Proceedings of The Institute of Acoustics

PLANNED MAINTENANCE OF PRODUCTION MACHINERY USING VIBRATION DIAGNOSTICS.

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BASIC CONCEPTS

Machines seldom break down without some warning that is detectable. Almost always the signs of impending failure are present a long time before catastrophic failure takes the machine out of service. With key process machinery it has been usual to adopt policies of regular overhauls to minimise the likelyhood of sudden breakdown. This is a plausible technique giving a reasonably accurate assessment of downtime and spare parts cost that can be equated to the economic life of the machine. However, m.t.b.f. of the component parts of a complex machine are obviously variable and there are many instances when a shutdown, between maintenance periods, could be usefully utelised to replace minor components whose premature failure could escalate into a major defect. Provided that the condition can be determined reliably whilst the machine is in operation, considerable savings can be made by increasing meantime between shutdowns and by the important factor of avoiding failure whilst in service. The loss in production alone in shutting down the machinery referred to in this paper can be several thousand pounds per day.

With Condition Monitoring repairs are initiated only when the machine/component has deteriorated past a predetermined condition. The problem of course is to determine the condition of the machine while it is in operation. In many ways this is not a new approach, as any engineer will be aware, sight, sound, smell, touch are a day to day way of life and many an intuitive decision has saved costly failures of equipment. However, this is a subjective approach and can only offer at its best a broad assessment.

What should we measure?

Vibration conforms to a number of mathematical laws, often complex yet capable of logical interpretation into practical engineering terms. Noise and vibration signals measured at the external surfaces of a machine can provide sufficient information for the Vibration Engineer to accurately assess the machines condition under actual running conditions. The past two decades have been a remarkable increase in the availability and sophistication of equipment available for noise/vibration monitoring and analysis. It is not our intention to present in this paper any comparisons or assessments of such equipments, however, we will be referring to specific techniques that are within the compass of our experiencies and it should be understood that these have been selected to meet the rather different demands of industrial as apposed to research/laboratory conditions. Basically, vibration signatures at the surface of a machine are made up of many individual signals at different frequencies and amplitudes. To reduce these signals into a usable form it is necessary to a)measure the overall vibration level and b)frequency analyse, i.e. reduce the overall signal into discrete frequency bands and measure the vibration level in each band. The former may be achieved with a relatively simple vibration meter; the latter demands the greater complexity of filters, spectrum analysers etc. Instrumentation used for Machinery Condition Monitoring should be accurate, light in weight, portable and easy to use and in certain instances intrinsically safe.

PLANNED MAINTENANCE OF PRODUCTION MACHINERY USING VIBRATION DIAGNOSTICS.

RECORDING INFORMATION

The whole concept of machinery condition monitoring is based upon comparison with previous measurements. It is therefore essential to keep clear concise records of measurements taken. We have evaluated several methods and found the $\frac{1}{3}$ octave tabulation and narrow-band frequency plot meets most requirements without involving over-complication. In particular the $\frac{1}{3}$ octave tabulation is an ideal format for the Computer Information Retrieval System currently in preparation. The narrow band frequency plot; generated early in the recorded history of the machine and subsequently after machine overhaul, is the most informative document for the vibration analyst. Whilst many valid diagnoses are possible from a cursory glance at a $\frac{1}{3}$ octave tabulation, more complex machinery configurations often demand a rigorous analysis drawing upon every available scrap of information. In these situations reliably recorded data, a thorough understanding of the construction, engineering principles and operational characteristics of the machine complement the diagnostic skills of the Vibration Engineer. Therefore in addition to information collected during routine monitoring, it is most helpful to create a file of pertinent facts and figures relating to each machine and to have this information readily available. e.g. Gear ratios, Number of gear teeth on gear wheels, Number of blades on pump/fan impeller,etc.

