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Clapper as a simple impulse sound source for acoustics assessments in enclosed spaces

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ABSTRACT

Assessing the vibrational and acoustic behaviour has become a relevant part within vehicle development. That is particularly important for electric vehicles, where low noise and vibration level will require a higher level of soundproofing and insulation to avoid discomfort to the occupants.

The search for suitable noise sources, with good behaviour at low and medium frequencies, easy to transport and quick to operate, is not an easy task. When a small and not very expensive source is also intended, it becomes even more complicated to achieve.

After a quick assessment of the different kinds of available noise sources, this paper presents the design and characteristics of a clapper, specifically developed as an impulse noise sound source. Near-field omnidirectional radiation in the frequency range of interest, between 10 to 800 Hz, is where this work is focused.

This self-made source intends to operate as a quick alternative impulse sound source for experimental assessments in vehicle cabins or small spaces. Sound power, spectral characteristics and directivity of the clapper impulse noise are described here.

Keywords: Acoustic assessment; Impulse sound source; Reverberation time; Impulse response.

1. INTRODUCTION

Many approaches in acoustic assessment need one, or several, acoustic sources located in determinate points, and therefore many kinds of noise sources have been developed for these specific tests.

Electroacoustic noise sources are the more common, and several companies offer different models, depending on the requirements in each occasion. Usually these sources require an omnidirectional loudspeaker, plus a power amplifier, and a signal generator is necessary as well. Even when noise sources incorporate all devices in one unit, the necessary equipment is extensive or quite big. These noise sources are difficult to transport, and to install, in the corresponding location. Especially when it is intended to work in enclosed spaces, like small rooms or vehicle cabins.

Moreover, conventional omnidirectional loudspeakers are quite expensive, and they don't provide good omnidirectional behaviour at nearfield. Adequate sound pressure levels are difficult to achieve as well, especially at the low end of the frequency range of interest.

In addition, most impulse noise sources are developed for architectural acoustic purposes, in order to measure the reverberation time, or the impulse response of a room, or enclosed space [4,5]. In this field, the standard rule for checking the suitability of a noise source is the ISO 3382 [6]. This ISO requires a sound source as omnidirectional as possible, and powerful enough to provide an appropriate dynamic range of the signal at the receiving point. The source level should be at least 45 dB above the background level in the corresponding frequency band.

But the source evaluation method does not work well when applied inside a small space, like a car or a small room. One of the reasons is the scale of the measurement space, as ISO3382 is relevant to architectural places. Here the method of evaluating omnidirectionality states a minimum distance between source and microphones of 1.5 meters.

Such a distance is clearly too big for the requirements of a source inside a space that can be as small as 2 meters long or less. In this case, omnidirectionality should be assessed closer to the noise source, as the passenger compartment of a car rarely exceeds 1.5 meters from the driver position in any direction.

It seems obvious that ISO 3382 fails to be the most appropriate procedure here.

The goal, therefore, is to find an alternative noise source to the electroacoustic ones. An assessment of the suitable sources of excitation for the given problem will be necessary, and other methods for characterization of the source will be used in this work.

Several sources will be evaluated knowing that the required main targets in this project are: appropriate Sound Power Level (SWL), in the required range of frequencies, and omnidirectional near-field behaviour.

It is possible to find different kinds of impulse sound sources: balloon pops (filled with air or Hydrogen-Oxygen), firecrackers, gunshots, spark train or clappers. These sources have been studied, assessing their applicability and suitability for being used inside an enclosed space, as specified in the following paragraphs.

<u>Balloons</u>. The impulsive nature of a popping explosion is the fundamental property of interest for using balloons in measurements. In [7], average directivities were compared against ISO3382 which defines the allowed directional variation for an omnidirectional source.

In all cases deviations below the 500 Hz octave band are between 6–9 dB, well above the standard limits. Only the largest balloons are close to the standard in the 1 kHz band. This present analysis shows that the directivity would not conform to the standard for lower frequency bands, which is where the present work is aimed.

