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IMPULSE NOISE – A BRIEF REVIEW

by

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IMPULSE NOISE – A BRIEF REVIEW

ABSTRACT

This paper contains a brief review of the results of recent research into impulse noise and its effects. It sets out the important parameters and the various methods of measurement to enable anyone familiar with the measurement of steady state noise also to measure impulse noise.

The physical parameters necessary to describe an impulse noise are considered and their importance discussed. Methods and problems of the assessment of subjective loudness are considered including the use of the impulse sound level meter. The risk of hearing damage due to high levels of impulse noise is discussed and the conclusion reached that equivalent continuous noise level is a good measure of damage risk. Methods for calculating it are detailed. Equipment needed to measure impulse noise is also considered, including oscilloscopes, tape recorders, sound level meters and dosemeters.

1. INTRODUCTION

This review arises from a project to assess the noise from motorway construction sites, in which it was felt that impulse noise might be important. In order to assess the conditions under which noise should be considered impulsive and how it should then be analyzed a brief literature survey was conducted, the results of which are given here.

Noise research has been in progress for many years but has been concentrated on steady-state continuous noise so that there is now general agreement upon its nature and physical and subjective effects. Research into impulse noise, however, has been much less extensive and there are still many aspects on which there are varying opinions. It is not the purpose of this review to discuss the merits of these various theories but to draw out those important points on which there is agreement. It may be instructive, however, to consider briefly the following, which illustrates some of the problems of basic audiology research in order to better understand why agreement is hard to reach.

The first modern study of impulse noise was conducted by Bekesy in 1929, who conducted experiments to determine the relationship between stimulus duration and subjective loudness. He used tone bursts of variable duration over a frequency range of 300-2000 Hz which were compared by the subject with a 200 ms duration standard in the opposite ear. He found that at 800 Hz, the subject reported an increase in loudness as the duration of the sound was increased up to 180 ms at which point no further loudness increase occurred. At higher frequencies the maximum was attained at shorter durations. The same effect was found if the stimulus intensity was increased. Since these results were published many similar experiments have been conducted, with poor agreement between them. Differences occur in the rate of growth of loudness, the critical duration, whether it is frequency or intensity dependent etc.

There are a number of factors which contribute to these discrepancies. For instance, all experiments of this type rely on the subjective responses of a large number of individuals, which are then averaged. The variation in response to impulse noise between one subject and another is considerably greater than for continuous noise and averaging the results can disguise any trend which is present. Another problem is that different emphases can be given to the results by the design of the experiment and the wording of instructions to the subject. There is also a danger of misinterpreting results. For instance, there is evidence to show that a subject finds it very difficult to separate the effects of amplitude and duration for short pulses, so that a researcher unaware of this might draw incorrect conclusions from his experiment. An important source of difficulty is in the choice of a control stimulus. Most experiments of this type rely on the subject comparing a test stimulus at one ear with a control stimulus at the other, and the results are seriously affected by the nature of the control, eg its duration and intensity.

The foregoing serves to illustrate the difficulties of research into the subjective effects of impulse noise and provides a perspective for the remainder of this review although it should be mentioned that it is this area of loudness assessment which is the most difficult, other aspects being much more reliably established.

The review continues under four main headings. Firstly, the physical nature of impulse noise will be considered, followed by a discussion of its subjective loudness, its potential for causing damage to hearing and finally methods of measuring it.

2. PHYSICAL NATURE OF IMPULSE NOISE

Impulse noise is characterized by a short duration and a high peak sound pressure compared with the average, being, for example, the result of an impact between two solid bodies or an explosion. The noise may be repetitive as with a pile driver or a drop forge or consist of a single event as in an explosion. The following parameters can be used to give a complete description of an impulse.(1)

1) peak sound pressure level
2) rise time
3) duration
4) frequency spectrum
5) repetition rate

Since the duration of an impulse is short and the peak pressure level usually high, the rise time is very short. The response time of the ear is of the order of several milliseconds, and the impulse will therefore be experienced by a subject as an instantaneous change of sound pressure. Garinther (2) suggests that rise time need only be considered if greater than 0.5 ms.