UNITS OF MEASUREMENT

The vibration severity standards and recommendations mentioned in the references are in linear units, e.g. RMS Velocity, mm/s or inch/s. However, aspiring candidates in the field of Vibration Analysis will soon become aware of the usual proliferation of terms and units that beset the profession of Engineering, ranging from displacement mils to acceleration dBs. The role of Consultant is to smooth the way over these "academic hurdles", assessing and establishing the most viable, perhaps not rational, system to meet the clients requirements. We have therefore adopted the following approach:-

1) General condition of balance/unbalance of fans etc. displacement mils pk-pk
2) Machinery condition ($\frac{1}{3}$ octave analysis) pumps, gearboxes, motor etc. velocity RMS inch/s
3) Baseline (narrow band frequency analysis) all equipments. velocity RMS dB

A principal reason for the latter is the very real advantages obtained when recording the wide dynamic range of vibration spectra.

SUMMARIES AND CONCLUSIONS

Based on a 9 month survey at Bowater Scott Corporation, Barrow-in-Furness.

Monitoring Methods

With a plant as vast and comparatively complex as at Park Road Papermill, it was extremely difficult to lay down categorically a strict monitoring programme. We therefore resorted to drawing up a list of priorities, based on the criteria of capital cost, downtime factor and past experience of failure, and used this as a starting point.

The first task, the most time consuming, was to establish a base line for each piece of equipment. Methods differed slightly depending upon which instrumentation was in use, but ultimately resulted in a set of data sheets based on $\frac{1}{3}$ octave analysis velocity units pk-pk.

These data sheets are effectively a live-file for each item of equipment and are updated weekly/monthly. The period of updating is still very flexible and must depend, to a degree, on the past history of the item under consideration.

An overall, single figure level of vibration, as obtained from a portable vibration meter, can give some indication of a defect, but in our experience and considered opinion is not sufficient on its own to enhance a planned maintenance programme. In-depth analysis of the major items of machinery, gearboxes, compressors, pumps, etc. is necessary if objectively correct conclusions are to be reached. The more detailed analyses required demand considerable man-hours, and this in turn influences the periodicity of monitoring the major portion of the machinery items.

At present we feel adequate cover, using all the techniques described above, is being maintained at 130 man-hours/month. However, this is often escalated by the demands of special surveys and more complex balancing tasks.

The vibration monitoring activities have now gained a wide acceptance having proved a reliable means of diagnosing vibro-mechanical conditions, without taking a machine off-stream. We believe the programme has resulted in a lower incidence of breakdowns, damage and cut-backs in manufacturing speeds.

Financial Benefits. One could spend much time in assessing in detail the financial benefits resulting from the vibration monitoring programme in Barrow Mill, and many individual instances can be quoted to illustrate cost savings.
An indication of "return on investment" may be deduced from the following figures.

a)	Assume forced roll changes resulting in unplanned shuts	£16,000
b)	Assume failure of one key gearbox resulting in unplanned shut	£ 2,500
c)	Assume fan unbalance results only in minimal reduction in drying capability	£ 3,500
	(Figures include overheads, loss of revenue only)	
	Estimated minimum cost saving Total	£22,000

These figures are a gross simplification from a large amount of data and we appreciate that readers cost indexes will vary largely as their operating efficiency, resources and market involvement.

Engineering Benefits Experience before vibration monitoring suggests that equipment failure prediction by touch and listen method in the papermill environment is extremely unreliable and costly to say the least. Probably the most significant benefit from the vibration programme is the simplest to achieve and the key to it all - being able to measure vibration in absolute terms. By regularly monitoring running equipment most mechanical defects are picked up before they become serious. Detection of the early stages of failure enables remedial work to be organised before failure. In practice most work can be arranged to coincide with machine clothing changes and/or planned shuts. Because we are monitoring defects and taking timely remedial steps prior to failure, it follows that the probability of equipment failure in service is reduced.

In conclusion, experience is tending to shift the emphasis away from time-scheduled maintenance measures, towards preventive maintenance "triggered" by vibration analysis. It is considered that should activity in vibration monitoring cease, then the result would certainly be detrimental to the plant.

