound of a bullet hitting the butt is audible and noticeable on the time-domain graphs of all data. What is more, there was also observed an echo effect. During the decay of firearm shot impulse, reflections from nearest surfaces are easy to find on the waveforms. They appear in form of little bumps interfering the decay.

Presented graphs (Figure 3-4) allow to notice important phenomena occurring during registration of firearm shots. The complex firing process, represented by two amplitudes, and its repetitive echo appears in each recording. Those reflections are usually 3 to 5 per shot. As the impulse disappears, noise significantly increases for a while once again. It is caused by a bullet trap sound registered approximately 0.3 s after firing. It refers to the time bullet needs to hit the bullet trap and the sound to reach the microphone diaphragm. This acoustic event is also duplicated in form of an echo. The stages of the shot described and illustrated above are a starting point for further researches aimed at identification and classification of different types of weapons.

In the next stage of the research, frequency content of the noise generated by the sources was analyzed. Formula (3) specifies the minimum frequency bandwidth that can be analyzed maintaining accurate results.

Table II. Juxtaposition of measured parameters.

		L_{Cpeak} [dB]	L_{AFmax} [dB]	L_{AE} [dB]	V_{LA} [dB/s]
AKMS	7 m	143.5 - 144.3	119.0 - 119.4	111.4 - 111.9	7150 - 7270
Emperor		143.5 - 144.3	119.7 - 120.1	112.5 - 112.8	3615 - 3680
FEG FP9		143.4 - 143.9	116.9 - 117.7	109.3 - 110.3	7040 - 7070
Galil SAR		143.5 - 144.8	120.8 - 121.2	113.6 - 113.8	7350 - 7440
Mauser 1942 model 24		144.2 - 144.5	119.9 – 121.0	112.4 - 113.7	7290 - 7450
Margolin		138.1 - 139.2	107.1 – 108.0	99.6 - 100.2	6000 - 6120
TT model 33		143.9 - 144.3	118.1 - 119.7	110.6 – 112.0	3545 - 3625
Vostok CM-2		120.1 - 121.6	94.9 – 96.0	87.0 - 88.8	601 - 620
AKMS	40 m	99.0 - 100.5	80.4 – 81.0	74.8 - 75.1	262 - 784
Emperor		102.8 - 106.2	82.7 - 85.7	76.6 - 79.8	261 - 415
FEG FP9		95.8 - 97.2	77.9 - 81.4	72.8 - 75.5	177 - 355
Galil SAR		85.9 - 86.4	82.8 - 83.3	76.8 - 77.2	265 - 414
Mauser 1942 model 24		100.5	78.9	73.3	369
Margolin		83.9 - 86.4	67.9 - 68.6	62.1 - 62.9	167 - 266
TT model 33		95.5 - 97.3	79.8 - 80.2	74.3 - 74.6	243 – 351
Vostok CM-2		74.4 - 74.9	55.3 - 56.6	50.7 - 52.5	37 - 77

Due to the choice of the time resolution, the analysis was based on 1/3-octave bands range from 500 Hz to 20 kHz.

$$BT \geq 1, \qquad (3)$$

B – minimum frequency bandwidth, Hz,
T – recording time resolution, s.

For most weapons, except Galil and Vostok, value of spectral centroid of analyzed shots moved towards the lower frequencies relative to the acoustic background. In addition, with respect to the first shot spectroid, the second shot spectroid also moves in that direction. The reason for this is certainly the saturation of the acoustic background with high sound levels at frequencies lower than the background central spectroid as a result of generating the noise from the first shot. During the butt hitting echo phase, values of spectral centroid decrease, however, this time it was observed for each of the tested weapons.

Kurtosis of most firearms, except TT and Vostok, have positive values, what indicates a high concentration of results around the average. For Mauser rifle, the firing spectra show a relatively high concentration for both amplitudes. These spectra, using the Emperor, AKMS, FEG and Margolin riffles, are concentrated only in the first amplitude of the firing process. These spectra, using the Emperor, AKMS, FEG and Margolin riffles, are concentrated only in the first amplitude of the firing process. In the following peaks, kurtosis reach values close to zero what would be expected for further stages of the process - those where the impulse character of the signal decreases. Shots from Galil and TT reach this concentration in all amplitudes. For the remaining weapons, kurtosis of butt hitting sound does not show regularity. Probably, this is caused due to the firearm construction aspect.

Table III. Values of spectral centroids of particular time series.

