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ANNOYANCE FROM LOW FREQUENCY AND INFRASONIC NOISE

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INTRODUCTION

The A-weighted sound level is by far the most widely used objective measure of noise. For the majority of noise sources, there is a fair correlation between A-weighted sound level and annoyance. Only minor corrections of the A-weighted levels are needed, if, for instance, the noise contains pure tones or is impulsive.

If the noise contains considerable energy in the low audio frequency region 20-125 Hz, the correlation breaks down. Countless case stories have told about nuisances from power plants, compressors and ventilating systems at places where the A-weighted levels were low and all restrictions were observed.

Problems also exist at infrasonic frequencies. Several investigations have shown that infrasound may affect people. The first articles that discussed this appeared in the mid sixties and they suggested physiological effects and effects on task performance from even very low levels of infrasound. Later on, these effects have proven to be exaggerated and it is now believed that the nuisances from infrasound derive from the fact that humans can hear infrasound when the sound pressure level is sufficiently high.

The following describes results from loudness and annoyance experiments at low and infrasonic frequencies. The possibility of deriving new weighting curves for these frequencies is discussed. Emphasis is made on the special infrasonic weighting curves G1 and G2 [1].

LOUDNESS EXPERIMENTS

Curves of equal loudness were determined for pure tones in the frequency range 2-63 Hz using the method of maximum likelihood [2]. The results are given in Figure 1 together with a threshold curve based on recent data given in the literature.

From the threshold curve it is seen that the lower the frequency, the greater the sound pressure level must be in order to make the tone audible. It is worth noting that the curves go down to at least 2 Hz. The widely accepted limit of audibility around 20 Hz does not exist, although the tonal character of the sound disappears below this frequency.

It is also seen that the curves are much closer in the infrasonic region than at audio frequencies. For example, the distance between the 20 and the 80 phon curves has decreased from 60 dB at 1 kHz to approximately 16 dB at 8 Hz. Consequently, infrasound only a few dB above the hearing threshold will seem loud and possibly annoying. It is also possible to explain the fact that a small change in the infrasound content of a complex sound is able to change the loudness considerably.

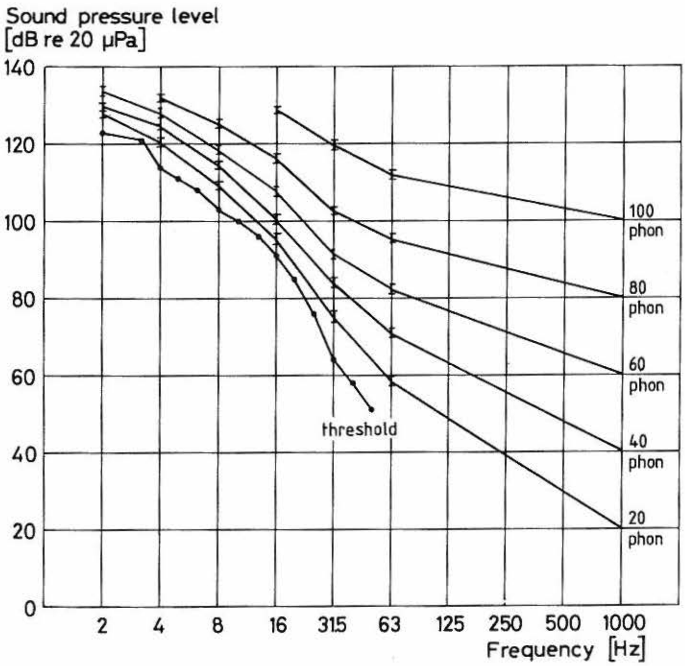

Figure 1. Curves of equal loudness. Vertical bars indicate ±1 standard error of mean. The threshold curve is based on four recent studies.

ANNOYANCE EXPERIMENTS

The loudness curves were determined through direct comparisons between two short tones. A similar procedure is not possible when determining curves of equal annoyance, as it is believed that the duration of the stimuli must be much longer in order to obtain a proper assessment of the annoyance. Therefore, an indirect method was used. After being exposed to a stimulus for 15 minutes, subjects rated the annoyance on a 150 mm scale, of which the ends were labelled "not at all annoying" and "very annoying". From these ratings, curves of equal annoyance were determined [3] (not shown).

The equal annoyance curves are very similar to the equal loudness curves, and the results seem to indicate that the annoyance from infrasound is closely related to the loudness of the sound. As the loudness curves are determined with the best accuracy, they will be referred to in the following.