PLANNED MAINTENANCE OF PRODUCTION MACHINERY
USING VIBRATION DIAGNOSTICS.

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Proceedings of The Institute of Acoustics

AUDIOMETRY AS A SCREENING PROCEDURE FOR OCCUPATIONAL DEAFNESS

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Medical screening procedures have been defined as tests which can be rapidly applied for the presumptive identification of unrecognised disease or defect (10). They were successfully introduced for the early identification of contagious disease, where the objectives were twofold:

(a) that treatment provided at an early stage would increase the chance of recovery or reduce the extent of permanent disability;
(b) that isolation of the sources of infection at an early stage would reduce the number of persons subsequently infected.

More recently, a number of screening procedures have been developed for the detection of chronic degenerative diseases, with objectives limited to (a) above. They are less successful than had been hoped and as a result better evaluative methods were developed (7, 11 and 2).

A number of functions have been attributed to the use of audiometry in industry, which can be classified into two types: (a) screening (as defined above); (b) education. Only the screening function will be discussed further but this does not imply that the educational function of audiometry is without value (8). The objectives of screening audiometry in industry have been described as (1):

(a) CASE FINDING, which aims, by serial tests, to identify those individuals who have suffered a significant degree of noise-induced hearing loss but have not yet sought treatment;
(b) DIAGNOSIS, which aims to identify and fully diagnose those who are suffering from noise-induced hearing loss whether or not they have sought treatment;
(c) PRE-EMPLOYMENT SCREENING, which aims to identify those who have suffered noise-induced hearing loss as a result of previous exposure (the first test in a series for case finding purposes would not be included);
(d) GROUP MONITORING, which aims to detect changes in group hearing levels in order to evaluate the effectiveness of a hearing conservation programme.

Criteria have been developed whereby evaluation can give an indication of the effectiveness of a screening programme (1).

1 BIOLOGICAL CRITERIA

These are requirements which must be met by the disease in question before it can be accepted as suitable for screening.

(a) The natural history must be reasonably well understood. The progression of noise-induced hearing loss and its relation to exposure are now well understood (9) and are shown in Figure 1.

AUDIOMETRY AS A SCREENING PROCEDURE FOR OCCUPATIONAL DEAFNESS

The hearing loss described in the Figure is the result of two factors, noise and age, which are assumed to be additive. The noise-induced component is responsible for the rapid rise during the early years of exposure and is preventable.

There is one aspect of the natural history which is not understood, the apparently hypersensitive individual. We do not know whether these are a fundementally distinct group or simply the extreme end of the range of sensitivity exhibited by a population.

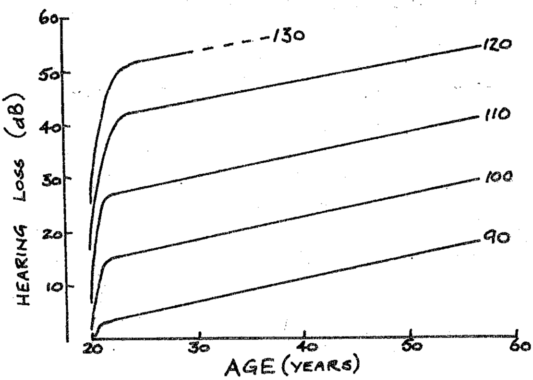

FIGURE 1
The progression of noise-induced hearing loss over a working lifetime (habitual exposure) for a variety of noise levels (dB(A)). Hearing loss is expressed as dB averaged over the frequencies 1, 2 and 3 kHz. (1)

(b) Tests are available which make it possible to recognise the disease in a latent or pre-symptomatic stage. As indicated in Fig. 1, there is no latent or pre-symptomatic stage in the progression of noise-induced hearing loss. Thus we cannot hope to prevent the disease by screening although we may be able to limit its progress and thus reduce the resulting disability.

