A comparison of impulse-like sources to be used in reverberation time measurements

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As a part of an extensive ongoing research on reverberation time measurements, efforts have been made to find an impulse-like source that will comply with certain demands concerning its spectral content and sound pressure levels it can provide. Although the relevant standards state that such kind of sources should be avoided due to the lack of measurement repeatability, their use has proved to be necessary due to inability of conventional omni-directional loudspeakers to provide adequate sound pressure levels, especially at the low end of the frequency range of interest, thereby ensuring sufficient dynamic range. Therefore, the emphasis of this investigation has been made on peak sound pressure levels and the amount of low frequency content each source is able to provide. The investigated sources include 6 mm and 8 mm pistols, firecrackers with different amount of explosive compound and explosive mixtures of acetylene gas.

1 Introduction

In order to perform reverberation time measurements in compliance with relevant standards, appropriate measurement equipment is required, specifically, an omni-directional loudspeaker as a source of excitation driven by a power amplifier. In addition, some kind of signal generator and analyzer is necessary, implemented as a computer application or otherwise. Clearly, the list of the necessary equipment is rather extensive and the equipment itself can be difficult to transport to the measurement location and is not always available. Therefore, effort has been made to find ways to reduce this list to the very essential components while maintaining the accuracy of measurement results.

Since the omni-directional loudspeaker and its driving amplifier represent the heaviest and the most voluminous pieces of equipment, the principal goal is to replace them with a different source of excitation still appropriate for use in reverberation time measurements. The most logical choice is some kind of impulse-like source. Unfortunately, the standardized measurement methods require a loudspeaker source in order to provide the repeatability of the measurements, while the use of impulse-like sources is generally not recommended due to their inability to meet the fore mentioned requirement. Therefore, the use of impulse sources should be limited to survey measurements that provide initial data on the reverberation time. However, the difference between the results obtained from survey measurements and the results of measurements made using standardized methods must be maintained as small as possible in order to gain a realistic insight into the acoustic situation in a measured space.

As a part of our ongoing research on reverberation time measurements, different sources of excitation have already been examined [1, 2], focusing on their influence on measurement results. Specifically, loudspeaker sources have been investigated due to the influence of their directional properties on measurement results. Furthermore, the results obtained using loudspeaker sources have been compared to the results obtained using certain types of impulse-like sources, namely, balloons of different sizes and pistol shots.

The goal of this paper is to measure and compare the characteristics of the impulse sources themselves, ranging from balloons of different sizes to firecrackers having different amounts of explosive charge. The requirements on the sources remain the same: they have to provide sufficient amount of energy in the whole frequency range of interest in order to ensure the available dynamic range as high as possible. Therefore, the properties of the sources are investigated by comparing the maximum peak sound pressure level and the spectral content of the impulse sounds they emit.

2 Types of investigated sources

Although the investigation of several different types of impulse-like sources has been announced, only two major groups of sources were measured and compared, namely, firecrackers and balloons. The reason for this is that the measurements have been performed in an anechoic chamber, which was viewed as an unsuitable facility for investigating other types of sources, namely, the ones that utilize explosive mixtures of air and certain gases. Therefore, the investigation of the fore mentioned gas sources in the anechoic chamber was perceived as a serious safety and health hazard. However, the decision has been made that in the future work a second set of measurements will be made outdoors on firecrackers and balloons, as well as on all other sources that could not be investigated due to the reasons stated above. Furthermore, the direct comparison of results obtained in the anechoic chamber and outdoors will be made for firecrackers and balloons.

The first group of sources includes balloons of different sizes produced by the same manufacturer. The size of the balloons is expressed with their diameter when inflated. Specifically, three balloon sizes were investigated, having the diameters of 15, 25 and 95 cm in their inflated state. The initial hypothesis was made that the size of a balloon is in proportion with the total amount of energy the balloon will emit when explodes, as well as with the amount of energy emitted at low frequencies.

The investigated balloons are shown in Figs.1 and 2.

Fig.1 A small and a medium size balloon (3 and 2).

Fig.2 An extra large balloon (1).

The second group of sources includes firecrackers with different amounts of explosive charge, as stated earlier. Specifically, six different firecrackers have been investigated, ranging from a very small and harmless class 1 product to potentially hazardous class 2 products. A hypothesis similar to the one made for balloons has been formed for firecrackers as well. The only difference is that the amount of explosive in a particular firecracker will have the dominant influence on the amount of acoustic energy provided by firecracker explosion, as well as on the amount of energy emitted in the lowest part of the frequency range of interest.