WEIGHTING CURVES FOR LOW AUDIO FREQUENCIES

Our annoyance experiments included exposures to 1 kHz noise bands and to pure tones and noise bands at 31.5 Hz. These frequencies are in the range supposed to be covered by the A curve. Figure 2 shows annoyance rating versus A-weighted sound level for these frequencies. It is clearly seen that the annoyance from 31.5 Hz (unfilled circles) does not follow the same line as the annoyance from 1 kHz (filled circles). The annoyance from 31.5 Hz rises much steeper than that from 1 kHz. The two regression lines intersect at approximately 45 dB.

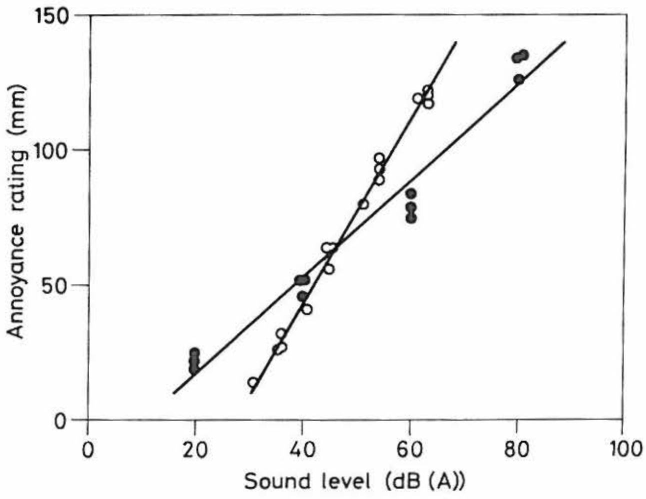

Figure 2. Annoyance rating versus A-weighted sound level. Filled circles represent mean values for 1 kHz exposures. Unfilled circles represent mean values at 31.5 Hz. The lines are regression lines (r^2=0.97 for the filled circles, 0.99 for the unfilled).

The origin of the A curve explains this. The A curve is approximately the reciprocal of the 40 phon curve. Assuming a close relationship between loudness and annoyance, then A-weighted levels will reflect the annoyance of noise with levels around 40 phon. For low frequencies at levels well below 40 phon the annoyance is expected to be lower than that predicted by the A-weighted level. At levels much above 40 phon, the annoyance is expected to be higher than that predicted by the A-weighted level. This is exactly what is seen in Figure 2.

Originally, the intention was that the A curve should be used only at levels around 40 phon, while the B and C curves should be used at higher levels. This procedure is almost never used in real life and that is most probably the reason why it has been so difficult to obtain a good correlation between objective measures and subjective ratings for noises containing considerable low frequency energy.

WEIGHTING CURVES FOR INFRASONIC FREQUENCIES

The A curve is not intended to cover the infrasonic frequency range and frequencies below 20 Hz are only transferred through the A filter due to the finite slope of the filter low frequency cut-off. When the sound level of infrasound is measured with a commercial A-weighting sound level meter, the obtained values will be low - and they will depend on the particular sound level meter since the tolerances of the A curve are large at these frequencies. Consequently, it has no meaning to refer to the A-weighted level of noise having a significant content of infrasound.

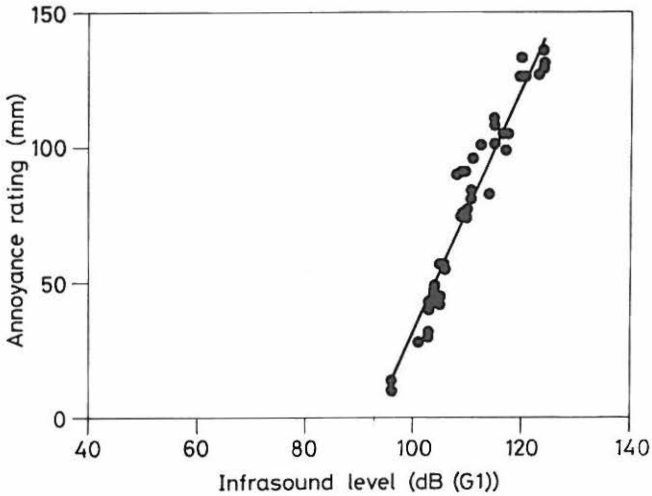

Figure 3. Annoyance rating versus G1-weighted infrasound level. Filled circles represent mean values for all infrasonic exposures in our experiments. The line is a regression line (r^2=0.93).

It is seen from Figure 1 that the loudness curves are almost parallel in the infrasonic region. Therefore, it may be possible to develope a weighting curve suitable for measuring loudness and annoyance of infrasound. The mean slope of the curves are approximately 12 dB per octave. A weighting curve with this slope and restricted to the frequency range 1-20 Hz is proposed by ISO and named the G1 curve. A weighting curve for the same frequency range but with a slope of 6 dB per octave is named the G2 curve [1]. Having the slope of the equal loudness curves in mind, one would expect the G1 curve to give a fair indication of the loudness and annoyance associated with infrasound.