(c) Effective treatment must be available. This is both an ethical and a practical requirement. Since the screening procedure involves the seeking of people who have not sought treatment it is considered unethical to then be unable to provide treatment. In the practical sense there is little point in seeking out those who suffer from a disease if nothing can be done for them. Noise-induced hearing loss is not treatable (5), hence early detection must aim to prevent further deterioration of hearing acuity either by personal protection or removal from the noisy environment.

Thus there are three ways in which noise-induced hearing loss fails to meet the requirements of the biological criteria. These are, in order of importance:

i) there is no latent or pre-symptomatic stage;
ii) there is no effective treatment for the disease and attempts to reduce further disability may be unacceptable or unsuccessful;
iii) there may be hypersensitive individuals for whom the natural history of the disease is not understood and particularly the rate of progression of the disease is not known.

AUDIOMETRY AS A SCREENING PROCEDURE FOR OCCUPATIONAL DEAFNESS

2 ECONOMIC CRITERIA

The degree to which audiometry is a net loss or benefit to a company is an important criterion. If the programme constitutes a net benefit then failure to meet some of the biological or social criteria may be acceptable. The area of cost-benefit studies is poorly researched but Kolozyn (6) has examined the audiometric programme of a large manufacturing company and failed to show any net benefit for case finding. Although it is not possible to generalise from such limited evidence we cannot assume that the economic criterion has been fulfilled.

3 SOCIAL CRITERIA

Merriman (8) has shown that the acceptability of the test to the target population (the workforce) is very important in the case of occupational audiometry. There are two aspects of acceptability:

(a) Acceptability of audiometry - freedom of choice in whether or not they are tested is an important element in workers attitudes to audiometry (8). Although there are now recommended test procedures (4) which make it difficult for individuals to consciously influence the test results without detection, a screening procedure which results in a substantial amount of non-compliance would not be likely to be successful. It would appear that such non-co-operation with the test is a possibility for some workers.

(b) Acceptability of the consequences of a positive result - even when a test procedure is acceptable, a screening programme may fail because the required treatment, in the event of a positive result, is unacceptable. In the case of audiometry the alternatives are hearing protection or a change of work. It seems likely that both of these may be unacceptable to some workers(3).

4 TEST CRITERIA

These are specific factors relating to the test procedure which must be taken into account in any evaluation (2).

(a) Accuracy - The test should measure the variable under investigation and accurately reflect the state of health or disease of the individual. There is little doubt that audiometry fulfils this requirement.

(b) Precision (test-retest variation or repeatability) - There are three sources of bias: subject error, observer (operator) error and method error. A number of studies have examined this aspect of audiometry and they tend to suggest that subject error and observer error are important (1). Variation at 4kHz generally gave a standard deviation of approximately 4dB.

(c) Sensitivity and specificity - Sensitivity is defined as the ability to give a positive result when the individual has the disease under investigation (ie high sensitivity results when the numbers of false-negative results is low). Specificity is the ability to give a negative result when the individual does not have the disease (ie the number of false-positive results is low). Because these two aspects of the test are linked it is often not possible to reduce both at the same time. One estimate of specificity gives 0.7% false-positives in a high risk group (5). Since sensitivity was not estimated we do not know if this high specificity means there were a large number of false-negatives.

The objectives of an audiometric screening programme will affect the application of these criteria. For case finding there appear to be a number of factors which imply that such programmes may not be fully effective: (i) there is no latent stage; (ii) there is no effective treatment; (iii) the consequences of a positive result may be unacceptable or the action taken unsuccessful; (iv) poor precision means that large numbers of repeat audiograms are necessary; (v) possibly low sensitivity may result in unacceptable numbers of false-negative results; (vi) there is no evidence of a positive cost-benefit relation. For diagnostic audiometry the poor precision and doubtful sensitivity would appear to be insuperable problems. The factors itemised above for case finding also apply to pre-employment audiometry. These problems do not apply to such an extent to group monitoring but this is an aspect of audiometry which has received little attention.