There are two measures of duration, generally known as A and B-duration (fig 1). 'A'-duration is applicable to an explosive noise in free-field conditions whilst B-duration is appropriate to an explosion in reverberant surroundings and most industrial impacts. B-duration includes reflections, if any.

The effect of frequency spectrum has not been thoroughly investigated but on the evidence available this is not thought to be a very important physical parameter.

3. SUBJECTIVE LOUDNESS OF IMPULSE NOISE

Reference was made in the Introduction to studies on this subject. The problems of determining subjective loudness are considerable and agreement between different researchers is poor. However, the following trends seem to be generally found.(3) For single impulses perceived loudness increases with duration up to some critical duration beyond which no further increase occurs. This critical duration is frequency dependent and probably intensity dependent. The growth of loudness appears to lie in the range 10-17 dB per tenfold increase in duration whilst the critical duration varies depending on experimental technique between 40 and 300 ms.

It is generally assumed that the ear responds to the energy of the incident sound averaged over a certain time (4). This offers an explanation of the critical duration effect, this being equivalent to the averaging time of the ear. The precise value of this averaging time is uncertain.

The impulse sound level meter, subject of a draft IEC recommendation and included in DIN45633-2, is designed to correlate with subjective loudness. It simulates the ear's energy averaging process by integrating the sound over 35 ms. Whether this accurately represents the response of the ear is not certain. The main point that should be noted is that the Impulse Sound Level Meter in 'Impulse' mode does not measure any of the parameters (1-5 in section 2) that are used to describe the form of an Impulse, but is only intended to give a measure of subjective loudness.

4. PHYSICAL EFFECTS OF IMPULSE NOISE

Research has been in progress for some time on the risk of permanent hearing damage due to exposure to impulse noise and although the question is not completely resolved it appears that the principle of 'energy immision' is fairly widely accepted.

Some rough indication of levels of noise likely to be dangerous may be helpful. For short duration steady-state noise, an upper limit of about 135 dBA is acceptable but for impulse noise the limit may be higher, say 140-165 dBA. As an example, a .303 rifle produces about 154-9 dBA at the firer's ear. It should be remembered, however, that there is a large variation in response to impulse noise between individuals, so that these levels may cause hearing damage to a few individuals. Another important point is that impulse noise in reverberant surroundings tends towards a steady-state noise so should have a lower limit.

When a subject is exposed to any loud noise he experiences a change in his hearing threshold from which gradual recovery is made. It has been shown (5) that for steady-state noise this temporary threshold shift (TTS) correlates with the permanent hearing loss which would result from continued exposure to that noise over a period of several years. Research does not indicate the existence of a similar relationship in the case of Impulse Noise. It appears that TTS is dependent more on the noise exposure pattern (6) eg pulse duration, repetition rate etc, than on the total energy received, but that permanent hearing loss depends on the total energy received. In other words TTS does not appear to correlate with permanent hearing loss in the case of impulse noise. A possible reason for this is an effect known as the acoustic reflex. When the ear is exposed to high intensity sound the muscles of the middle ear contract after a short latent period, altering the impedance of the middle ear and thus attenuating the sound transmitted by it. During exposure the muscles adapt and the attenuation decreases. In this way TTS is affected and varies with the pattern of exposure. For example, if pulses are too close together for the adaptation process to be complete before the next pulse occurs, then some attenuation will always be present.

Experiments also show surprising results when steady and impulse noises occur together (1)(7). For instance, if a non-hazardous level of steady-state noise is added to a hazardous level of impulse noise, TTS is actually reduced, although the total energy received is increased. In this context, a hazardous level means one which causes a significant TTS when used on its own. This may again be explained by the effect of the acoustic reflex since the steady-state noise plus the impulse noise is enough to ensure that there is some degree of acoustic reflex attenuation remaining at the start of each new impulse. Further research is necessary before the mechanism of the acoustic reflex is fully understood.

If Atherley and Martin's "energy immission" principle (8) is accepted then the complexities of TTS need not be considered in assessing hearing damage risk for industrial type impulse noise. Instead, the total incident A-weighted sound energy is determined and converted to an Equivalent Continuous Noise Level (ECNL). The methods for doing this are described in section 5. It may be possible to extend the method to include noises such as firearm noise but this still needs verification.