All investigated firecrackers are shown in Fig.3. A ¼" phone jack has been included in the photograph as a size reference.

Fig.3 Investigated firecrackers.

3 Measurements and results

In order to ensure a free-field and noise-free environment, all measurements have been performed in an anechoic chamber. The chamber itself has the following dimensions: L = 7 m, W = 7 m and H = 5 m. The dimensions of the chamber allowed the distance of 8 meters to be set between the measured impulse sources and the microphone. It was expected that all of these sources will produce very high peak sound pressure levels. Therefore, the fore mentioned distance has been chosen to avoid overload of the measuring equipment.

The measuring equipment itself consisted of a Bruel&Kjaer 2231 sound level meter equipped with a ZF0020 attenuator and a matching 4155 microphone capsule. The whole system enabled accurate capturing of impulse waveforms emitted by explosions and provided a dynamic range sufficient for performing the measurements. The signal from the sound level meter has been sent to an RME Fireface 400 audio interface connected to a laptop computer and recorded as a wave sound, after which a spectral analysis of the waveform has been performed.

The initial part of the measurements has been focused on verifying the existence of free-field conditions inside the anechoic chamber. For this purpose, several measurements of sound pressure level have been performed at different distances from the source and it was found that the sound pressure level is actually inversely proportional to the distance from the source as it decreased by 6 dB with the increase of distance by a factor of 2.

The second test has been made on the measuring equipment itself. Specifically, two Behringer ECM8000 microphones connected to the RME Fireface 400 were used for recording the explosions produced by the investigated sources simultaneously with the sound level meter. The goal of this experiment was to determine whether or not these microphones will be able to handle sound pressure levels produced by the investigated sources. Figs. 4 and 5 show a 50 millisecond portion of the shock wave produced by the explosion of the largest investigated firecracker, as recorded by the sound level meter and the Behringer ECM8000.

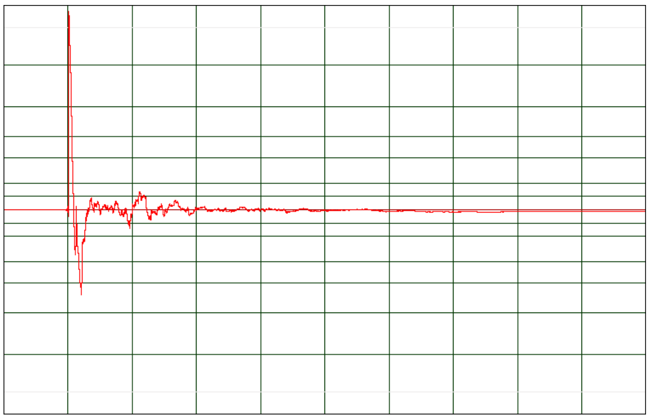

Fig.4 The waveform produced by the explosion of the largest firecracker, as recorded with the sound level meter.

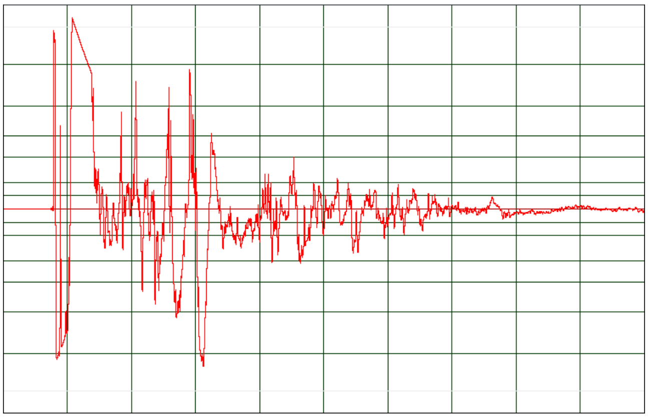

Fig.5 The waveform produced by the explosion of the largest firecracker, as recorded with a Behringer ECM8000.

The results shown in Figs. 4 and 5 are somewhat disappointing, as it becomes clear that the Behringer microphones cannot be used for accurate recording of events that produce sound pressure levels at this order of magnitude, despite our initial desire to utilize them for that exact purpose. These findings also raise the question whether or not these microphones can be used for reverberation time measurements when impulse sources are used as the excitation.

Upon the completion of the initial stage of the measurements and the finalization of the measurement setup, actual measurements on the investigated sources have commenced. The measurements have been made as simple as possible, focusing on measuring the peak sound pressure level (MAXP) using the sound level meter, in order to obtain a reference value, as well as on recording the waveform of the sound wave emitted by the explosion of the investigated impulse source. As stated before, the measurement distance has been set to 8 meters in order to avoid overload of measuring equipment. However, since the existence of free-field conditions in the anechoic chamber has been verified by initial control measurements, the decision has been made to extrapolate the actual measured values to the standard distance of 1 meter.

