Sound Propagation of reverse alarms used on heavy vehicles

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INTRODUCTION

Each year, serious accidents occur in noisy workplaces because a warning sound is not heard.[1] In the last 15 years, a minimum of 22 deadly accidents occured in Quebec on construction sites because workers did not hear the reverse alarm or the noise emitted by a heavy vehicule. In Canada and United States, such accidents have occured and involved trucks and buses.[2-4]

In Quebec, the regulation related to the use of reverse alarns on heavy vehicules referred to the SAE J994 Standard.[5] Regarding acoustical characteristics, this standard states that the predominant sound frequency of the alarm should fall within the frequency range of 700-2800 Hz. The cycles of sound pulsations from the alarm shall be of the order of 1-2/sec. The duration of the "on" and "off" intervals shall be approximately equal in length. The alarm should be tested in free field, 4 feet above a horizontal reflecting plane or laboratory equivalent, with the microphone 4 feet from the alarm's horn along its 0 degree axis. The alarm is then classified according to its sound pressure level: Type A: 112 dBA, Type B: 107 dBA, Type C: 97 dBA, Type D: 87 dBA and Type E: 77 dBA. The accidents reported above raise the question as to what extent such a standard insures that every worker will perceive the alarm at any position behind the heavy vehicule.

METHOD

In order to answer this question, measurements were made in a typical situation under which reverse alarms are used. Five reverse alarms of two kinds (pulsed alarms and modulated alarms) were tested at the rear of four heavy vehicles (ten wheel truck, grader, cement mixer, loader). Two positions of the alarms were tested: at the rear and under the vehicle. The ground was similar to what is found on construction sites: earth and gravel. There were no obstacles near the measurement sites.

Figure 1 illustrates the positions where measurements were made. They were made at 1 meter behind the vehicles, along the axis 1 to 9 and on axis 5 at 1, 2 and 4 meters . The sound emitted by the alarms was collected with a type 1 microphone (Cirrus MK-224) plugged into a numerical audio-tape recorder (TEAC, DA-P20). The recordings were transferred to a 1/3 octave band analyser (dBFETE) in the lab.

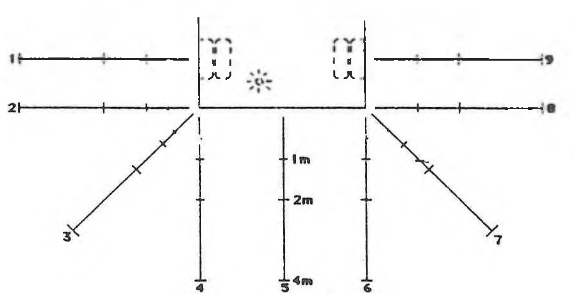

Fig.1 Axis position behind the heavy vehicles.

RESULTS

The frequency content of the alarms varied from 1140 to 3025 Hz. It is characterized by a pure tone in the case of the pulsed alarms and by two pure tones for the modulated alarms. These alarms were typical of what is found on the market.

The most interesting results were obtained at 1 meter behind the vehicles. Figure 2 presents the results of a serie of measurements for a modulated alarm (Warrick #12). From this figure, it is clear that strong attenuations, amounting to 20 dB, occur along this axis. The same kind of attenuations were noted on the other vehicles. When the alarms were put under the vehicles, the attenuations were more important.

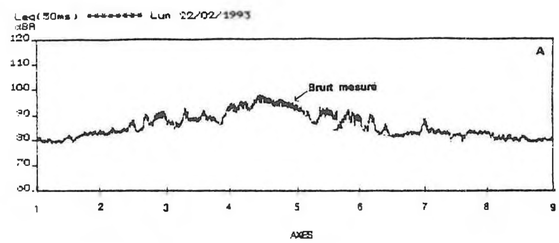

Fig.2 Sound pressure levels of the Warrick #12 modulated alarm measured at 1 meter at the rear of the grader , along axis 1 to 9.

Measurements were also done along the number 5 axis. The same kind of attenuations were noted. Near the vehicle, direct and reflected sound waves are highly diffracted on the sides of the vehicle before reaching the worker ears. At around 1 meter, levels are higher because there is less diffraction. Farther from the vehicle, there are attenuations due most probably to the cancellation of the direct and reflected waves.