<u>Hydrogen-oxygen balloons</u>. Balloons cannot only be filled with air; there are also studies where the behaviour of hydrogen-oxygen balloons have been assessed [8]. In comparison to other impulsive noise sources, hydrogen-oxygen balloons produce moderate peak Sound Pressure Levels (SPL). However, the time-waveform produced is much less shock-like than sources of similar amplitude. Because of this, such balloons have a lower characteristic frequency and are close to omnidirectionality, with very little angle-dependent deviation from the mean. The maximum deviations fit within the range required by ISO 3382 (6dB) at the high frequencies, and nearly within the range at the low frequencies.

Although hydrogen-oxygen balloons are nearly omnidirectional, they must be discarded due to the risk of causing an explosion of a hydrogen-oxygen balloon (0.4 m approx. diameter) inside a vehicle cabin or small space.

<u>The spark train</u>, used as a sound source in scale model investigations [9], could be a worthy source to be considered. The simulation of acoustic phenomena using scale models requires the use of small and powerful sound sources with a wide frequency bandwidth and omnidirectional radiation.

Among different source types able to provide these characteristics, spark discharge in air is an interesting solution. The principle is based on the generation of an electric discharge by applying a high voltage between two electrodes. First the gas becomes electrically conducting, the electric current heats up the gas, causing the formation of an impulsive sound signal. The main advantage is its small size, which is particularly important for investigations on a limited scale. Although the spark gap is not truly omnidirectional, it can be constructed so that the shape has a negligible influence on the sound field to be measured, for any scale factor.

However, security reasons advise avoiding this kind of source in a small space or the interior of a car.

<u>Gunshots, firecrackers and explosives</u>. For many years several kinds of guns have been used as impulse sources, usually to study reverberation times in rooms [10]. They are potentially useful as a sound source to measure some acoustical parameters such as early-to-late arriving sound ratios, and can also be used in Noise, vibration and harshness (NVH) analysis. The gun is easily portable, and a repeatable, reasonably omnidirectional noise source, radiating sufficient acoustical energy in all octave bands from 125 to 8000 Hz.

Firecrackers, on the other hand, also offer good results [11,12]. Their explosions release energy very quickly, and the waveforms recorded for different firecrackers show the described behaviour regardless of the quantity of explosive contained in the firecracker, leading to a conclusion that firecrackers offer a certain degree of repeatability when performing measurements.

Nonetheless, using such sources is completely inappropriate for this application, since they require ignition and explosion of the source inside the work space. Safety issues strongly advise against the use of these sources here.

Clappers. The clapper consists of two identical plates connected by a hinge, allowing the two plates to revolve around the same axis. These two plates can be struck against each other, thus generating an impulse sound. Both plates have handles fitted on the reverse side to allow for easier manipulation.

The work of Sumarac-Pavlovic et al, [13] shows that an impulse produced by a clapper has a longer duration than an impulse produced by any of the various commonly used explosive sources or balloon bursts. Clapper sound level fulfils the requirements for a minimal dynamic range at all relevant octave bands (In his case: 125 Hz to 8 kHz).

Diagrams of the directivity show that the clapper has a better uniformity of sound radiation, compared to a gun and/or a balloon burst. If the clapper is operated by trained personnel the results of its impulse repeatability are even better than those of balloons and firecrackers.

In view of these characteristics, the clapper could be the easiest method to adapt in small enclosed spaces. However, as normal clappers are made to work in architectonic spaces, it would be preferable to make a specific design of such a device, in order to improve its response to the following requirements:

- To emit enough impulses power in the frequency range of interest.
- To be omnidirectional, in the close field.

This paper outlines the design, the construction and the experimental characterisation of the developed clapper.

2. DEVELOPING OF AN IMPULSE SOUND SOURCE

Generally, clappers used in architectural acoustic have a rectangular shape [13], for simplicity of manufacture and because the shape does not interfere too much in the directivity of the sound when it is working in non-close field.

Considering the interest of using the source in the close field, it was decided to use a circular shape to avoid corners on the impacting surfaces, thus improving the spread fluency in near field, and favouring the omnidirectionality. Figure 1 shows the proposed design.