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Proceedings of The Institute of Acoustics

DIGITAL ASSESSMENT OF LOUDSPEAKER PERFORMANCE

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Introduction

In the past few years there has been an increasing use of digital signal processing methods in acoustics (1,2,3). The area of application dealt with in this paper is the use of these digital techniques for the analysis of loudspeaker performance. The implementation of these techniques in a general-purpose computer means that not only can conventional measurements be made and displayed in many forms but also "non-standard" measurements, which may be difficult or impossible to perform on analogue equipment, can be made just as easily. Only one such application is considered here, and this is the use of homomorphic filtering (4) to determine the minimum and maximum phase components of the loudspeaker's amplitude response.

Experimental Techniques

An estimate of the frequency response (both magnitude and phase) of a loudspeaker system is made as the ratio of the discrete Fourier transform of its sampled output and input signals. The motivation behind this method is as follows:

It is well known that in the time domain, the output, $y(t)$, of a linear time-variant system to an input $x(t)$ is given by the convolution integral:

$$y(t) = \int_0^\infty h(\tau)\ x(t - \tau)d\tau \qquad (1)$$

where $h(\tau)$ is the impulse response of the system, i.e. the response of the system to an input of a unit impulse applied at a time τ before. By taking the Fourier transform of both sides of equation (1) we obtain:

$$Y(f) = H(f)\ X(f) \qquad (2)$$

where $X(f)$, $Y(f)$ are the Fourier transforms of $x(t)$, $y(t)$ respectively, and $H(f)$ is the frequency response, defined as the Fourier transform of the impulse response $h(t)$.

Now by dividing equation (2) by $X(f)$ we can obtain a formula for the frequency response as:

$$H(f) = Y(f)/X(f) \qquad (3)$$

If X(f), Y(f) are now the discrete Fourier transforms of x(t), y(t) respectively then we can obtain an estimate of H(f) given by equation (3) at each value of f for which X(f) $\neq 0$. If H(f) is evaluated from d.c. to WHz and x(t) and y(t) are measured for T seconds, there will be WT estimates of H(f) available at frequency intervals of 1/T.

The input signal x(t) was chosen to be a pseudorandom binary signal (5) (PRBS) which has three advantages in this type of application. First, the magnitude of its spectral components $|X(f)|$ are constant over the frequency range of interest and secondly, the transform of these signals and, in the absence of noise, the transforms of the corresponding system responses are deterministic. That is, statistical errors from this source are eliminated as are the need for large sample sizes and spectrum-smoothing techniques usually associated with the use of random signals. The third advantage is that these signals are easy to generate and can be made to be repeatable as opposed to the true randomness of genuine white noise.

The apparatus used consists of a Computer Associates Alpha minicomputer with 32k of store. It has a disc handler for two floppy discs, on which the programs are developed and held. Within the computer are the digital-to-analogue (D/A) and analogue-to-digital (A/D) converters together with sample/hold and multiplexing arrangements. The programs are written in Fortran except where high-speed processing is required, when assembler is used. The suite of programs is interactive, giving the user the ability to make various decisions, for example, to select the sampling frequency or to decide which displays to use. The requests for information appear on a Tektronix 613 VDU which also displays the various output graphs. User input is by means of a Keyboard and an optional X-Y plotter is available to produce a hard-copy output of any of the graphs.

The loudspeaker output is normally picked up by a ½" B. & K. microphone and amplifier and fed via an antialiasing filter to the A/D converter in the computer. Figure 1 shows the arrangement of the equipment. The PRBS is generated within the computer and sent via the D/A converter and amplifier to the speaker under test. The program samples the microphone output signal for one complete period of the PRBS, and many of these signals can be added together and averaged to improve the signal-to-noise ratio. The input signal is also sampled in a similar way and the ratio of the discrete Fourier transform of these two signals gives the complex frequency response according to equation (3).

