ACOUSTICAL CONSIDERATIONS FOR EFFECTIVE EMERGENCY ALARM SYSTEMS IN AN INDUSTRIAL SETTING

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This poster was created to highlight several aspects that must be considered when evaluating an existing alarm system or designing a new emergency warning system.

Background - OSHA Regulations

Compliance with the OSHA regulations regarding Employee Emergency Response Plans (29 CFR 1910.38 and 1910.120) requires that an alarm system must be installed which complies with 29 CFR 1910.165 "Employee Alarm Systems." The alarm system is an integral part of proper emergency response training and procedures. In the alarm system regulation, the *General Requirements* section states "The employee alarm system shall provide warning for necessary emergency action as called for in the emergency action plan, or for reaction time for safe escape of employees from the workplace or the immediate work area, or both." Emergencies that may likely be encountered include fires, toxic chemical releases, tornados, etc.

To fully comply with the OSHA regulations and ensure appropriate actions are taken in an emergency situation, several pieces of information must be conveyed to employees throughout the plant. As a minimum, the type and extent of the emergency condition, location of the emergency, and the weather conditions are required for effective emergency response actions. A voice alarm system is not absolutely necessary to meet the requirements of 29 CFR 1910.165, however, this type of system is best equipped to rapidly disseminate the necessary information to employees.

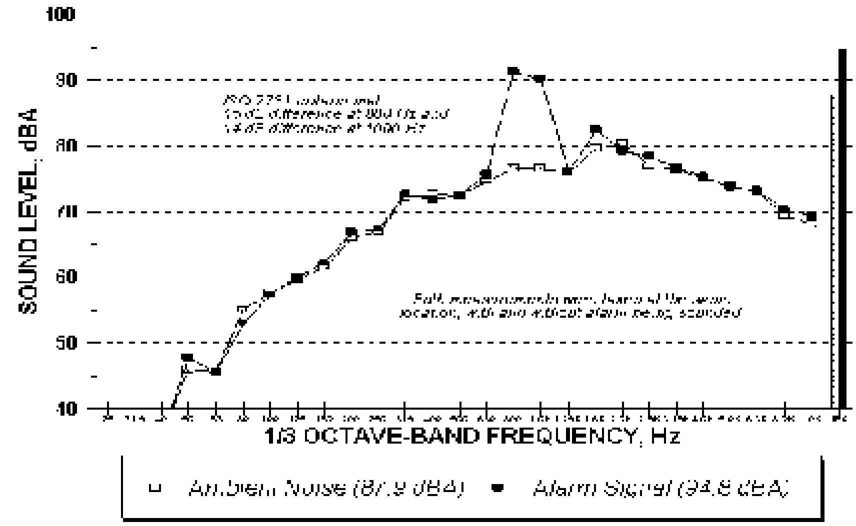
Warning Signal Detection

An alarm signal will not be audible unless the sound pressure level of the alarm is great enough to overcome the masking effect of the background noise. Research conducted during the development of criteria for audible warning signals has shown that the alarm signal should be at least 15 dB above the employee's effective threshold of audibility in noise, or "masked threshold." Some investigators in this field advocate an 18 dB signal-to-noise ratio for 100% detectability, especially while hearing protection is being worn. A range of 15 to 25 dB above masked threshold is considered to be most desirable.

An International Standard was issued in 1986 (ISO 7731) that defines criteria applicable to the recognition of auditory danger signals, especially for high ambient noise areas. Guidelines are given in this standard for sufficient audibility based on overall A-weighted sound level readings, octave-band analysis, or one-third octave-band measurements. Using the A-weighting scale, the signal should exceed the level of ambient noise by 15 dB or more. More accurate predictions can be made by obtaining octave or one-third octave-band sound levels and comparing these to the employee's masked threshold.