Some work has been done by Hempstock, Else and Powell (9) on the possible use of the Impulse Sound level meter as a means of assessing hearing hazard, by deriving a relationship to convert ISLM readings to ECNL values. The relationship obtained requires a knowledge of decay time to make the conversion. This could be obtained from a tape recording but eliminates the potential advantage of the ISLM of being able to make very simple "in-the-field" assessments. If a tape recorder must be used then it would be easier to analyze the recording directly to find ECNL rather than using the ISLM.

As well as causing actual damage to hearing, impulse noise can result in reduced efficiency of workers, even at much lower intensities than would be considered dangerous, if they are performing a task which requires response to some auditory stimulus. Experiments in which subjects had to make decisions based on a stimulus following closely after a loud impulse showed that their judgement and their response time was significantly and progressively impaired throughout the exposure period, which has implications both for productivity and safety.

5. MEASUREMENT OF IMPULSE NOISE

The technique adopted for the measurement of impulse noise depends on the amount of information required [1]. For the complete specification of the noise by the parameters mentioned in section 2, the only satisfactory method is to use a microphone and a cathode ray oscilliscope with a storage facility. By this means a precise visual display of the impulse wave-form is obtained. The system must have a good high frequency response in order to reproduce the initial very rapid rise of the impulse. The oscilloscope must first be calibrated and a trace of an impulse is then stored. From this, peak pressure, rise time, duration and repetition rate can be found. The frequency spectrum can be obtained by subsequent analysis.

For making measurements in the field it may be more convenient to make a tape recording and to analyze it in the laboratory later. High quality tape recorders are capable of giving accurate results for impulses with rise times of greater than 50 μs, which includes most industrial impact noises but may exclude firearms.

If less information is required then there are other possible methods. Some impulse sound level meters have a 'peak hold' measuring facility and this will give a true peak value for impulses with rise time as short as 20 μs, though as already mentioned, these instruments in the 'impulse' mode do not measure any of the required parameters.

If the objective is to assess risk to hearing then there are situations in which a conventional sound level meter can be used. If the repetition rate is greater than 10 impacts per second then the reading with the meter set on A-weighting and slow response can be used to calculate ECNL. A recent development in noise measuring instruments is the noise dosemeter and although no tests have been published as yet, it seems likely that it will be capable of measuring exposure directly over long periods, enabling ECNL to be very easily obtained.

The following is a description of the method recommended by Martin [10] for assessing ECNL, the equivalent continuous noise level of impulse noise. Three ranges of repetition rate are considered.

1) Greater than 10 impulse/sec
   Use a precision sound level meter set to slow response and A-weighting and average by eye fluctuations of less than 5 dBA. For fluctuations of between 5 and 10 dBA, add 1 dBA to the average. If the exposure continues for 8 hours per day then the meter reading L_A is the ECNL value. If the exposure is less than 8 hours a correction factor can be determined from fig. 2. Where fluctuations of greater than 10 dBA occur the length of time at the high and low levels must be calculated, the ECNL worked out for each period and then the two ECNLs summed.

2) 1-10 impulse/sec
   Use an oscilloscope.
   a) If peak/minimum pressure level is less than or equal to 10 calculate the function $20 \log_{10} P_h/P_m$ shown in figure 3.

      The peak sound pressure P_h is then converted to dB(P) by using the expression $dB(P) = 20 \log_{10} P_h + 94$. Fig 4 is next used to find L_A and the correction for exposure time is applied as before using fig 2.

   b) If the peak/minimum pressure level is greater than 10 dB, the decay time can be determined with reasonable accuracy and method 3 can be used.

3) less than 1 impulse/sec
   Use an oscilloscope.
   In fig 5, t_e is the decay time, ie the time required for the level to fall to $1/_e$ or 0.37 of its maximum value.
   Calculate the number of impulses N_T which would occur in 8 hours.
   Total duration D_T is then found from $D_T = N_T \times t_e$.
   Convert P_h to dB(P) using $dB(P) = 20 \log_{10} P_h + 94$
   Use fig 6 to obtain the correction factor γ. $ECNL = dB(P) + \gamma$

If the noise level varies slowly with time so that a single level L_A cannot be used to describe the whole period, then ECNL should be calculated for each level and then summed. Short term fluctuations of P_h and P_m in N/m^2 of less than 20% should be averaged arithmetically whilst for larger fluctuations separate ECNL's must be found and then summed.