Once the frequency response has been obtained in this way, its Fourier transform gives the impulse response of the system, from which room reflections and the time delay between the microphone and loudspeaker can be easily removed.

This impulse response is now available for any number of operations to be performed on it, both "standard" and "non-standard". For example, it can be transformed back into the frequency domain to give the familiar frequency and phase responses, but now without the time delay. An example of a "non-standard" technique, which can only be performed digitally, is that of homomorphic filtering, or cepstrum techniques, which will now be elaborated upon.

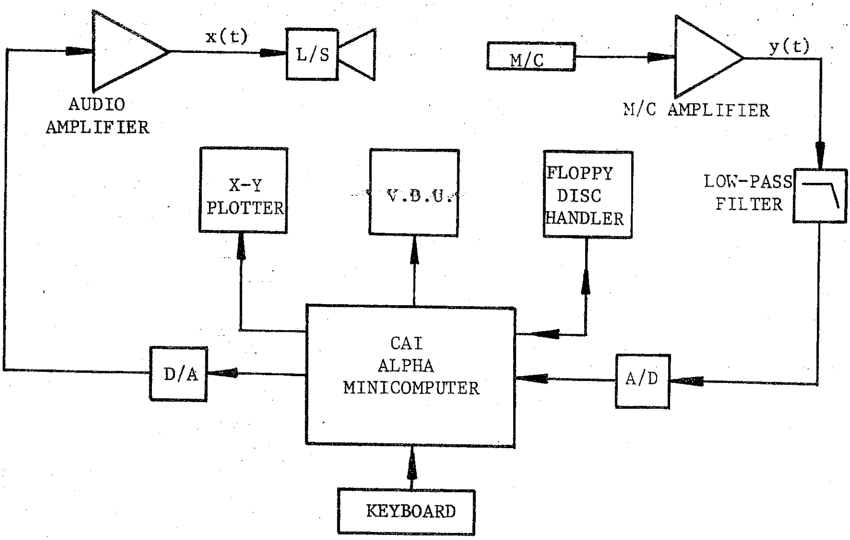

Figure 1 Computer-based test system

Lately there has been an upsurge of interest in minimum-phase systems for which there exists a unique relationship between the magnitude and phase responses, so that the measurement of either magnitude or phase is sufficient to determine the frequency response completely, and it is here that the complex cepstrum can be used to determine the minimum-phase portions of the loudspeaker's response. The complex cepstrum is the inverse Fourier transform of the complex logarithm of the Fourier transform of the time sequence and one of its properties is that the component for negative time corresponds to the non-minimum (maximum) phase part of the response, while the positive time component corresponds to the minimum phase portion of the response. Thus by obtaining the complex cepstrum and then transforming the negative and positive time portions individually, the frequency responses corresponding to the minimum and maximum phase components of the speaker can be found, and kept for further processing if necessary.

Results and Conclusions

The frequency responses obtained by digital means compare favourably with conventional analogue results and thus give confidence in the methods used. However, with the newer, purely digital techniques used, there are no equivalent analogue results for comparison and so greater care must be taken in the interpretation and use of these results.

DIGITAL ASSESSMENT OF LOUDSPEAKER PERFORMANCE

The digital techniques used provide an extremely flexible and useful tool in evaluating loudspeaker performance. Not only can conventional measurements be made but also the use of digital signal processing methods can provide new measurements which can give a new insight into loudspeaker performance, thereby leading to new understanding and improvement in loudspeaker design.

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Proceedings of The Institute of Acoustics

CRITERIA FOR NOISE STANDARDS

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In this introduction to the session on noise standards, I would like to put forward some general views on noise standards and guidelines, related to experience over a number of years, and hope that this will lead to a discussion on the merits and otherwise of the standards used in this country at present.

Firstly, one has to decide whether in fact noise standards are required at all, and if so who they are intended for. It is possible in academic and scientific discussions to get lost in the finer detail of some aspects of a noise standard and in doing so to lose sight of the purpose for which it is required by ignoring the real needs of the customer. In the Scientific Branch at the GLC, we are in the position of both being customers needing standards in order to enable us to advise other Departments of the Council, and occasionally other Local Authorities on particular issues, as well as having to set standards ourselves in those cases where none are so far available or we feel them to be inappropriate.