In Figure 3 mean annoyance rating is shown versus G1-weighted infrasound level for all infrasonic exposures from our experiments. The figure shows a very close linear relationship (coefficient of correlation r^2=0.93).

Figure 4 shows the same results versus the G2-weighted infrasound level. Here r^2=0.77 and it is clearly illustrated that the G2 curve provides a measure of the annoyance that is much inferior to that of the G1 curve.

Figure 3 showed a good correlation between G1-weighted infrasound levels and annoyance rating. Thus, if a "one-figure" measurement is wanted for infrasound, the G1 curve might be a good choice. However, this curve provides a frequency weighting only and G1-weighted levels do not reflect the fact that the annoyance increases steeply above the threshold. Thus, the conversion shown in Figure 5 may be useful. For a given G1-weighted infrasound level it can be read which A-weighted level that causes the same rating of annoyance.

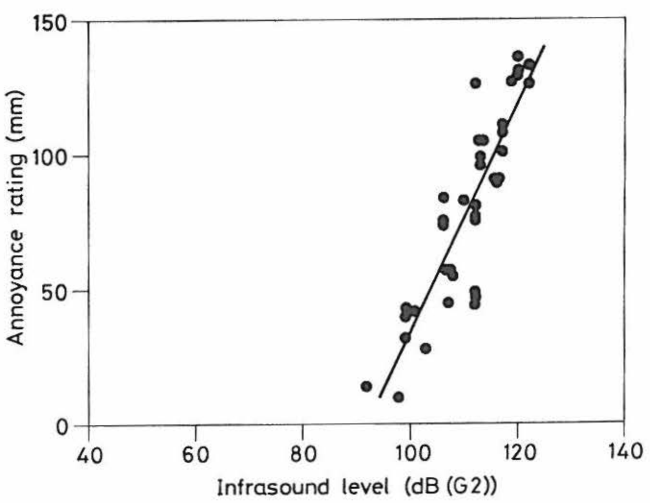

Figure 4. Annoyance rating versus G2-weighted infrasound level. Filled circles represent mean values for all infrasonic exposures in our experiments. The line is a regression line (r^2=0.77).

CONCLUSION

The proposed ISO G1 weighting curve provides an objective measure that correlates very well with subjective annoyance ratings for infrasonic frequencies. Values obtained with the proposed G2 weighting curve do not correlate as well.

Because of the low dynamic range of the ear at infrasonic frequencies, care should be taking when evaluating G1-weighted levels. The numerical values should not be directly compared to A-weighted levels.

Low audio frequencies are not covered by the proposed G-weighting curves and they are insufficiently covered by the A curve. A possible solution may be the originally intended level dependent use of the A, B and C curves. Further research is needed in this area.

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3. Jente Andresen and Henrik Møller: Equal annoyance contours for infrasonic frequencies. Journal of Low Frequency Noise and Vibration, vol. 3, no. 3, 1-9, 1984.

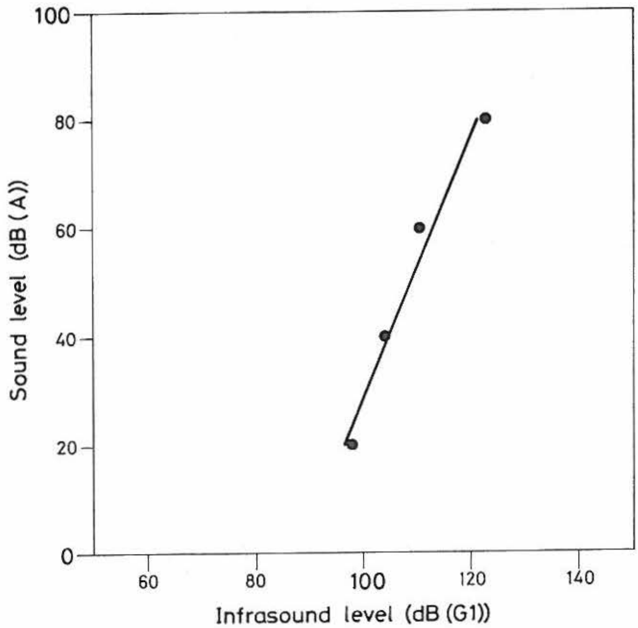

Figure 5. Conversion of G1-weighted infrasound level to the A-weighted level of an audio frequency noise that causes the same rating of annoyance.