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Noise and the Householder

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II. SOCIAL EFFECTS OF NOISE

Noise and the householder

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Introduction

To the householder, noise is important mainly in respect of its capacity to annoy. Rarely in residential noise problems arising from industry are we concerned with levels which are sufficiently high to interfere with communication or to cause deafness. It is this fact that makes assessment of the intrusive value of industrial noise extremely difficult. One can make objective measurements of hearing loss, or of interference with communication, but one cannot describe, in objective terms, the emotional reactions to noise of people enjoying the privacy of their homes. The problem, therefore, is to decide how we can express the intrusive propensities of a noise in terms of its physically describable characteristics.

It might be argued that previous experience is the real guide—that is, a survey of noises which people have found to be acceptable in the past, which can be used to predict reaction in new cases. This is, in fact, the basis of criteria of acceptability as assessed by such methods as those currently proposed by the Wilson Committee on the Problem of Noise (1963), and the International Standards Organization; and, indeed, one finds that for noise from traffic, aircraft, and (apart from some extreme examples) noise from air-conditioning plant, such criteria provide a reliable indication of what is acceptable.

The method has weaknesses, however, when applied to problems involving complaints of annoyance from the noise of industrial plant. The reason for this is that factory noise usually has a very complex frequency spectrum. This is particularly true for large plants where a large number of quite different sources are contributing.

It is true that if comparison is made on a wide-band basis, in terms of dB(A) or an octave-band spectrum, some correlation can be found between individual plant noises from a specific range of industries, but the detailed narrow-band spectra are liable to exhibit almost any permutation of recognizable characteristics (discrete frequency components, amplitude modulation of narrow frequency bands, and the like) that can be envisaged. Moreover, it is just these characteristics that give rise to the subjective descriptions and complaints of 'whine', 'rumble', 'hiss', etc.

One of the main difficulties in making appropriate allowances to the wide-band criteria to allow for such reactions is that the very features of the noise which are subjectively noticeable contribute little or nothing to either the over-all noise level or even any octave-band level. Ideally, one would determine the frequency spectrum of each noise in terms of its power spectral density to ensure an accurate assessment of its subjective value. Such a procedure, however, would be tedious to measure in an existing case of complaint, and

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probably impossible to predict for a case involving industrial planning. There is clearly a need for wide-band assessment, but before we can examine how the wide-band criteria can be used to assess more accurately the significance of spectral detail, we have to determine which characteristics are important.

This paper describes some of the characteristics of industrial noise which have been found to be the cause of specific complaints. The three examined are pure tones, narrow-band energy concentrations, and amplitude modulations.

The significance of pure tones

It does not seem unreasonable to assume, at this stage, that a guide to the acceptability of noise which contains pure tones superimposed on a broad spectrum is the perceptibility of the tones. This is tantamount to saying that a person who is subjected to the noise in his home is more prone to complaining about it if he can recognize and describe the noise which is annoying him by some subjective term such as 'whine' or 'hum'. The problem of ascribing a limiting level to the pure tones is thus one of determining the level at which they will cease to be masked by the broad-band spectrum.