This process is rather tedious so the development of a dosemeter to do the work would be of great benefit.

6. CONCLUSIONS

The decision as to whether or not a noise should be considered as impulsive is very much a matter of judgement depending on the particular circumstances and the point of view from which it is being considered. The simplest guide as to whether a noise is likely to be impulsive without making any measurements is to consider the mechanism by which it is made. If the noise is the result of impacts then it will have a fast rise time and should be treated as impulsive. This should be distinguished from a noise which is fluctuating, even very rapidly, but which rises and falls smoothly. If the repetition rate of an impulsive noise is rapid and the surroundings are reverberant then the noise can be assessed by normal steady-state noise methods.

If the noise is to be assessed with respect to hearing damage risk then ECNL should be determined by the methods described in section 5. As assessment in terms of annoyance is more difficult as there is no established method for determining this. Until some criterion is worked out ECNL may be suitable, at least for comparing noises, or the peak sound pressure and repetition rate could perhaps be specified. Impulses which occur only occasionally and for short periods at levels which are well below hazardous levels may be ignored. However, sudden impact noises occurring against a relatively low noise background may cause appreciable startle if unexpected. So assessments, other than for damage risk, must in the absence of any more definitive criteria, rely very much on the judgement of the researcher.

7. ACKNOWLEDGEMENT

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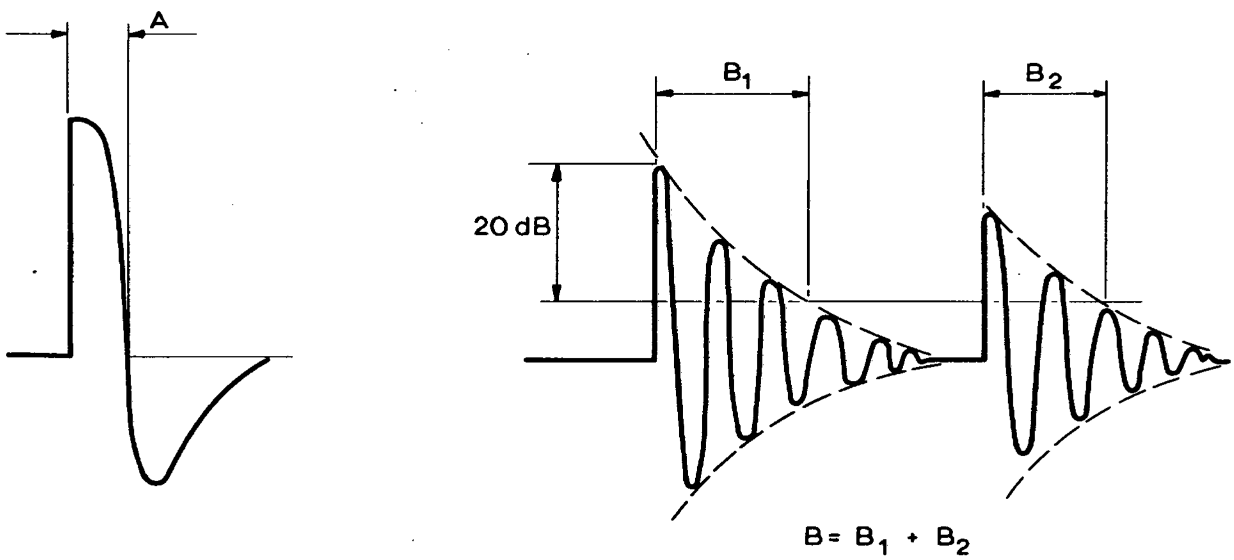

