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NOISE CONTROL - TIPS AND CHECK LISTS FOR WORKS DESIGNERS

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INTRODUCTION

It is usual for a responsible company to implement national policy on industrial noise taking into account likely future requirements. It can be described in terms of:

(a) The risk of hearing damage due to the exposure of employees to high noise levels.

(b) Nuisance to employees from noise levels on the working site.

(c) Nuisance to the public outside from noise levels arising from within the working site.

There is a general duty of care to achieve noise levels of the lowest practicable level taking economics into account i.e. to apply best practicable means to obtain minimum noise levels.

In any case noise levels should be below those which cause risk of hearing damage, where this cannot be achieved, as a last resort the relevant employees must be safeguarded by personal hearing protection.

Noise levels must also be acceptable for the various working conditions within the site and comply with the statutory and other requirements to meet the needs of the public outside the site.

All new plant and equipment should be designed and installed so that it conforms with these requirements, and existing plant and equipment should be modified appropriately if necessary.

Noise control costs money and must be allowed for when costing a project, failure to do so inevitably leads to either a) over expenditure or b) excessive noise levels.

In a major plant or works programme to reduce noise it is rarely possible to carry out all the noise control measures at once. Both practical and financial constraints have to be considered. The practical constraints often requiring a considerable design period, are equipment delivery, physical parameters such as size and weight, safety considerations and effect on operation.

There will be increasing pressure on companies to reduce existing noise and to limit noise from new plant. It is essential that all branches of engineering appreciate this.

NOISE CONTROL - TIPS AND CHECK LISTS FOR WORKS DESIGNERS

RECENT CASE HISTORIES OF FAULTS IN DESIGN AND PROCEDURE

Recent experiences have shown that noise problems still arise at commissioning of new plant and machinery because the contractor/works designer have failed to make adequate provision for noise control at the design stage. This, despite extensive publicity, noise specifications and data provided by suppliers. Recent examples are:

(a) Fan manufacturer supplied data showing acceptable noise levels. Fan installed on site producing dangerous noise levels, due to severe turbulence introduced by badly designed pipework on site.

(b) Blowers fitted with silencers installed in blower house. Delivery pipework, after the silencer unlagged, taking in noise generated in the blower house and being conveyed beyond the room wall.

(c) Machine installed, producing high noise levels, works considered fitting of acoustic enclosure. Investigation showed enclosure unnecessary as high levels were due to unmatched belt sets. Predicted levels from published or internal data should have been available for comparison purposes.

(d) Works air supply used for removing moisture from cast ingots. Air supplied at 100 psig. 20 psig was sufficient for the particular purpose. A specially designed system was installed delivering a low air pressure through an elongated slot. An attenuation of 10dB(A) was obtained and a power saving of £6000 per year.

(e) Barriers, screens, erected without appreciation of the essential information required i.e. frequency to be attenuated and location of screen for maximum effect.

(f) Placing of machines in factories, i.e. machines installed close to highly reverberant surfaces, and placed where internal environmental problems have been created.

DESIGN LIAISON

Lines of communication need to be established with works engineering design staff to assist in reducing the number of avoidable noise problems which arise at new installations.

Works engineering staff welcome simple guidelines in deciding where noise control is necessary and when to seek expert advice.

NOISE CONTROL INFORMATION LISTS

A few examples of the type of information in brief which need to be communicated are:

Electric motors

Motor noise tends to be cooling fan turbulence and speed dependent only. Noise can start to be a hazard at 10kw for a 3000 rpm motor and at 50kw for a 1500 rpm machine.

Consider reducing the turbulence noise by using a smaller and/or more efficient (uni-directional) fan rotor to replace the bi-directional type. Refer to BS.4999:Part 51. "General requirements for rotating electrical machinery".

Blowers
Be wary that manufacturers noise data are not silenced blowers because blowers may be supplied unsilenced. A reactive silencer designed for low lobe-passing frequency attenuation will be large. The size can be reduced by keeping the strict dB(A) objectives in mind, i.e. it may be possible to ignore a heavily weighted fundamental frequency and size the silencer to attenuate the second harmonic frequency in preference.