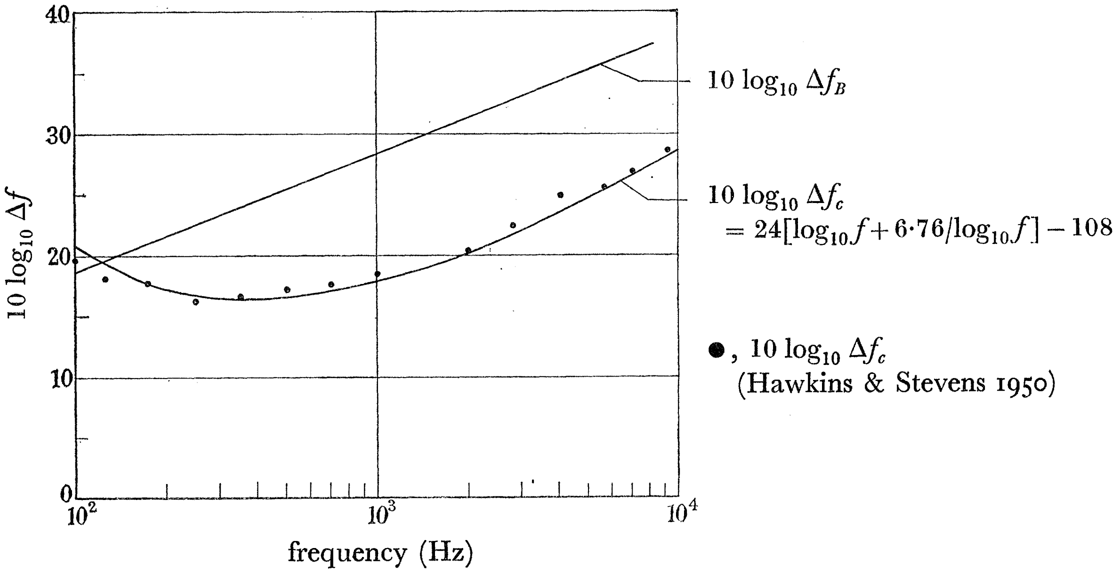

Figure 1. Relative contributions of octave and critical bandwidths to octave-band level.

An indication of this can be obtained from the work of Hawkins & Stevens (1950), who examined the threshold of pure tones with varying levels of masking white noise. A fundamental assumption in this work is that the energy in a pure tone, which is just masked, is equal to the total energy of the masking noise contained in a 'critical band' of frequencies around the frequency of the tone. This critical bandwidth appears to be independent of the amplitude of the masking signal and its experimental values as a function of absolute frequency are shown in figure 1. Also shown in this figure is the variation with frequency of $10 \log_{10} \Delta f_B$, where Δf_B is the bandwidth of the octave centred on any frequency f.

A comparison of the two curves shows that if we assume that the broad spectrum of the intruding noise is smoothly distributed in any octave band, since

$$\text{octave-band level} = \text{mean spectrum level in octave band} + 10\log_{10}\Delta f_B \tag{1}$$

where Δf_B is the octave bandwidth, the contribution of any discrete frequency tone above about 250 Hz which is just masked, to the over-all octave-band level, can be neglected.

The significance of this observation can be judged by considering the case where a measured octave-band level exceeds the appropriate n.r. octave-band level (Kosten & van Os 1962) corrected for the presence of a discrete frequency component. Figure 1 indicates that above about 400 Hz the tone could be up to about 7 dB above perceptibility before it makes any measurable difference to the octave band, and up to 10 dB above before its contribution increases the octave-band level by more than 2 dB. This means that to obtain any reduction in the octave-band level we must control the source of the broad-band spectrum. But if we reduce the broad-band noise we reduce its masking level, thereby making the pure tone more noticeable and, by inference, the overall noise becomes no less objectionable and possibly more objectionable. We now have a measured octave-band level which meets the criterion, but because of the increased perceptibility of the pure tone, the noise is still unacceptable.

We could match the indication of the criteria with the actual acceptability of the noise by applying, instead of the present correction of 5 to the n.r. curve (Kosten & van Os 1962), a correction which would bring the n.r. octave level down below the measured level after the broad-band noise had been reduced. This would then require a scale of corrections for each octave band which would be determined by the degree of perceptibility of the pure tones after the broad-band noise had been reduced to an acceptable level. a rather more simple approach would be to use the n.r. curves, as they would be used at present in the absence of any perceptible pure tones, to determine the acceptable levels of the broad-band spectrum. For a given n.r. curve, all that is required then is the maximum permissible level of any pure tone in the spectrum. This is readily determined from Hawkins & Stevens (1950), for example, by interpreting 'maximum permissible' as the auditory threshold of the pure tone when masked by the broad-band spectra.