A computerized model (ALARM) based on the state of the art knowledge in outdoor sound propagation (6,7) has been developped to simulate the cancellation phenomena. Figure 3 shows that the model accurately simulates, in terms of shape, the results obtained on the sites.

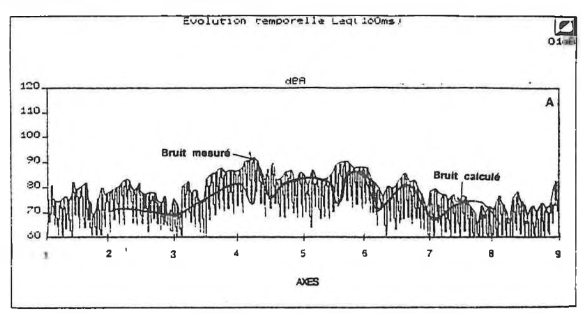

Fig.3 Comparisons between the measured and the predicted sound pressure levels based on ALARM software.

DISCUSSION

These results show an important flaw in the SAE J994 standard[5]: even if the studied alarms had met the requirements of the standard 4 feet behind the truck on the 0 degree axis, it does not mean that the sound pressure levels is uniform everywhere behind this same truck. Strong attenuations occur due to the use of pure tones in the majority of reverse alarms available on the market.

Based on these results, the detection of reverse alarm is largely dependent on the position of the receiver behind the truck. At some positions, the alarm is clearly audible whereas at others, it is inaudible due to the cancellation of waves and to the background noise which can be high enough to mask the alarm.[8]

Faced with these results, it is important to propose modifications in the design and the positioning of reverse alarms on vehicules. Any change must also take into account other factors which can explain the fact that reverse alarms are not heard. For example, high noisy backgrounds and noise-induced hearing loss can also interfere with the perception of reverse alarms.[8] Habituation to the pulsed tones is also often mentionned by workers.[9] There are so many alarms sounding at the same time in some worksites that workers become insensitive to the different signals. In that same conditions, localisation of the sound source is also a problem.[9]

At this stage, the following recommandations can be made. First of all, reverse alarms should not be pure-tones because they are strongly subject to diffractions and reflections. Even tones modulated between near frequencies are not adequate. The alarm should contain many frequency components in the 500-2000 Hz range. Extending this range above 2000 Hz is useless for those affected by noise-induced hearing loss which can affect hearing above this limit.[10]

Secondly, the position of the alarm on the vehicule should be studied in order to limit the diffraction phenomenon as much as possible. This may raise difficulties if one considers the limited space available as it is the case, for example, on a lorry-truck. It is almost impossible to install the alarm on the lorry door because of the danger of damaging it when the door is rocked and because of the possibility that the door be removed to carry instruments or merchandise.

Thirdly, studies on the habituation phenomenon should be performed in order to find a way to make the alarm audible without creating habituation. Research in the field of obstacle detectors may help solving this problem.[2-4,11] These detectors can be used to sound the alarm only when there are obstacles (humans, other vehicules or static obstacles), thus reducing considerably the number of times workers are exposed to such sounds.

Fourthly, the use of an electronic mirror, allowing to see in the blind spot, could help the driver. This technology is not yet fully developped. Studies should continue in that field with consideration for ergonomic constraints in terms of the driver's workload.

Fifthly, the trucks owners should be informed about the problems associated with back-up alarms and should ask for better reverse alarms to the manufacturers. Very often, trucks owners look for the cheapiest alarm (often the less intense) in order to save few dollars. Prevention of deadly accidents largely justifyies expense for better alarms.

Finally, one must insist on the need to reduce the noise levels on construction sites or anywhere where reverse alarms are used. This action would limit the masking effect of the background noise and would reduce the risk of acquiring noise-induced hearing loss which is highly prevalent among çconstruction workers.[12]

CONCLUSION

The use of reverse alarms was introduced in order to solve the blind-spot problem and to reassure the vehicule driver while backing-up. At this time, little concern has been expressed about the conditions that need to be met in order to ascertain that reverse alarms are perceived. In most cases, signalmen help the driver to reverse but in many cases, the signalman is the one who is fatally hit. These facts reinforce the need to improve the signals and to pursue studies on safety related to reverse alarms. Studies on optimal acoustical characteristics and position should be continued in conjonction with studies on obstacle detection. This technology could help to overcome the habituation phenomenon and localisation problems reported by many workers which are probable responsible for some of the deadly accidents that have occured.

Acknowledgements

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