Fig 1. IMPULSE WAVE FORMS : DEFINITIONS OF 'A' AND 'B' DURATION

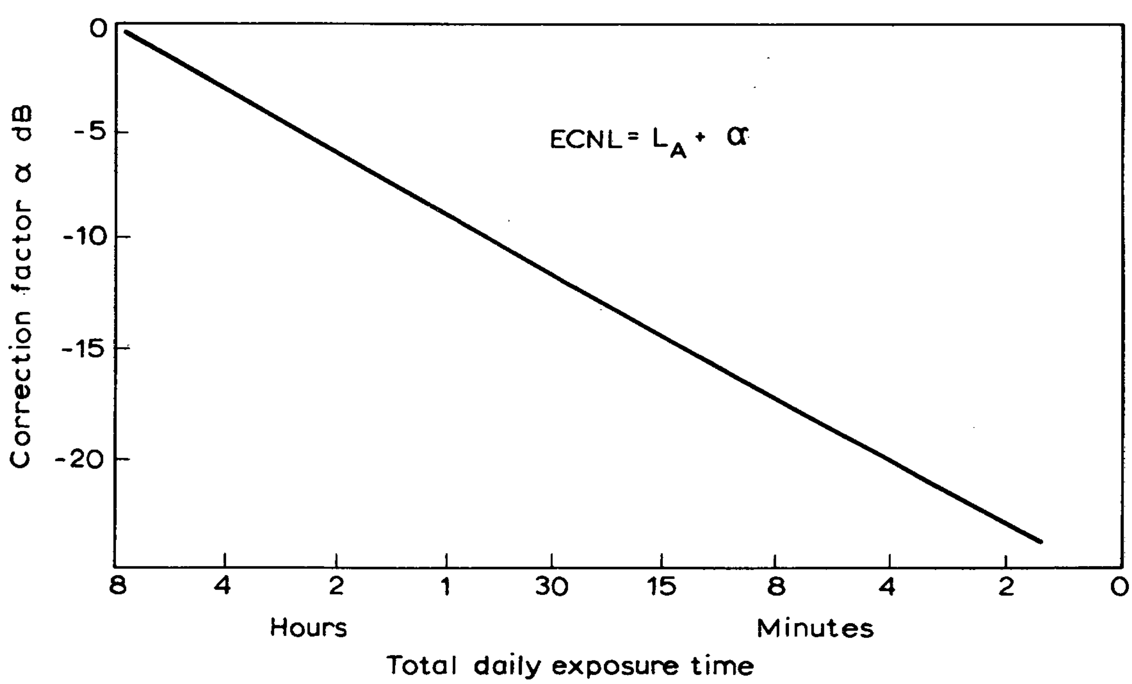

Fig 2. CALCULATION OF CORRECTION FACTOR α

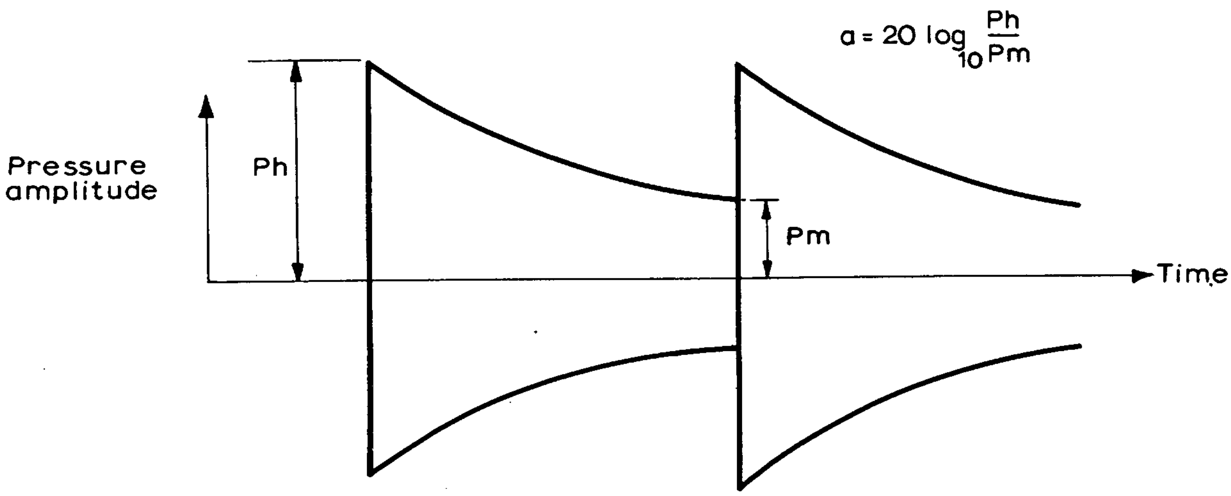