On the critical bandwidth theory, the level of the pure tone is now given by

$$L_p = L_s + 10\log_{10}\Delta f_c \tag{2}$$

where L_s is the broad-band spectrum level in the vicinity of the pure tone, and Δf_c is the critical bandwidth.

An empirical representation of the experimental values of critical bandwidth shown in figure 1, is the lower solid curve in that figure, given by

$$10\log_{10}\Delta f_c = 24(\log_{10}f + 6{\cdot}76/\log_{10}f) - 108, \tag{3}$$

where f is the absolute frequency.

The spectrum level L_s will, if the noise is to be acceptable, have to be reduced to the relevant n.r. spectrum level, which, for the most frequent range of interest (say n.r. 20 to 50), can be expressed by

$$L_s = \tfrac{4}{3}\text{n.r.} + (209 - \text{n.r.})/\log_{10}f - 98, \tag{4}$$

where n.r. is the designated value of the n.r. curve.

If, for example, the measured broad-band noise is equal in spectral shape to the appropriate n.r. curve overall the frequency range, we can use equation (4) directly in (2), and with (3), obtain an envelope of maximum permissible (just masked) amplitudes of pure tones, i.e.

$$L_p = (\tfrac{4}{3}\,\text{n.r.} - 206) + (371 - \text{n.r.})/\log_{10} f + 24 \log_{10} f. \tag{5}$$

Four envelopes are shown in figure 2 which are appropriate to n.r. numbers from 20 to 50.

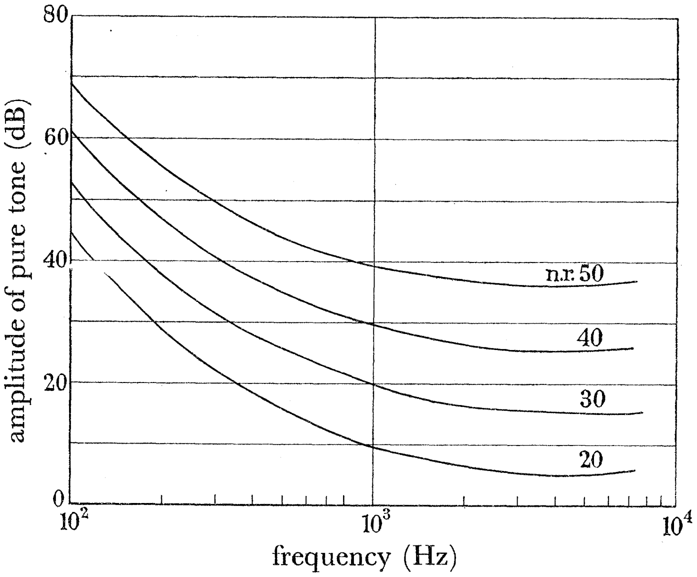

FIGURE 2. Suggested maximum permissible levels for pure tones when the broad band spectrum is equal to the n.r. curves indicated.

Thus the procedure for determining the community acceptability of a noise containing audible pure tones would be to determine the mean spectrum level of the noise from measurements of octave band levels, as in equation (1). This has been found from narrow-band analysis of industrial noise in residential areas to be an acceptable approximation, since with few exceptions, and certainly in the 500 Hz octave band and above, even tones which are quite audible, contribute very little to their respective octave-band levels. In fact, the error from estimating broad-band spectrum level from measured octave level has rarely been found to exceed 4 dB. Also to be determined are the amplitudes of the pure tones. These can be obtained either by recording on site and replaying through a suitable narrow-band wave analyser, or by measuring directly on site with a portable analyser. Comparison of the octave-band levels with the n.r. curve in the usual way, and of the pure tone amplitudes with the envelopes in figure 2, will then indicate the acceptability of the noise, and, equally important, which components of the spectrum require control.

If the broad-band spectrum level is already low (i.e. if the octave-band level is less than the appropriate n.r. level), and the octave still contains an audible pure tone, the tone could well be perceptible even if it is within the envelope of figure 2. In that case, however, the curves of figure 2 would not apply, and to determine the masking threshold of the pure tone for use in equation (2), one would have to use the actual spectrum level, L_s, together with equation (3).