The masked threshold is the level of sound at which the alarm signal is just audible above the background noise, taking into account the hearing deficiencies of the listeners as well as the attenuation of hearing protectors. When using octave band analysis, the alarm signal must be at least 10 dB greater than the employee's masked threshold in one or more octave bands between 300 and 3,000 Hz. If one-third octave-band levels are used, the alarm signal must exceed the masked threshold by a minimum of 13 dB in one or more one-third octave-bands in the frequency range 300 to 3,000 Hz. Extensive testing of the alarm signal strength throughout the plant is conducted; a typical graph depicting these results is shown below:

FIGURE 1
ALARM SIGNAL TEST LOCATION 1A -
BUILDING 7B, 1st FLOOR, SOUTH END



Another important consideration is that the sound level of the alarm signal should not be so intense as to cause undue startle, which is possible when the level increases more than 30 dB in 0.5 seconds. Further, it is easier to hear the alarm signal if the frequency where the background noise is loudest is different than the frequency where the output of the signaling device is highest. The alarm signal should be based on the 300 to 3,000 Hz frequency range, with sufficient energy below 1,500 Hz to meet the needs of individuals with hearing loss, or employees wearing hearing protection.

Temporal characteristics of the alarm signal are also discussed in the ISO Standard. Pulsating signals are preferred over signals that are constant in time. A repetition frequency range of 0.2 to 5 Hz is specified; however, the pulse duration and repetition frequency must not be identical to any fluctuating ambient noise source in the surrounding area. The frequency (pitch) of the signal may also be varied, instead of using a single continuous tone.

Factors Influencing the Intelligibility of Speech Messages

The acoustic qualities of speech are characterized by strong vowel sounds in the low frequency range (500 Hz and below), and relatively weaker consonant sounds in the higher frequencies. Despite their lower overall intensity, the high frequency consonant sounds contribute most to speech intelligibility. Fortunately, spoken language contains built-in redundancy, which makes a sentence understandable even when a particular word is not correctly recognized. Grammatical structure, sentence length, context, and listener familiarity with the speech material contribute to understanding a message in less than optimal listening conditions. This redundancy is extremely beneficial when high background noise levels exist and hearing protectors are worn.

High frequency speech sounds are most readily affected during transmission through standard communication systems, which typically have poorer reproduction capabilities above 3,000 Hz. In industrial settings, low frequency sounds tend to mask or obscure mid- and high frequency sounds, which leads to decreased speech intelligibility. The combination of a degraded speech signal and high background noise levels result in a greater loss of speech recognition ability than otherwise would be expected.

Speech intelligibility can be predicted or quantified by a variety of methods. The Articulation Index (ANSI S3.5-1969 R1986) is a popular and highly respected measurement tool used to predict speech intelligibility in noisy conditions. The Articulation Index (AI) is a numeric value between zero and one that represents the effective proportion of the normal speech signal that is available to a listener (i.e., 0% to 100%). Acoustical measurements of the speech signal and background noise are used to compute the AI for a particular listening situation.

A graph is provided in the AI calculation instructions to convert the computed AI value to estimated speech intelligibility scores. Each curve in the graph represents the expected speech intelligibility based on a different set of speech materials. As the Articulation Index increases from zero to one, the percentage of correctly understood test items increases, although at a different rate, depending on the type of test material. A test vocabulary of 32 single words yields 100% intelligibility at an AI value of 0.4, while a test comprised of 1000 unexpected words or nonsense syllables requires much more information (i.e., a higher signal-to-noise ratio or higher AI value) to achieve even 90% recognition. Curves with steep slopes indicate that the expected intelligibility reaches a maximum more quickly, meaning that the speech material may be understood more easily.

As discussed earlier, the redundancy of connected speech (i.e., sentences) and potential familiarity with the content of the message will aid in its intelligibility. The intelligibility of a typical public address system would be closely approximated by the curve corresponding to sentences being presented to listeners for the first time. Therefore, a high degree of intelligibility can be expected for AI values above 0.4. Unfortunately, there is no single AI value that can be specified as a criterion for “acceptable” communication. ANSI S3.5 indicates that commercial communication systems generally provide AIs above 0.5, while an AI of 0.7 or higher appears appropriate for communication systems used under a variety of stress conditions and by a large number of different talkers and listeners.