Basically, there are two types of noise standards. Firstly, emission standards are needed for machinery, vehicles, aircraft and other specific noise sources, and the customers requiring these are mainly engineers and manufacturers. Emission standards are required to limit the level of noise so as to cause minimum annoyance or disturbance, compatible with the purpose of the equipment causing it. Ideally, of course, standards should be set so that no-one would be annoyed by noise, there would be no disturbance to sleep, and no enhanced risk of hearing damage. Unfortunately, to achieve this with present or foreseeable technology, could well mean the ending of civilisation as we know it today, and therefore a compromise is required, although the philosophy on which this compromise needs to be based is open to discussion. Low external levels are not in themselves good selling points on vehicles, aircraft or machinery, and, as it costs money to achieve noise reductions, manufacturers need to be persuaded to do so by the legal enforcement of standards. It is unlikely that many manufacturers would be sufficiently altruistic to incur extra costs in the production of, for example, motor cycles, merely to ensure a quieter environment if their less socially responsible competitors could undercut them and probably outsell them, without incurring penalities.

By setting emission standards manufacturers are encouraged both individually and jointly through research organisations to engage in research aimed at achieving these standards by the most practical and economic means. Emission standards need to be considered as being constantly in need of updating, and advances in noise reduction technology can be used to

60

progressively improve standards, thus ensuring that at least no worsening of the environment occurs, as the number of aircraft, vehicles and other noise emitters continues to increase. This process of improving on previous standards is now taking place, albeit very slowly, examples being the new EEC regulations on vehicle noise limits, and revised ICAO limits for aircraft noise certification.

Immission or environmental standards are required to protect residential areas, the interiors of dwellings, schools and offices, theatres and concert halls, and parks and gardens, to name but a few. In this case, the customers are mainly local authorities, government departments and amenity societies, with the professions mainly concerned being planners, architects and administrators, including Inspectors at Public Inquiries.

Environmental standards are essential for planners and architects whose task it is to provide pleasant and acceptable conditions for future residents or workers, while recognising the conflicting needs of traffic, industry and public entertainment. In planning as in many other fields, prevention is not only better but also cheaper than cure, and by designing to correct environmental standards, future problems can mostly be avoided. Subsequent remedial measures, necessitated by insufficient regard to the environment, can be both costly and unsatisfactory. On the other hand the provision of sound insulation beyond a certain level provides no additional benefit and becomes increasingly costly. It is therefore particularly important for architects to be able to design for optimum sound insulation, and to do so, standards which are relevant, reliable and practical are needed. As in many other matters, financial considerations must always be taken into account and, if limited resources are available, complete noise protection at one site cannot be provided if this implies neglecting some other amenity at that site or if it is at the expense of some other section of the community.

Environmental standards are also needed to provide an objective basis for assessing eligibility and extent of compensation for people adversely affected by noise, and to settle legal disputes. They are also necessary to ensure that as far as possible remedial measures are taken in cases where they are needed most, rather than those where the most articulate and vociferous complainants live or work.

Both for emission and immission standards, it is only rarely that scientists or acousticians are directly involved as customers, although often of course they act as advisers or consultants. Thus it is considered that the most important requirement is that sufficient consideration is given to the relevance of that standard to the particular 'customer' for whom it is intended.

Secondly, the formula on which the standard is based must provide a good correlation between the level of noise and subjective reaction by the listener or between the level of noise and objective criteria, such as speech interference, sleep disturbance, or hearing damage. There is a danger, however, in the case of subjective standards, of too much emphasis being placed on precision, for example in the evaluation of frequency spectra, while the real factor determining annoyance is overlooked. The level of annoyance is usually dependent not only on the level and frequency characteristics of the noise, but also where and when it is heard and on many non-acoustic factors, such as views on the usefulness of the source causing the noise, to the community and/or the listener, views on the preventability or otherwise of the noise, its possible representation of danger, and other personal attitudes. It seems likely in fact that these non-acoustic factors are of greater importance than the characteristics of the noise, however precisely these are defined, in determining the level of annoyance, and the noise itself is simply the identifiable symbol of these factors.