	BACK-GROUND	SHOT		BULLET TRAP	
		1	2	1	2
AKMS	6408	5603	5552	4986	4811
Emperor	6451	5740	5502	5134	5013
FEG	6478	6146	5457	4798	4776
Galil	6443	6631	5472	4837	4814
Mauser	6396	5616	5512	5066	4904
Margolin	6482	5849	5698	4945	4749
TT	6394	5520	5443	5222	5038
Vostok	6378	7196	7082	5203	5196

Table IV. Frequency spectra kurtosis of particular time series.

	BACK-GROUND	SHOT		BULLET TRAP	
		1	2	1	2
AKMS	0,04	4,59	0,29	0,59	0,87
Emperor	-0,23	6,95	0,12	0,4	-0,16
FEG	-0,43	2,45	0,59	-0,3	0,15
Galil	-0,28	0,12	-0,88	0,6	0,43
Mauser	0,09	6,1	3,17	1,23	0,36
Margolin	-0,6	4,7	-0,76	-0,53	-1,05
TT	-0,46	-0,66	0,53	-0,13	1,38
Vostok	0,01	-1,35	0,31	-1,21	-0,32

3.3. Harmfulness rating of the firearm impulses

Tables V-VI present values of parameters L_{Cpeak} and L_{AFmax} received at different distances from the source. To determine the annoyance and danger of firearms noise, results obtained in measurements should be compared to the maximum permissible values. Gray columns contain measured results. They were a base for the calculations of theoretical values that could be acquired in free field conditions for other distances (white columns). Order of weapons was determined on the basis of measured values at the point located in the distance 7 m from the source. Bolded data indicate no exceedings of L_{Cpeak} and L_{AFmax} according to regulations provided in Polish standard [4] and NIOSH recommendations [5].

Table V. Theoretical and measured values of L_{Cpeak} parameter. Sorted descending.

Distance from the source [m]	0.1	1	7	40	40*
Mauser	181.3	161.3	144.4	**129.2**	**100.5**
Galil	181.2	161.2	144.3	**129.1**	**86.4**
Imperator	181.0	161.0	144.1	**128.9**	**106.2**
TT	181.0	161.0	144.1	**129.0**	**97.3**
AKMS	180.8	160.8	143.9	**128.8**	**100.5**
FEG	180.6	160.6	143.7	**128.5**	**97.2**
Margolin	175.4	155.4	138.5	**123.4**	**86.4**
Vostok	157.9	137.9	**121.0**	**105.9**	**74.9**

Table VI. Theoretical and measured values of L_{AFmax} parameter. Sorted descending.

Distance from the source [m]	0.1	1	7	40	40*
Galil	157.9	137.9	121.0	**105.9**	**83.3**
Mauser	157.7	137.7	120.8	**105.6**	**78.9**
Imperator	156.8	136.8	119.9	**104.8**	**85.9**
AKMS	156.0	136.0	119.1	**104.0**	**81.0**
TT	156.0	136.0	119.1	**104.0**	**80.2**
FEG	154.3	134.3	117.4	**102.3**	**81.4**
Margolin	144.4	124.4	**107.5**	**92.4**	**68.6**
Vostok	132.9	112.9	**96.0**	**80.8**	**56.6**

* maximum values from measurement (Table II)

For each weapon at a distance of 0.1, 1 and 7 m from the source (shooter's position), permissible values of L_{Cpeak} and L_{AFmax} are exceeded. Therefore hearing protection is absolutely necessary, but e.g. for Vostok riffle, shooters do not always use such protection, what, as it turns out, can also be harmful (especially in case of a long-term exposure). At the distance 40 m obtained results are much lower than calculated, due to the presence of the building at the propagation path.

4. Conclusions

Each shot is characterized by high values of impulsive noise indicators and rapidity of impulse rise. They allow to classify this type of noise as highly impulsive noise source. It is possible to classify the weapons by the values of L_{Cpeak} and L_{AFmax}, which may lead to predict the potential annoyance and risk of hearing damage. Even the quietest of the registered impulses, which is commonly regarded as not very troublesome (Vostok), exceeded the normatively imposed values of L_{Cpeak} and L_{AFmax} at the shooter position. That imposes the need to use hearing protectors by people in the shooting range, especially shooters.

Acknowledgements

Work was supported by Polish Ministry of Science and Higher Education.
Grant number: MNiSW/2017/50/DIR/NN2.

References

[1] ISO 1996-1:2016 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures.

[2] P. Rasmussen et al., *Measuring recreational firearm noise*, Sound and Vibration, 2009, 43.8: 14-18.