Research has been conducted to investigate the relationship between different methods of estimating speech intelligibility. As indicated above, the Articulation Index is commonly used since it typically shows the least variability in predictive capability. However, the AI can be somewhat complicated to use in terms of measurement and calculation. A-weighted sound level readings can be used to estimate AI values by measuring both speech and noise levels to obtain a speech-to-noise ratio. An AI score of 1.0 (100% of the speech information available to the listener) corresponds approximately to an 18 dBA speech-to-noise ratio, and a 15 dBA speech-to-noise ratio will achieve an AI of approximately 0.9.

<u>Plant Ambient Noise Environment</u>

Noise levels should be measured throughout the plant to assess the acoustical environment in which the warning/notification system must operate. Sound level survey results may be displayed graphically on plant layout drawings, to aid in determining required system coverage for the entire plant. Additionally, correct speaker selection and placement can be achieved by supplementing the overall sound level readings with one-third octave-band measurements. These measurements are used to separate the noise signal spectrum into distinct frequency bands one-third of an octave in width, enabling a better characterization of the type of background noise present.

<u>Implications for Engineering Noise Controls</u>

A majority of noise sources encountered throughout many plants are relatively steady-state, which means that their sound levels do not fluctuate over time. However, periodic steam or compressed air releases may temporarily exceed the ambient level by 10 dB or more. These (and other) types of intermittent noise sources may interfere with effective communication by temporarily masking the alarm signal or notification message.

Designing an emergency warning system against steady-state noise levels is much easier than trying to account for sporadic fluctuations in the background sound level, particularly when the intermittent sounds are high intensity and of relatively short duration. Therefore, consideration should be given to eliminating or reducing the noise from these types of sources, as another method to ensure adequate voice communication. Properly selected and installed silencers or mufflers may solve most of these problems; however, it is recommended a detailed acoustical engineering analysis be conducted to define the appropriate control technique.

Although implementation of engineering noise controls may not be required to maintain compliance with the OSHA Occupational Noise Exposure Standard (29 CFR 1910.95), reduction of noise levels may still be desirable. In addition to treating intermittent noise sources, engineering control treatments should be investigated for certain high intensity steady-state noise sources as well. Lower noise levels will allow for more effective communication, provide a better working environment, and may enable hearing conservation measures to be eliminated in some buildings or areas.

Special Considerations

It is important to recognize that all contingencies may not be able to be accounted for in all circumstances. In particular, the hearing and auditory processing abilities of an individual employee may vary from day to day, which may cause an alarm signal to go undetected or unrecognized. Therefore, persons with known or suspected hearing deficiencies or problems may have to be accounted for on an individual basis.

Effects of Hearing Protection and Hearing Loss on Warning Signal Perception

Significant communication problems are often encountered by individuals with various degrees of hearing loss. High frequency hearing loss is usually the consequence of long-term exposure to excessive noise levels, as well as a typical result of the aging process. As previously mentioned, high frequency hearing ability is essential to the understanding of spoken language. Therefore, hearing impaired individuals are at a disadvantage even before the effects of an inadequate communication system or high ambient noise levels are introduced. The problem is exacerbated when an employee with hearing loss must wear hearing protection in the work environment.

Many industrial employees dislike wearing hearing protectors based on their complaints that the protectors interfere with necessary speech communication. However, hearing protectors attenuate both the speech and background noise by equal amounts, and therefore should not adversely affect speech reception ability for normal-hearing listeners. In fact, wearing hearing protection in high noise areas (above 85 dBA) actually improves speech recognition by lowering the overall sound level reaching a listener's ear, which reduces the potential for auditory distortion.