Fig 3. CALCULATION OF a

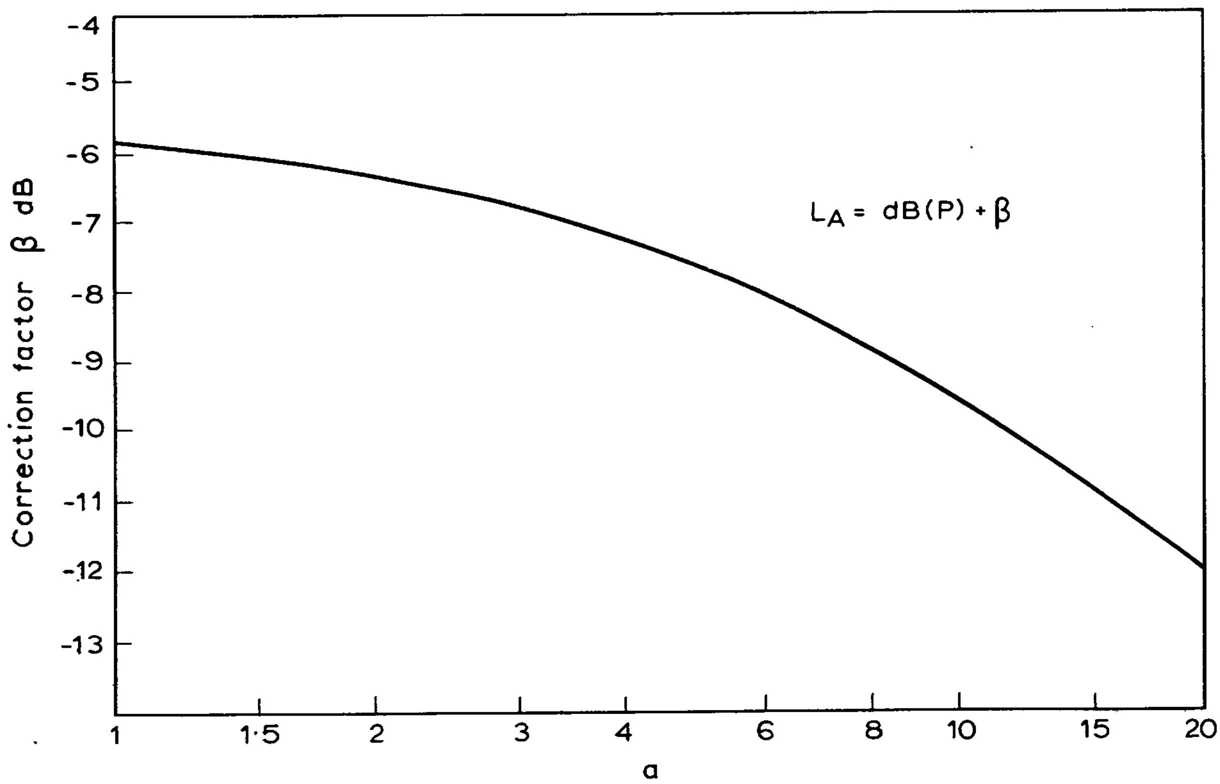

Fig 4. CALCULATION OF CORRECTION FACTOR β

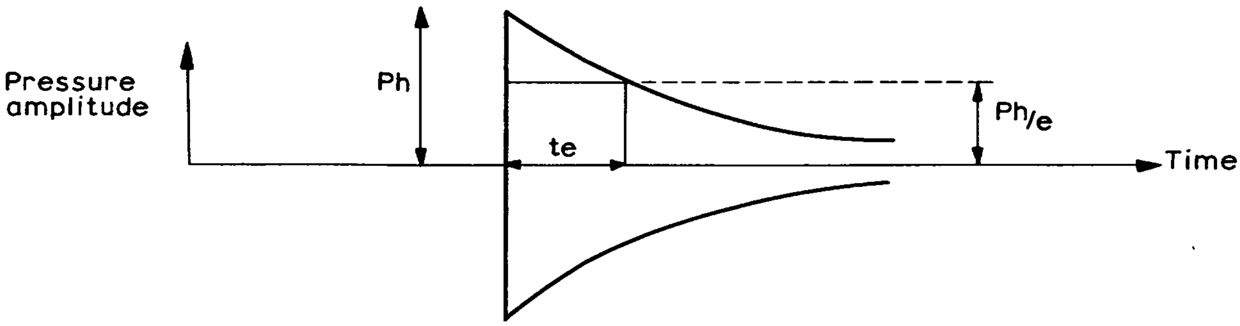