[3] W. Konopka et al., *Assessment and analysis of the acoustic environment of soldiers exposed to impulse noise*, Medycyna pracy, 2002, 53.5: 391-396.

[4] PN-N-01307:1994 - Noise - Permissible values of noise parameters in the work environment - Requirements for performing measurements (in Polish)

[5] L. Rosenstock, *Criteria for a recommended standard: Occupational noise exposure*, NIOSH, 1998, 98–126: 1-122.

[6] B. Kukulski, *The research on objective parameters dedicated to differentiate of impulsive noise events*, INTER-NOISE and NOISE-CON Congress and Conference Proceedings. Vol. 255. No. 5. Institute of Noise Control Engineering, 2017.

[7] http://strzelec.pwsz.nysa.pl/wp-content/uploads/2012/05/Podstawy-balistyki.pdf (access 23.02.2018) in Polish: Ballistic Basics.

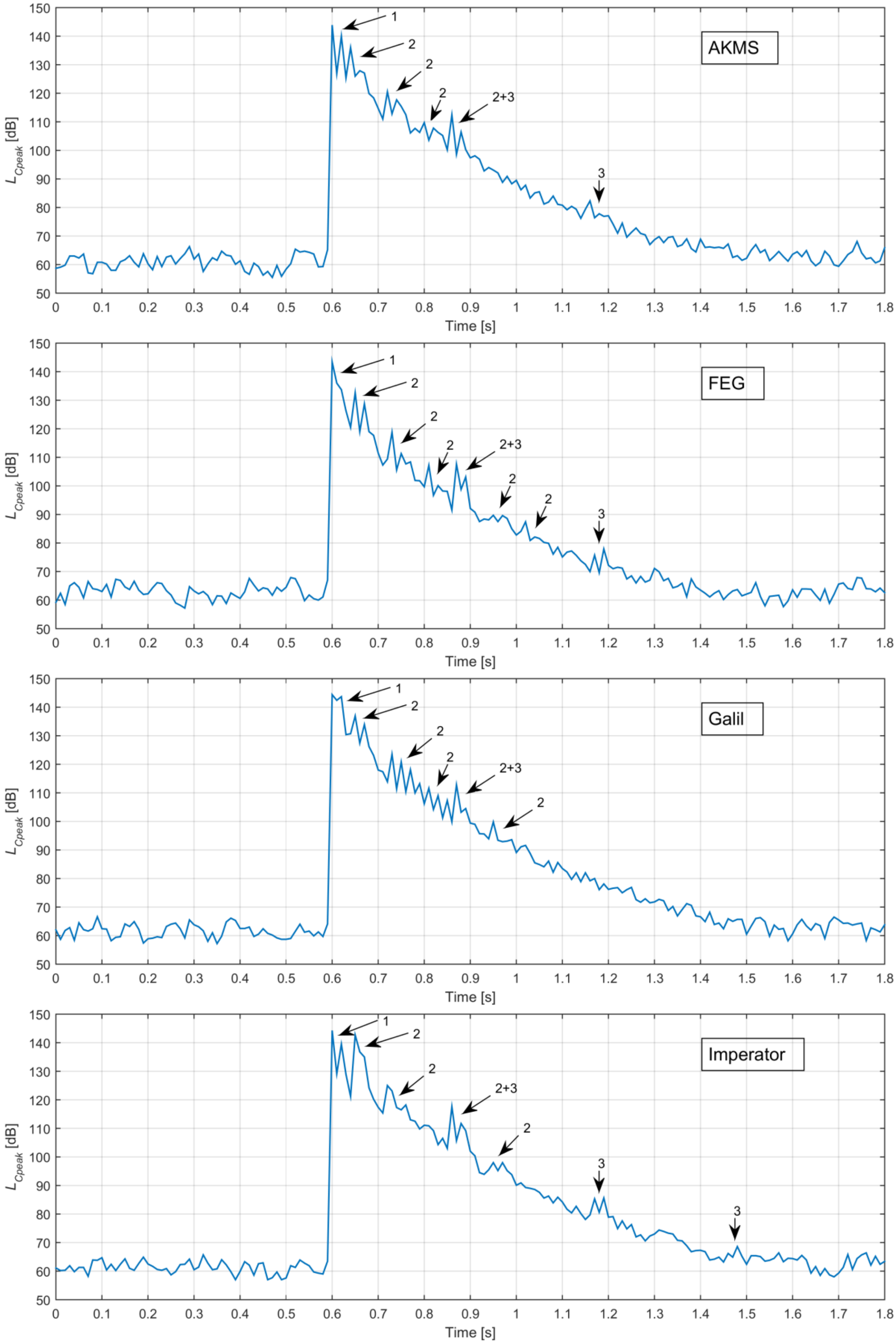

Figure 3. L_{Cpeak} value changes of single shots recorded at a distance of 7 m from the shooter. Marked fragments correspond to: 1 – shot, 2 – sound reflection from nearby facades, 3 – butt hitting.