There are situations, however, where a particular hearing protector may attenuate high frequencies substantially more than the low frequencies. In these cases the residual low frequency sounds will mask or obscure the high frequency components, and cause the important consonant sounds to be unintelligible. Similarly, when hearing impaired employees wear hearing protection, the higher frequency sounds may be attenuated to a point below the level of audibility. Therefore, too much attenuation (i.e., inadequate hearing protector selection) may be the cause of communication problems for normal-hearing as well as hearing impaired employees.

These considerations provide support for reducing background noise levels through the implementation of engineering controls. Until such controls are in place, hearing protectors should be selected that provide adequate but not excessive attenuation. Octave-band noise data from the workplace should be used to select the appropriate hearing protector for use in a particular noise environment. The degree of protection provided may be determined by using the National Institute for Occupational Safety and Health (NIOSH) Method 1 or "Long Method." This technique uses the measured spectral information, and is the most accurate procedure to estimate the hearing protection provided by a particular device as used in a specific noise environment. Over-protection, or similarly, wearing hearing protection in areas with sound levels below 80 dBA will interfere with speech communication and notification message intelligibility.

As indicated in a previous section, the alarm signal or speech message should be 15 to 25 dB above an individual's masked threshold. In areas with high background noise levels, this will necessitate sounding of the alarm at very high intensities. However, in these cases hearing protection will already be required, so that the overall sound level reaching the employee's ear should not pose a hearing hazard. Hearing protectors should continue to be worn during a broadcast of the warning signal and notification message. When the sound level of the ambient noise is greater than 110 dBA, a secondary alerting device (e.g., visual signal) should also be used.

Requirements of ANSI S3.41

The National Fire Alarm Code (NFPA 72) discusses the requirement for a fire alarm signal to be distinctive in sound from other signals and indicate that this sound not be used for any other purpose. Effective July 1, 1996, this required the use of the signal pattern described in ANSI S3.41-1990 "Audible Emergency Evacuation Signal." However, this signal pattern is to be used only to notify personnel of the need to immediately evacuate the building. In many plants total evacuation is not always desirable or necessary during an emergency. The National Fire Alarm Code states that the ANSI S3.41 Audible Evacuation Signal "...shall not be used where, with the approval of the authority having jurisdiction, the planned action during a fire emergency is not evacuation, but relocation of the occupants from the affected area to a safe area within the building, or their protection in place."

Outdoor Areas - Notification of Vehicle Occupants

The acoustical environment of the interior of a car or truck is highly variable, depending on the type of vehicle, whether the windows are open or closed, the condition of the vehicle, weather conditions, etc. Most of these variables cannot be evaluated to the extent necessary to realistically expect that an alarm signal will be heard in all types of vehicles and in all situations. Therefore, visual signaling devices should be used to alert all vehicle occupants that the alarm has sounded. Instructions should be given to all drivers to immediately stop the vehicle and roll down the window (or exit the vehicle) to listen for the subsequent voice notification message.

System Testing, Maintenance, and Backup

Requirements contained in NFPA 72, Chapter 7, should be followed for alarm system inspection, testing, and maintenance. These requirements should be supplemented by recommendations supplied by the equipment manufacturer and installer. When plant operating parameters change or process machinery is added or removed, the background sound levels may change. Therefore, testing and maintenance personnel should be aware that loudspeaker outputs may require adjustment from time to time.

Alarm system operation should be protected by an independent secondary or standby power supply. Additionally, a backup alarm system is necessary when the primary alarm system is temporarily out of service. This backup system must be capable of providing alarm service equivalent to the primary system, although it does not need to be an exact duplicate in terms of mechanical and electronic equipment. If a portion of the alarm system (e.g., one floor in a building) is undergoing maintenance or has an equipment failure, the backup system may involve the use of personal radios, telephones, or employee runners to adequately notify and inform all personnel of the emergency situation.