Fans
Most environmental complaints arise due to pure tones from fans. It must be remembered that because the ear is able to discriminate between different frequencies of sound, a pure tone can be clearly audible in a general noise, when the level of the pure tone is 10dB to 15dB below the sound level of the octave band which contains the pure tone.

A large slow speed fan will generally be much quieter than a high speed small fan with the same throughput. It is usually cheaper to buy the quiet fan in the first place rather than try to silence the noisy one. The tip speed of a quiet fan would usually be below 40m/sec.

Compressors
The compressor casing itself may not be the only significant noise source. The connecting pipework may be thinner and less stiff than the usually substantial compressor casings and the pipe noise radiating surface may be significant in large units.

Pipework systems
(a) Granule Conveying. Pneumatic conveying pipework is a regenerative line source - the noise does not decay appreciably with distance along the pipe, the break out noise attenuation is only 3dB for every doubling of distance from the pipe surface. Noise can increase by as much as 10dB at bends, so position bends away from work stations to protect employees.

(b) Where connecting pipework for fans etc is being designed, consideration can be given to the fitting of a flanged spool in the line, so that should it be found necessary to fit a silencer retrospectively then provision has been made for inexpensive ftting.

Vents
Steam, gas and air vents generate high noise levels when the gas speed exceeds 80m/sec. Silencers may be required above this speed. Consideration should be given to this when designing pressure relief devices for example.

Where works design staff have access to noise expertise at an early stage in design, noise problems at new installations are minimised. Information gained, based on experience is derived and can be used to set standards for use elsewhere.

THE ACTIVE CONTROL OF TRANSFORMER NOISE

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Topexpress Limited, Cambridge.

The idea of active sound control has been around for over 50 years [1]. It is based on the principle of superposition of linear waves which has been known for over a century. The idea of using active sound control to reduce the hum of large transformers was first patented by William Conover in 1955 [2], and the study of active control for transformers has continued sporadically ever since, yet transformer noise is still a problem today and active control has not been introduced.

To understand why active control is not yet used and also why transformers have featured so prominately in the literature we need to consider the basic requirements for active control. It is hoped that this will provide some ground rules for deciding if active control is a viable solution to a given problem.

We begin by looking at the underlying theory. This tells us that the sound radiated by a source contained within an imaginary surface S is given by Kirchhoff's formula

$$p(\underline{x}, \omega) = \int_S d\underline{x}' \left[G(\underline{x},\underline{x}',\omega) \frac{\partial p}{\partial n} (\underline{x}',\omega) - p(\underline{x}',\omega) \frac{\partial}{\partial n} G(\underline{x},\underline{x}'\omega)\right] \qquad (1)$$

where

$$G(\underline{x},\underline{x}',\omega) = \frac{e^{ik|\underline{x} - \underline{x}'|}}{4\pi|\underline{x} - \underline{x}'|}$$

is the response at position $\underline{x}$ to a point source at $\underline{x}'$, $k = \omega/c$ is the acoustic wavenumber, ω is the radian frequency of the source and c is the sound speed. $\partial/\partial n$ denotes a derivative in the direction of the normal to the surface S.

We see that sound sources are ambiguous and that any source distribution in S which gives the same values of pressure (p) and pressure gradient ($\partial p/\partial n$) on the surface S will produce the same sound field everywhere outside the surface. If we choose a source distribution which gives the opposite values of p and $\partial p/\partial n$ to those produced by the unwanted field then we have perfect cancellation everywhere outside of S.