Thirdly, the standard needs to be in a form where it can be used to make an objective assessment and therefore levels based on it should be readily calculable or measurable, preferably by the customer without external assistance. With the substantial advance in noise measurement technology which has been achieved over the past few years, this problem has become less acute, as even rather complex indices such as Equivalent Noise Level can now be measured by staff with limited specialist knowledge using relatively simple equipment.

The fourth requirement, particularly relevant to environmental standards, is that the formula should be suitable for prediction with a good degree of reliability. It is not sufficient for example merely to have a good correlation between noise exposure and annoyance at one site at one time, if this cannot be reliably used to predict what will happen in the future under different conditions.

Fifthly, a useful asset for an index or formula is that it can be used for a wide range of sources and conditions, particularly as this enables comparisons to be made on the relative importance of different sources in their effect on the overall environment. This is, however, not as important a requirement as the previous four and great care and commonsense is needed if such comparisons are not to be misleading. It seems most unlikely, for example, that if aircraft noise and pop music were both measured and found to give the same level on a particular index, that the response in annoyance terms of similar cross-sections of the community would be similar.

Finally, there are advantages if similar standards are used in different countries, but this is far more important in the case of emission rather than environmental standards. An obvious example is the noise certification of aircraft, where it is essential that all countries use similar methods of assessing the emission levels of aircraft types, both for the purpose of ensuring compatibility in aircraft design and manufacture and also for legislation relating to restrictions or bans on non-noise-certificated aircraft. Similarly, agreement is required between countries on mutually-acceptable methods of establishing noise emission levels for vehicles and machinery, to facilitate trade and ensure that domestic laws are not infringed by imported goods.

CRITERIA FOR NOISE STANDARDS

For environmental standards, there seems to be rather less reason for compatibility between countries, even though it may be of interest to make comparisons. Living conditions, design of buildings, climate, differing habits related to various times of day, all tend to make the formulation of universally-acceptable standards both difficult and probably unwise.

It is clearly obvious that no formula or index in use so far, or ever likely to be introduced in the future, is likely to meet all the above requirements and a compromise is required; but where the balance of such a compromise should lie varies with the purpose of the standard and is open to discussion.

A compromise is also required with respect to the level at which the standard is set. On the one hand, the level needs to be realistic and attainable with existing technology, it needs to be economically feasible, and it needs to be enforceable. On the other hand, there is little point in setting an environmental or emission standard unless it has some bite, and either provides an improvement over the existing situation, or at the very least ensures no worsening. This is particularly important, as one risk inherent in any standard is that as well as setting an upper limit, it can also be considered in the form of a licence to go up to that limit. The reaction of people to noise varies enormously, and, however good the standard, some people will remain dissatisfied, while conversely some people appear not to be disturbed or annoyed by noise at almost any level. A decision therefore has to be taken as to what percentage of the population it is aimed to satisfy in setting a particular level. In this case it is necessary to differentiate between effects which merely cause some degree of annoyance, and those which can cause actual hearing damage. Thus while the risk of permanent hearing damage cannot be tolerated for more than a minimal proportion of those exposed to industrial noise, it may have to be reluctantly accepted that some larger percentage of the population cannot be adequately protected from being annoyed.

Finally and perhaps the most difficult problem is to draw a balance between the rights of people to enjoy themselves, as for example by attending pop concerts, and the equal rights of residents to a quiet environment. Compromises are clearly necessary, both by setting limits and restricting times but in the long run the only satisfactory solution is to set a moral standard for people to be considerate and tolerant towards each other.

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