In addition, to reduce the phenomenon of reverberation in the clapper interior volume, a piece of medium-density polyurethane foam has been placed in each of the cavities. These foam parts, will absorb much of the clapper own reverberation.

It is clear the larger the clapper is, the better it will work at low frequencies. On the contrary, if priority is given to the directivity, the size of the plates should be as small as possible. Moreover, the clapper must be light and facilitate ease of operation inside a car. Thus, the selected material, to make the clapper, was medium density fibreboard wood.

When designing a small, and light, sound source, a good low frequency response is the most difficult

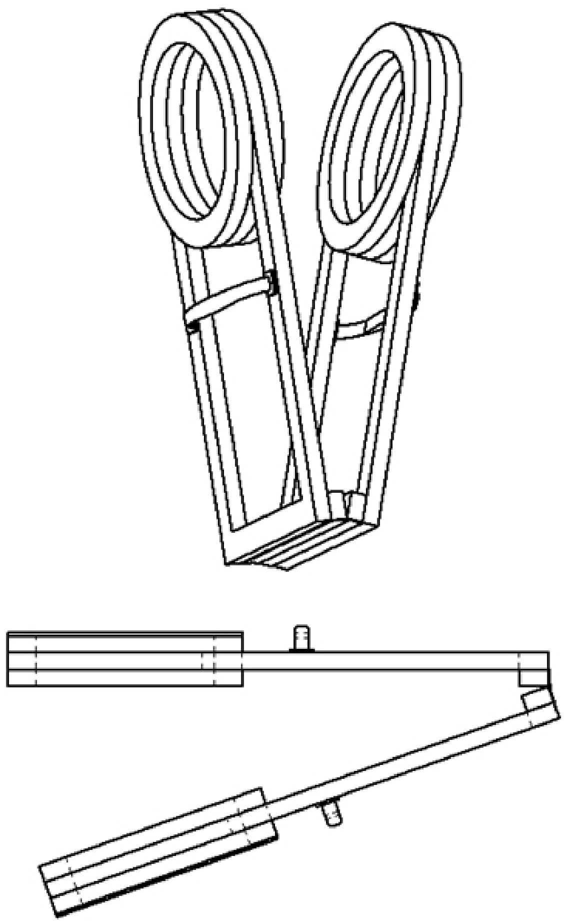

Figure 1. Clapper design.

challenge. To achieve the best possible performance, at low frequencies, a rubber slab has been installed on the outside of each clapper cavity.

These rubber slabs will act like the membrane of a drum, being able to bring a significant improvement in the emission at low frequencies, without the necessity of increasing the size of the clapper.

The final consideration of the design was an agreed balance between all the requirements as outlined above. The appearance of the clapper and work planes would be as shown in Figures 2a and 2b.

3. CHARACTERISTICS OF THE CLAPPER SOUND IMPULSE

To characterize the sound generated by the proposed clapper, work was divided into two main targets. Firstly, the sound power level was determined by using pressure measurements. Secondly, directivity was evaluated, but this will be shown in the next section.

As an anechoic environment was not available, the acoustical characteristics of the clapper have been analysed in a free field. Following the guidelines of the standard ISO-3744 [14], for an essentially free field over a reflecting plane, the engineering method has been performed.

An impulsive noise, or impact noise, means any sound with a rapid rise and decay of sound pressure level, normally lasting less than one second. Caused by sudden contact between two or more surfaces, or caused by a sudden release of pressure. This almost instantaneous increase in pressure, radiated by the clapper, is given by the integral of the pressure over a surface enclosing it. The direct method indicated by ISO-3744 has been followed to obtain the sound power levels in third-octave bands. This is particularly relevant as one of the goals in the present work is a good noise level at low frequencies.

Before doing the tests, the signals acquisition process was verified to make sure it provides reliable data. Figure 3 shows the signal generated by the clapper, similar to the typical shape of an impact noise.