Examples of the use of this approach in assessing community reaction are given by Richards & Sharland (1967).

Energy concentration in narrow frequency bands

The foregoing discussion of a possible approach to assessing the significance of pure tones indicates that we might employ the same methods for other recognizable spectrum characteristics. One which has been found to give rise to such subjective descriptions as 'rushing noise' or 'hiss', has been a hump in the spectrum due to the concentration of energy in a relatively narrow frequency band. Such humps cannot be described as 'broad-band' noise in the same sense as the continuous spectrum, but are certainly not pure tones.

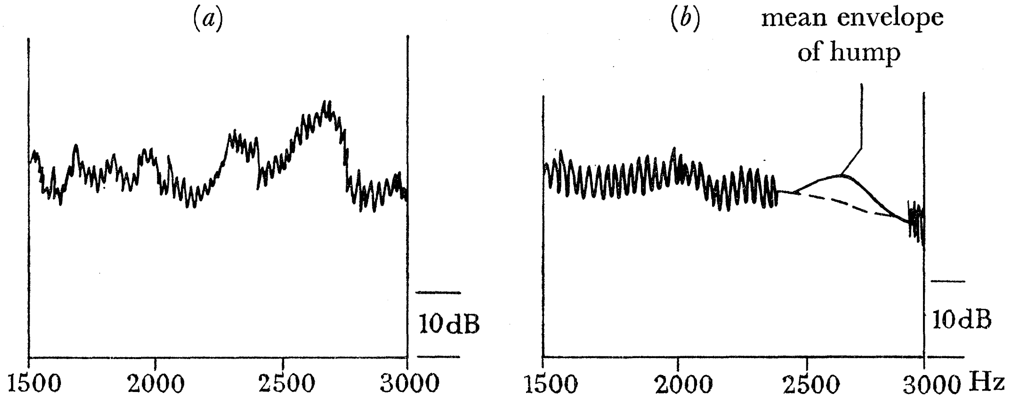

Figure 3. Effect of a narrow-band source on community noise spectrum: (*a*) Near source; (*b*) near houses at plant boundary.

An example is shown in figure 3, and this particular characteristic was audible in the spectrum, even well away from the source, when its spectral distribution was in the form shown in the right-hand diagram. Considering energy relations, the energy contained in the frequency band subtended by the hump is about 3 dB higher than that contained in the same band if the hump were not present, i.e. in the area under the smooth dotted line in the right-hand diagram.

The inference is that a source which has its energy in a relatively narrow frequency band, and which produces a level equal to the background level in that band, will be discernible, and hence is likely to be pin-pointed as a cause of objection. Unfortunately, there seems no way at present of stating maximum permissible levels for this type of spectrum feature to ensure it is masked. Besides the characteristic frequency and peak amplitude that we had to specify for a pure tone, we would have to add effective bandwidth and possibly profile as variables. It is to be hoped that studies will be made of the perceptibility of such features in the future. In the meantime, we have to accept that they can be detected only by relatively narrow-band analysis, and to ensure that they are not responsible for any subjective identification of the spectrum, we have to aim at their complete removal.

Amplitude modulation of narrow bands of frequencies

In assessing the subjective value of industrial noise it is generally the practice, unless the noise is significantly impulsive or intermittent, to consider only its amplitude-frequency relationship. It is valid to do this providing that at any particular frequency the amplitude remains reasonably steady. It is often a noticeably audible feature of certain plant noise, however, that some portion of the frequency spectrum has a time-varying amplitude—a phenomenon which can be caused either by the nature of the source generating mechanism, or, where large distances are involved, by atmospheric effects on propagation.

An example of modulation arising from the inherently unsteady nature of the source mechanism is combustion noise. A characteristic of noise spectra from many process furnaces or steam-raising plants, particularly those with rotary cup-type burners, is a strong pure tone occurring in the region of 50 to 150 Hz, the actual frequency depending on the rotational frequency of the burner, and on the size of the boiler. It is also to be observed that there are marked variations in the sensation of low-frequency sound from such plant, and this gives the subjective impression of 'rumble'. In fact, most complaints involving boiler noise include precisely this description.