The initial comparison of the two inherently different types of sources has been made by comparing the recorded waveforms of a typical firecracker explosion against the waveform of a typical balloon burst. The examples showing 50 millisecond portions of respective waveforms are shown in Figs. 6 and 7.

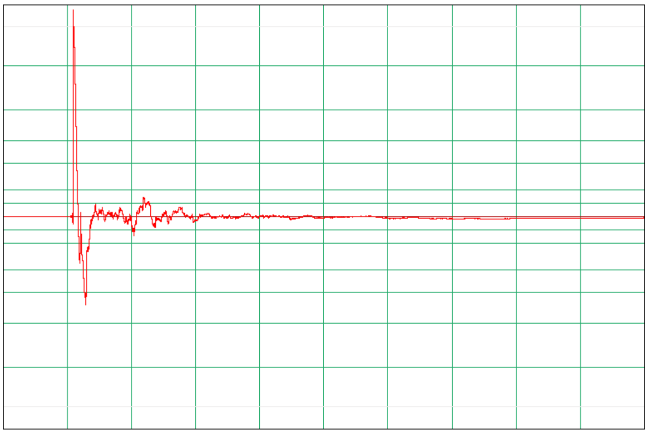

Fig.6 A typical waveform produced by a firecracker explosion.

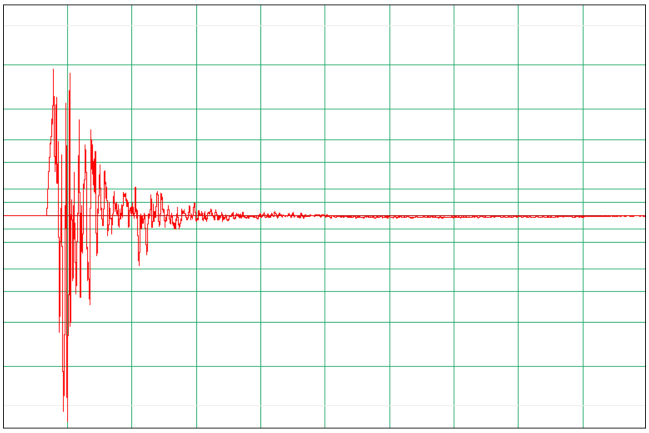

Fig.7 A typical waveform produced by a balloon burst.

The waveforms shown in Figs. 6 and 7 reveal a great difference between the two types of sources, both generally referred to as impulse-like. The explosion of a firecracker filled with explosive charge will provide a typical N-pattern sound wave, due to the fact that the burning speed of the explosive charge is high enough to enable almost instantaneous combustion of the whole quantity of explosive, thereby releasing a high amount of energy in a very short period of time. On the other hand, a balloon explosion does not happen as fast as a firecracker explosion simply because a balloon wall requires a certain amount of time to crack. Furthermore, the waveforms recorded for the same type of balloon show significant differences in appearance, suggesting that the manner in which the balloon wall cracks is different for each individual specimen. Earlier work [3] offers similar conclusions.

A comparison of waveforms recorded for explosions of a small and a medium size balloon has revealed that the size of a balloon has a significant influence on the shape of the sound wave generated by the burst of a balloon. Figs. 8 and 9 both show 50 millisecond portions of recorded waveforms.

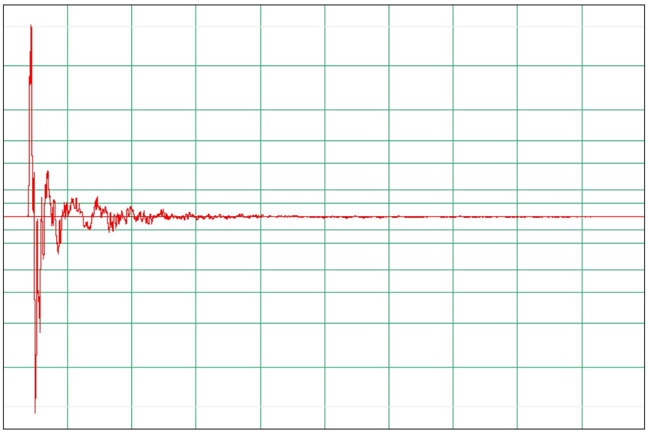

Fig.8 A waveform recorded for a small size balloon explosion.