As the clapper is manually actuated, sound impulse power depends on the force at which the clapper is closed. To check the deviation several successive impacts of the clapper were analysed. It was proved that with very little practice a high repeatability can be

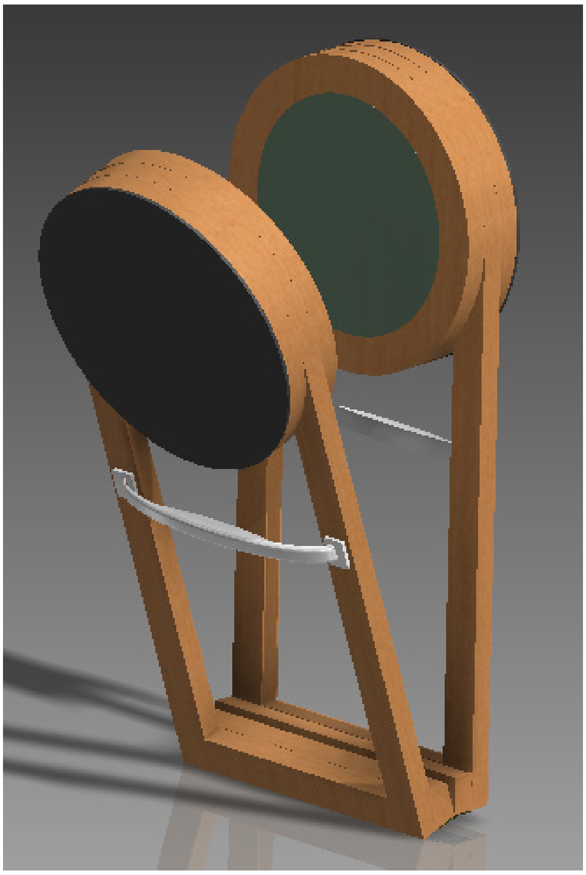

Figure 2a. Clapper appearance.

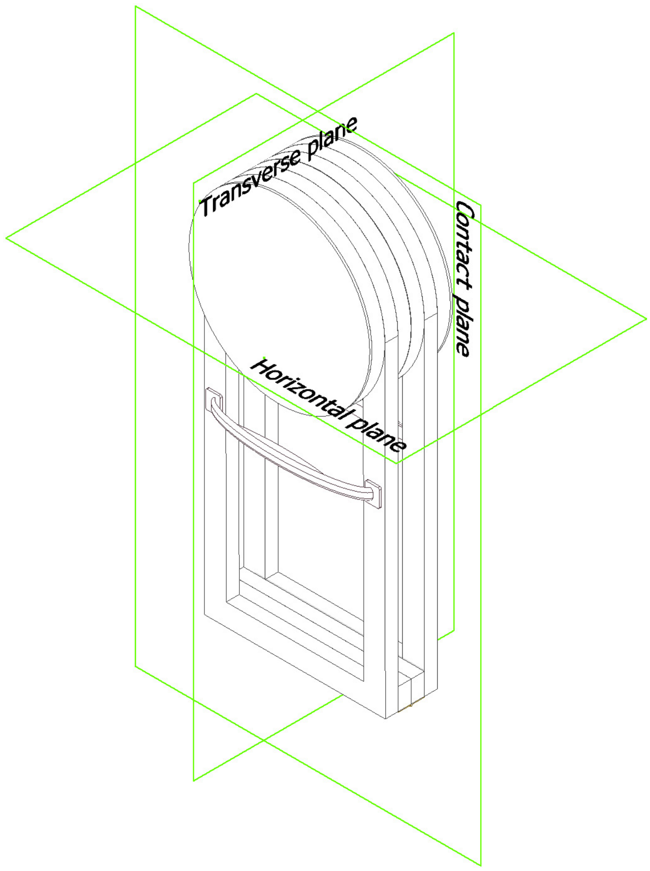

Figure 2b. Clapper work planes.