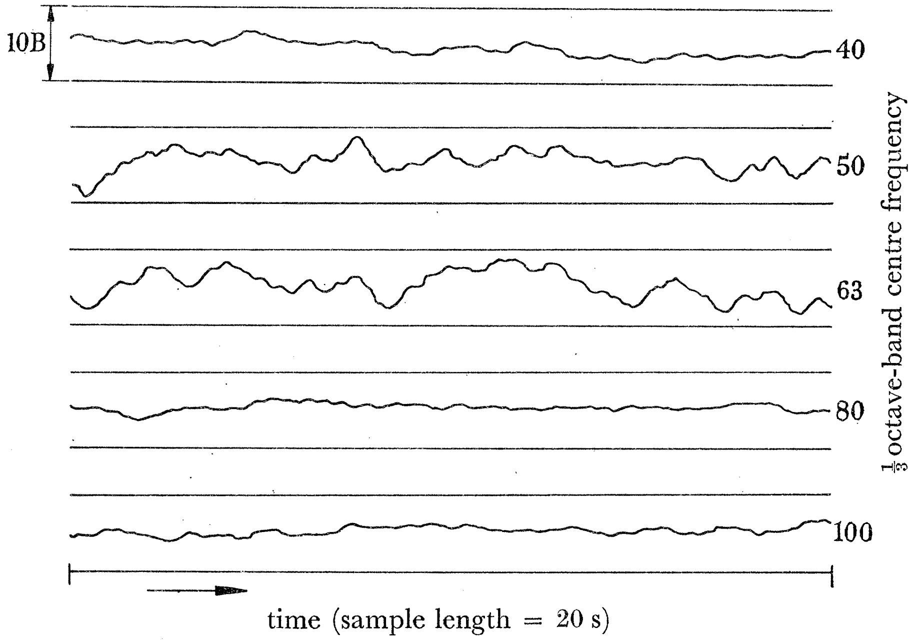

FIGURE 4. One-third octave band amplitude variation of a boiler noise.

The frequency spectral characteristic involved can easily be demonstrated by observing the time-varying amplitude of the noise passed through filters. An example of such an analysis is given in figure 4 which was obtained from the noise of a steam-raising boiler, as recorded outside residential property. Narrow-band analysis showed a strong pure tone component between 50 and 60 Hz, and when the noise was replayed through one-third octave band filters, the curves of figure 4 were obtained. It can be seen that in the bands not affected by the pure-tone component the level is fairly steady within about 3 dB, while in the bands centred at 50 and 63 Hz there are quite large amplitude variations of about 7 to 8 dB. The modulation appears to be random, although smaller amplitude variation (2 to 3 dB) can be detected at a frequency of the order of about 1 to 2 Hz.

In this particular case the octave-band level containing the boiler noise exceeded the appropriate n.r. criterion. We would clearly recommend reducing the contribution from the boiler by, for example, improving the insulation of the boiler house. This treatment would not, however, be expected to alter the modulation at a particular frequency. We would then be left with a contribution from the boiler which met the criterion, but, because the modulation of certain frequencies is still present, the noise could still be perceived and identified by the complainant with the original source of annoyance. It has in fact been observed that boiler 'rumble' can be detected aurally, and has caused complaint when the mean octave level is below the relevant n.r. level.

This indicates that where amplitude modulations are clearly audible, we have to aim for wide-band levels which are somewhat less than those indicated by the criterion limited for an audible pure tone. Again one is unable, at this stage, to be precise on the exact allowance that should be made, but experience suggests that in terms of n.r. numbers, the existing allowance of 5 for pure tones should be increased by a further 5 at least if modulation is clearly audible. To be quite sure, one would aim at reducing the pure tone energy until its maximum amplitude is masked by the ambient background. This can be estimated by methods referred to in the discussion on pure tones.

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