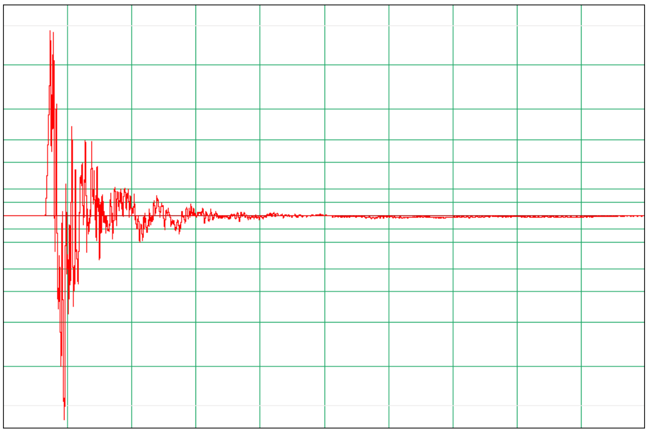

Fig.9 A waveform recorded for a medium size balloon explosion.

The waveforms shown in Figs. 8 and 9 clearly show that the explosion of the smallest balloon will produce a shock wave very similar to the one produced by a firecracker explosion. As the size of the balloon grows, the shape of the shock wave begins to show significant differences to the one recorded for a firecracker burst. In both cases, however, the initial N-pattern typical for explosions can be observed with more or less difficulty. Nevertheless, it is obvious that a balloon requires a greater period of time to release the acoustic energy, compared to a firecracker. The reasons for this have already been stated above.

As for the influence of balloon size on the shape of the waveform produced by its burst, two possible explanations are offered. First, the size of a balloon dictates the total surface of its wall in the inflated state. It is reasonable to assume that the amount of inevitable imperfections of the balloon wall is directly related to its surface area. Therefore, a large balloon will have a greater number of imperfections in its wall and will burst in a highly unpredictable manner, compared to a small balloon. Second, the air pressure that forms inside a balloon as a result of inflation is crucial to the manner in which the balloon will release its acoustic energy by bursting. In other words, higher air pressure inside the balloon will produce a blast that will resemble more to a firecracker explosion, as it will cause a short, but rather violent burst, resulting in an energy emission with similar properties. At this point, the human factor becomes important. To put it simply, if a balloon is inflated using only human power, higher air pressure will be achieved in a small balloon because the person inflating the balloon will tend to push it to its limits, despite the risk of premature bursting. On the other hand, when inflating a large balloon, the person doing it will inevitably show much more reluctance and caution in order to avoid a very unpleasant and possibly painful experience of a balloon bursting in their face. Therefore, lower air pressure will be achieved, resulting in a more gradual emission of acoustic energy.

As stated before, the peak sound pressure levels were measured for each source, thereby serving as a reference level for respective waveforms. The average values of peak sound pressure levels referenced to the distance of 1 meter are shown in Table 1 for each particular firecracker and balloon type. The firecrackers are lined up in relation to their basic property, i.e. the amount of explosive charge. Their markings are referred to the ones shown in Fig.3. The balloons are lined up in relation to their size, from the largest to the smallest one.

Source group	Peak SPL at 1 m (dB)
Firecrackers	
1 (largest)	165,9
2	162,9
3	162,1
4	161,6
5	158,3
6 (smallest)	155,7
Balloons	
1 (largest)	138,3
2	134,9
3 (smallest)	133,3

Table 1 Peak sound pressure levels measured for investigated sources

The peak sound pressure levels shown in Table 1 reveal that the basic properties of investigated sources, namely, the amount of explosive in the firecrackers and the size of balloons, are directly related to the peak sound pressure level they will provide by exploding. Furthermore, it is quite clear that balloons provide peak sound pressures that are at least an order of magnitude lower than the ones provided by any firecracker. A critical example of this finding can be made by comparing the peak sound pressure level produced by the largest balloon to the one produced by the smallest firecracker on the test.

Finally, the spectral content of both groups of sources has been calculated from the recorded waveforms using the measured peak sound pressure levels as points of reference. The results were calculated as power spectrum and displayed in ⅓-octave bands. Figs. 10 and 11 show the comparison of the results made for each group separately.