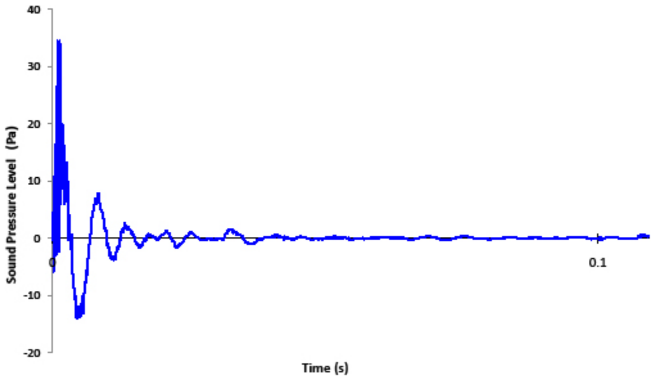

Figure 3. *Impulse signal.*

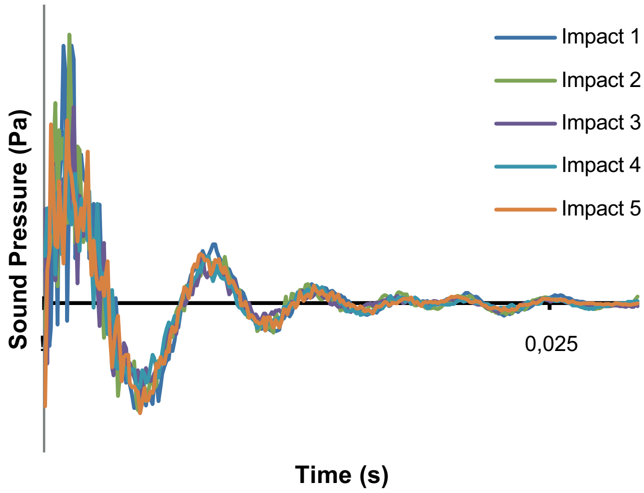

Figure 4. *Repeatability of five impulse signals.*

achieved. Figure 4 shows five different impact signals, which are superimposed on each other, with very little deviations.

All the presented results in this work were obtained by mean values from at least five successive claps to avoid unwanted variations in any specific clap. Sample frequency in experimental tests was set at 10 kHz.

Since the main goal is to develop an impulse source for low and middle frequencies, the most difficult challenge is to have precise results in the lower part of the spectrum without increasing the size of the source too much. Obviously, many previous tests were performed until the best configuration of the clapper was obtained.

Moreover, intending to avoid the reverberation between both sides of the clapper a maximum diameter of 35cm was set, as frequencies of interest in this work, are in the range from 10 to 800 Hz.

The reason to this limit is because the clapper diameter has a direct relationship with the wavelength (λ), which for a sound wave is: λ=c/f, where c is the speed of sound (343 m/s in dry air at 20 °C) and f is the frequency.

This limit to 35cm ensures that the reverberation effects would start around 1kHz, where the clapper diameter is equivalent to the longitude of the wavelengths and resonance effects can arise.

Taking into consideration all the above, finally, the size selected for the clapper diameter was a compromise in order to have the best response at low frequencies without reverberation effects

3.1. Sound Power Level (SWL)

The SWL test was developed following the method specified in ISO 3744. This standard describes a grade 2 (engineering grade) method of accuracy for determining the SWL of a noise source from SPL, measured on a surface enveloping the noise source in an environment that approximates to an acoustic free field.

The selected layout for this test corresponds to that shown in Figure 5 above.

This arrangement consists in placing the source within a hemispherical surface on which ten microphones are regularly distributed. After the dimensions of the clapper were introduced into the calculation process, the radius of the hemispherical surface was established at 1 meter.

The impulse signals of the ten channels were recorded and spectrums were calculated. Measurements were developed with a 16 chanels LMS Scada Mobile SCM05 with ten free-field type 4189 microphones of Bruel & kjaer, conveniently calibrated. The obtained SWL, in decibel, is presented in Fig. 6 together with the recorded background noise.

