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THE SELECTION AND SPECIFICATION OF AUDIBLE ALARM SIGNALS

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INTRODUCTION

In complex petrochemical, industrial and power plants, audible alarms are used to provide warnings for fire, gas, evacuation and security, in addition to the indication of process or equipment malfunction.

Each alarm signal is effective only if it draws the attention of a person involved in some other task, and is correctly recognised as having a specific meaning.

This paper presents objective criteria for the selection and specification of audible alarm signals to ensure their effectiveness. The criteria have been successfully applied to the design of major plant alarm systems.

SIGNAL LEVELS

Level criteria

The major factors in the selection of type, number and location of alarm sounders are the signal level criteria, which are :

(1) the MINIMUM SIGNAL-TO-NOISE ratio, to ensure perception and recognition;
(2) the MAXIMUM SIGNAL-TO-NOISE ratio, to prevent startle;
(3) the MINIMUM absolute SIGNAL level, to ensure audibility;
(4) the MAXIMUM absolute SIGNAL level, to prevent temporary or permanent hearing impairment.

Signal-to-noise ratio

The concept of signal-to-noise (S/N) ratio is fundamental to alarm system design. In the presence of background noise, recognition of an alarm is determined by the ratio of alarm signal level to background noise level. If the S/N ratio is inadequate, the signal will be totally or partially obscured (masked) by the noise.

The S/N level at which the alarm is just audible is the masked threshold level. The masked threshold, or audibility level, is not the same as the effective recognition level. Reliable recognition of an alarm requires a considerably higher S/N ratio than mere audibility.

Wilkins (1) has shown the 1/3 octave band (OB) masked threshold S/N to be approximately -3dB for noise levels <85dB(A), 0dB for noise levels between 85dB(A) and 100dB(A) and +5dB for noise levels >100dB(A). To ensure 100% probability of recognition, Wilkins has reported that the S/N should be +12dB relative to the masked threshold. For noise levels between 85dB(A) and 100dB(A), this corresponds directly to a 1/3 OB S/N of +12dB. Wilkins suggests that, to ensure attention demand, there is some evidence to support the requirement for a signal level +15dB above the masked threshold. This requirement has been proposed for offshore installations by the Norwegian Petroleum Directorate (2).

A S/N of +15dB is easy to achieve in low noise environments. In noisy plants, however, the number and output power of alarm sounders required to produce +15dB over a large area can be prohibitive. For these situations, a basic 1/3 OB S/N of +10dB has been successfully applied (from Wilkins, this corresponds to a probability of recognition of approximately 98%).

Most design data are available not in 1/3 OB's, but in OB's, or overall dB(A). It is therefore necessary to derive minimum S/N criteria for (i) OB's and (ii) dB(A).

Consider the typical distribution of plant noise within one OB. The overall level of 89dB is produced by a summation of the 1/3 OB levels, e.g. 86dB, 84dB and 82dB. With a S/N criteria of 10dB, the required overall signal levels for the three 1/3 octaves would be 96, 94 and 92dB respectively. To apply an OB S/N of 10dB (i.e. a signal level of 99dB) would result in over-design in many cases.

A minimum S/N ratio of 8dB in at least one OB (a signal level of 97dB in this instance) is therefore recommended. This S/N will be adequate in the vast majority of cases, but is not applicable where the noise is tonal in content (i.e. where all the noise energy is contained within one of the three 1/3 OB's). Conversely, if it is reliably known that the noise spectrum is flat, i.e. that the three 1/3 OB's are equal in level, the OB S/N may be reduced to 5dB.

Following the above philosophy, the minimum overall dB(A) S/N ratio recommended is 5dB(A). This is in agreement with British Standard BS5839 (3), and appears to be gradually gaining general acceptance. dB(A) calculations should only be applied where OB data are not available, however, since dB(A) noise levels include contributions at frequencies not affecting the signal masking.

S/N ratios in excess of 25dB(A) should be avoided, to reduce the risk of personnel startle reactions, and to avoid unnecessary interference with aural communication.

Minimum signal level

Notwithstanding the S/N requirements, a minimum absolute signal level of 70dB(A) is recommended for quiet environments. Where persons are sleeping this level should be increased to 75dB(A), as stated in BS5839.

Maximum signal level

To reduce the risk of permanent or temporary impairment of hearing, it is recommended that the maximum alarm signal exposure level should not exceed 125dB(A), with a preferred limit of 120dB(A). Alarm sounders with higher output levels may be used, provided that personnel access is restricted adjacent to the units.

SIGNAL FREQUENCIES

General requirements

The general recommended frequency range for audible alarms is 500Hz - 2kHz, the hearing mechanism being sensitive to sounds within this frequency band. The installation of alarms with fundamental frequencies above 2kHz is disadvantageous in public areas, or where the work-force may include persons with noise-induced hearing loss, due to the common loss in hearing sensitivity at high frequencies.

The sound insulation of building elements generally increases with frequency, as does the sound absorptive performance of internal finishes. To minimise the number of sounders within buildings the frequency should not exceed 1kHz, as recommended in BS5339. Similar considerations apply to external barriers and vehicle cabs.

In high noise level areas the masking spectra of the various noise sources must be considered, and the overall most appropriate alarm frequency selected. Also of interest are the type(s) and frequency(ies) of other warning devices on the site. An alarm will generally more effectively mask a second alarm if the second alarm has a higher frequency. This implies that over-riding alarms in multi-stage alarm systems should have lower fundamental frequencies than earlier-sounding local alarms.

External alarm systems

A further consideration in the design of alarm systems for large outdoor areas (e.g. process plant sites) is the frequency-dependent excess attenuation of sound with distance. Signal frequencies in the 2kHz OB and above should be avoided because of excessive air absorption losses. A standard prediction technique should be used to account for ground and meteorological effects, particularly in the 250Hz and 500Hz octave bands.

System design implications

The directivity of many sounders is frequency-dependent, with implications for system complexity and cost. As an example, typical horn loudspeakers have an output at 90^{o} off-axis which is -22dB re the on-axis level at a frequency of 2kHz; this difference is reduced to -11dB at 1kHz.

TEMPORAL CHARACTERISTICS

The temporal characteristic of the signal, e.g. wail, whoop or interrupted tone, should be considered. The signal selection is related to :

(1) the maximum number of distinguishable signals;
(2) the specific meaning of each signal, and individuals' learnt responses;
(3) the possibility of confusion between similar signals, particularly where the S/N is inadequate;
(4) the effective translation of audible signals into written descriptions.

In many cases the selection will be governed by national or industrial standards.

Work by Patterson and Milroy (4) has indicated that 5 different warning sounds can be reliably learnt, whilst warnings with similar rhythyms are often confused.

Signals with a distinct temporal pattern are generally recognised more readily than simple continuous or interrupted notes, which may be confused with tones produced by equipment.

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