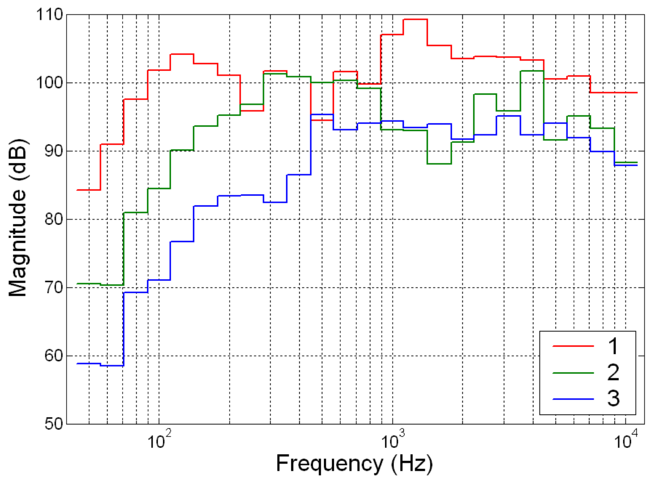

Fig.10 Spectral content of balloon bursts.

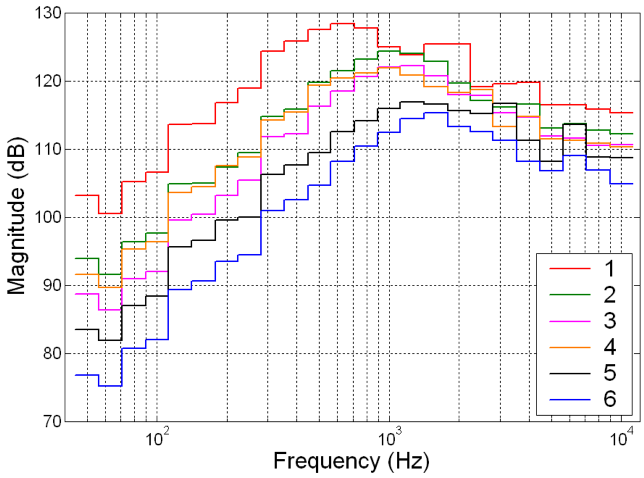

Fig.11 Spectral content of firecracker explosions.

The spectral content of balloon bursts shown in Fig.10 clearly indicates the direct relation between balloon size and the overall spectrum. Specifically, the largest balloon will provide the highest amount of excitation, especially at low ⅓-octave (or octave) bands, where proper excitation always represents a problem. As the size of the balloon gets smaller, the excitation at low bands decreases, as initially expected.

The spectral content of firecracker explosions shown in Fig.11 shows that the overall spectral shape is virtually the same for all investigated firecrackers regardless of the amount of explosive charge. However, it is clear that the most energy emitted by these explosions is concentrated in the frequency range from 500 Hz to 2 kHz, i.e. in the mid-frequency region. It can also be observed that the maximum of energy displayed in the spectral content is shifted towards lower frequencies with the increase of amount of explosive. This observation leads to the conclusion that a much larger quantity of explosive would have to be used in order to shift this maximum to the lowest frequency bands of interest. In order to achieve this goal, only a cannon of some kind could be used safely, as uncontrolled explosion of a large quantity of explosive would undoubtedly represent a serious hazard.

Finally, the direct comparison of spectral content provided by both groups of sources shows similar results to the ones obtained from earlier comparison of peak sound pressure levels. Specifically, the firecrackers are capable of providing much higher excitation levels, thereby ensuring a higher available dynamic range to work with during reverberation time measurements.

4 Conclusion

The principal goal of this paper was to compare two groups of impulse-like sources to be used in reverberation time measurements, namely, the firecrackers and balloons. From this research the following conclusions were made: firecracker explosions release its energy in a very short period of time, resulting in a very high initial peak in the emitted sound wave and the characteristic N-pattern typical for explosions. The waveforms recorded for different firecrackers show the described behaviour regardless of the quantity of explosive contained in a firecracker, leading to a conclusion that firecrackers offer a certain degree of repeatability when performing the measurements. The maximum excitation is provided in mid-frequency region between 500 Hz and 2 kHz, depending on the amount of explosive. On the other hand, balloons require more time to release the acoustic energy due to the certain amount of time required for cracking the balloon wall. Furthermore, the form of the sound wave emitted by a balloon burst will depend greatly on air pressure inside a balloon, introducing a human factor, as well as on balloon size, as shown earlier. Therefore, balloons do not provide repeatability required in reverberation time measurements. None of the investigated sources offer adequate excitation at the low end of the frequency band of interest.

Additionally, the choice of measuring equipment is crucial if impulse sources are to be used in reverberation time measurements. Namely, measuring microphones must be able to handle the peak sound pressure levels provided by impulse sources in order to perform accurate measurements.

As announced earlier, future work will include the investigation of these two groups of sources in an outdoor environment, along with all other sources that could not be examined due to the limitations imposed by the test space, i.e. the anechoic chamber.

Acknowledgments

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