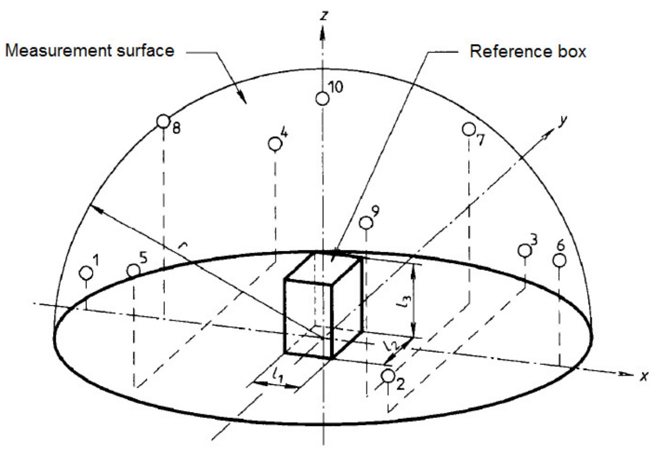

Figure 5. *"Figure B.2" from annex B of ISO 3744.*

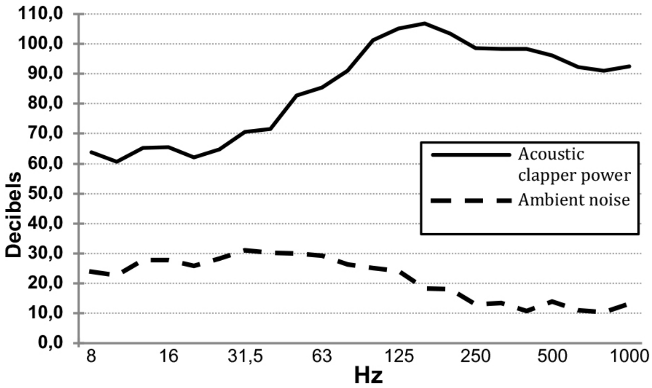

Figure 6. Spectrum of the acoustic clapper power.

It is worth noting that the background noise must be less than 6 dB below the noise from the device under test, in any octave or 1/3 octave, because compliance to ISO 3744 cannot be claimed at frequencies where the difference is less than these 6 dB.

In this case background noise was always more than 20 dB below the noise level registered in all positions for the whole range of analysed frequencies.

4. DIRECTIVITY

The clapper directivity was measured in a free field environment according to ISO specifications. During the measurements, the clapper was placed in the middle of a square structure in which nine microphones were proportionally disposed on two of its sides. Figure 7 shows the assembly arrangement.

The dimensions of the aforementioned square structure were 1.2 by 1.2 meters, and the clapper was located in the middle. The two nearest microphones were placed at 0.6 meters from the clapper, which is the intended distance to assess directivity.

The sound pressure levels recorded from the rest of the microphones, have been compensated to this distance of 0.6 metres according with the sound propagation equation.

Each position of the clapper was measured twice, rotating 180º between them to cover the full circumference. Microphones 1 and 9 were used as a control measure, overlapping their positions at the ends to increase the reliability of the results.

As a consequence, 16 sound pressure data points can be obtained, each being separated by 22.5 degrees. The results were obtained for the six octave bands on the range of frequencies of interest, and are shown in figures 8, 9 and 10.

The Omni-directional behaviour of the source will be presented by the Directivity Index in polar diagrams.

The said Directivity Index (DIi) is defined in ISO 3744 as the SPL for each microphone position minus the mean time-averaged SPL over all the microphone positions on the measurement surface for the noise source under test, in decibels.

Figures 8, 9 and 10 present the Directivity Index, at 0.6 meters away from the clapper, in the Contact plane, Transversal plane and Horizontal plane consecutively (according to the definitions in Fig. 2b).

Diagrams indicate that deviations from Omni-directionality are, in the worst cases, always under 4 dB. Standard deviations are around 1.2 dB in most cases and never exceeding 2.1dB.

Figure 7. Mounting example test.