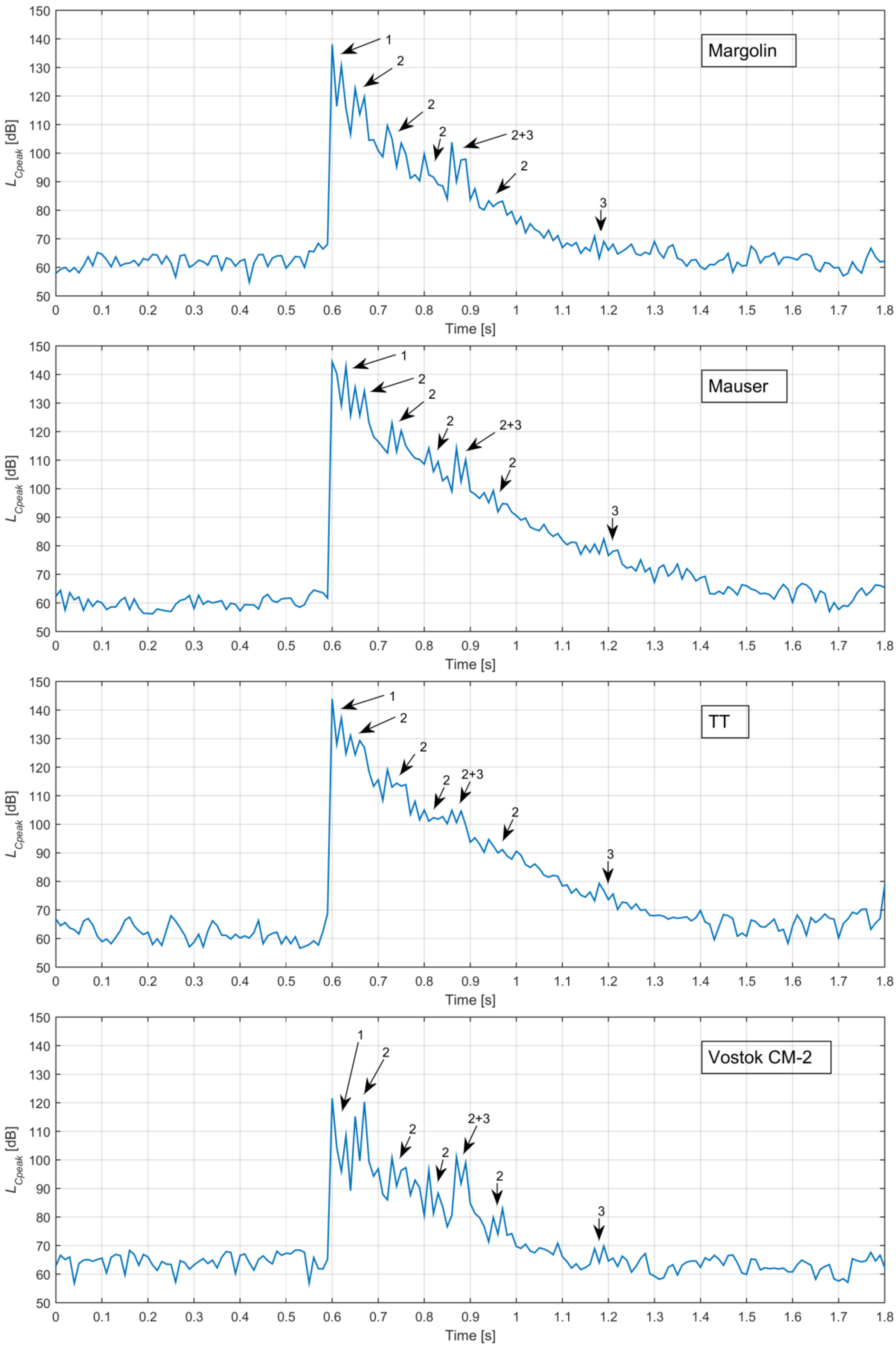

Figure 4. L_{Cpeak} value changes of single shots recorded at a distance of 7 m from the shooter. Marked fragments correspond to: 1 – shot, 2 – sound reflection from nearby facades, 3 – butt hitting.