Fig 5. CALCULATION OF DECAY TIME te

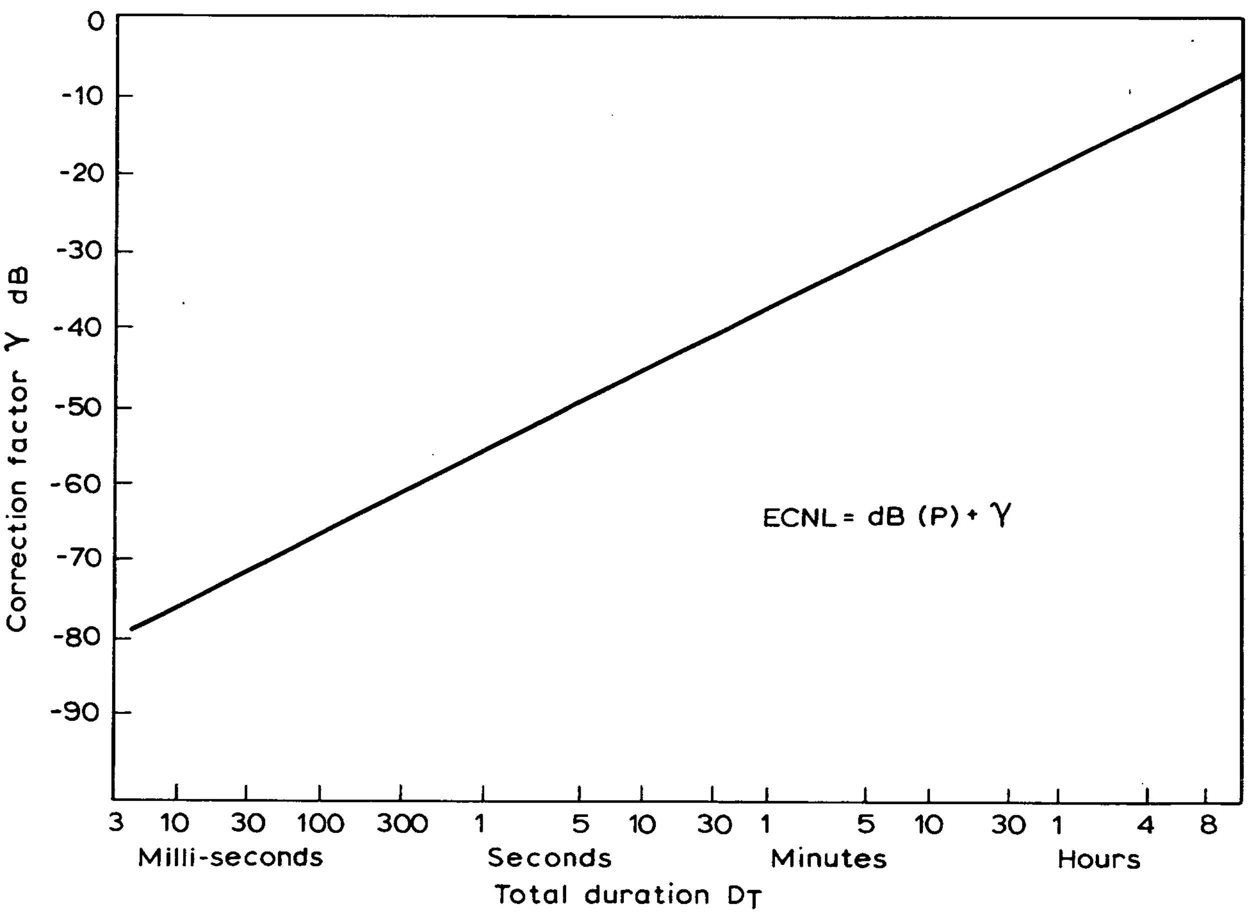

Fig 6. CALCULATION OF CORRECTION FACTOR γ

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