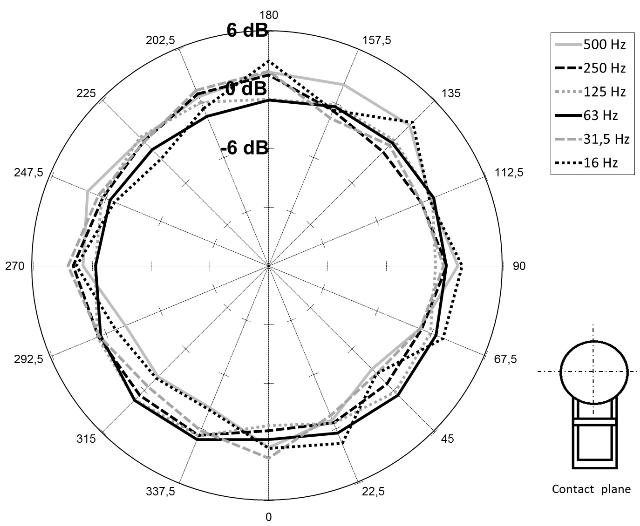

Figure 8. Clapper's directivity index on Contact plane.

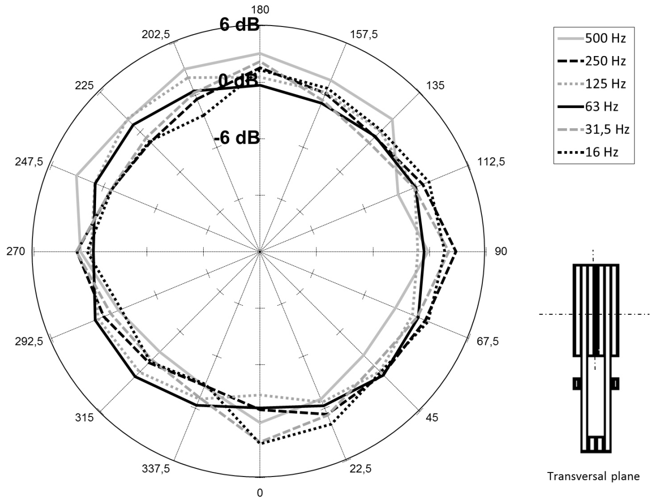

Figure 9. *Clapper's directivity index on Transversal plane.*

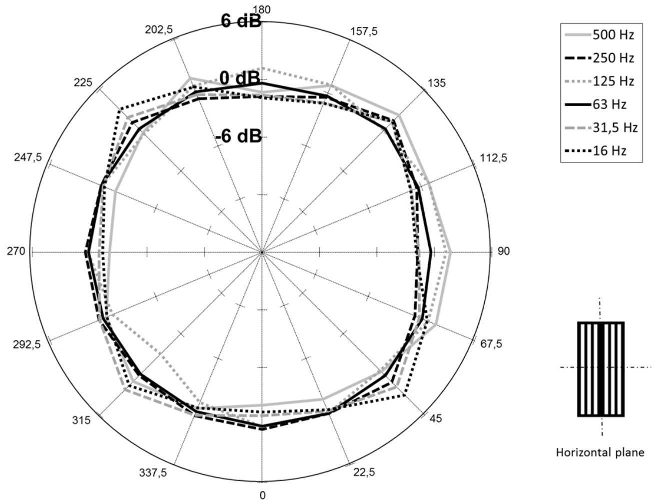

Figure 10. *Clapper's directivity index on Horizontal plane.*

5. CONCLUSIONS

This paper presents an empirical design and validation of a clapper as a noise source.

Experimental studies on the power level, the radiated spectrum and near field directivity of clapper impulses were developed.

The presented analysis reveals that although the clapper is a moderate size impulsive noise source, it has power enough at low frequencies to be used as a noise source for exciting structures.

Moreover, the clapper is almost omnidirectional at near field, superior than other sources such as balloons or guns. Maximum deviations of the directivity index are lower than 4 dB in all frequency range. This gives a clear idea of the good uniformity of sound radiation of the clapper.

Therefore, the present work determines that, in comparison to other impulsive noise sources, the clapper produces acceptable peak sound pressure levels, is cheaper, easy to transport and meets target specifications.

As a summary, this clapper could be used as an excitation source in an NHV test in vehicles and particularly in the small cabins of EVs.

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