The most commonly tried form of active control is to place loudspeakers at various positions on the transformer. The question then arises of how many loudspeakers are needed. To answer this question we return to equation (1). We divide the surface up into a number of regions S_j. With $\underline{x}_j$ as a point in the region S_j we find that

$$G(\underline{x},\underline{x}',\omega) = \frac{\exp\{ik|\underline{x} - \underline{x}_j - \underline{x}' + \underline{x}_j|\}}{4\pi|\underline{x} - \underline{x}_j - \underline{x}' + \underline{x}_j|}$$

$$\simeq G(\underline{r},\underline{r}_j,\omega)\ \exp(-ik(\underline{r}_j - \underline{r}').(\underline{r} - \underline{r}_j)/|\underline{r} - \underline{r}_j|)$$

$$= G(\underline{r},\underline{r}_j,\omega)\ \exp(-ik|\underline{r}_j - \underline{r}'|\cos\theta_j) \tag{2}$$

provided that

$$|\underline{r} - \underline{r}_j| >> |\underline{r}_j - \underline{r}'| \text{ for } \underline{r}' \text{ in } S_j\ . \tag{3}$$

If $k|\underline{r}_j - \underline{r}'| << 1$ then the region S_j is small on the scale of an acoustic wavelength and the first term in (1) becomes

$$\sum_j G(\underline{r},\underline{r}_j,\omega) \int_{S_j} d\underline{r}'\ \frac{\partial p}{\partial n}(\underline{r}',\omega) \tag{4}$$

which is the sum of point monopole sources at positions $\underline{r}_j$ with the appropriate strengths. The second term in (1) can be treated similarly giving a sum of dipole sources. The number of sources is therefore determined by the condition

$$k|\underline{r}_j - \underline{r}'| << 1 \text{ for all regions } S_j, \tag{5}$$

and depends upon the size of source compared to the acoustic wavelength.

Active control is therefore easiest for sources which are small on a wavelength scale, but it is fortunate that sources are only required on a surface and not throughout the whole of the volume to be controlled.

Condition (5) is sufficient for spatial matching of the sound at a particular frequency. If the sound is broadband then (5) is most stringent at the highest frequencies and in practice limits the upper frequency of control. The unwanted noise must be matched in time as well as in space. If the noise is broadband then we must have an advance measure of the unwanted noise since our control system must be causal. The control system must respond very quickly so in general broadband noise control is more difficult than the control of periodic noise, where good predictions can be made many cycles in advance. Research has therefore concentrated on problems where the spatial matching is very easy, such as sound propagation in long ducts below the cut-on frequency of the first cross mode and on problems involving periodic noise, where the temporal matching is very easy. Transformers have the advantages that the frequencies are fairly constant and a signal for synchronizing the sources is readily available.

Single channel controllers for broadband noise and multichannel controllers for periodic noise are now commercially available.

A typical transformer is composed of coils surrounding three laminated cores. This is enclosed in a tank of oil to provide cooling. A schematic plan view is shown in figure 1.

The sound from transformers is caused by magnetostriction of the laminated cores. The resulting vibrations are transmitted through the cooling oil to the outer casing of the transformer tank which in turn vibrates the surrounding air. Magnetostriction results from the presence of a current and does not depend upon its direction so the sound from a 50Hz transformer is at integer multiples of 100Hz. A typical spectrum is shown in figure 2. A 0.5MVA transformer might be 4m high x 4m long x 1m deep giving an exposed surface area of $44m^2$. At 100Hz the wavelength of sound in air is 3.4m so to cover the transformer with sources half a wavelength apart would require about 16 sources at 100Hz or 244 at 400Hz. The expense of 244 loudspeaker and amplifiers alone is likely to be prohibitively high, not to mention the cost and complexity of the control system and sensors, so it seems surprising that so much attention has been paid to active control for transformers. There are however some simplifications which can make things easier. Firstly, reductions may only be required in the horizontal plane or in the direction of a nearby residence. Many of the published reports, [3] - [6] have concentrated on these more specific problems. Secondly, it may be that only part of the transformer is vibrating, in which case covering that area with loudspeakers may be sufficient.

This suggests an alternative means of active control, which is to apply forces, produced by inertial shakers for example, to the casing to oppose the forces applied by the cooling oil [7]. However, measurements have shown that despite the simplicity of the source, the casing vibrations are far from simple. Hence there is unlikely to be a saving in complexity. In addition the power requirements for the actuators may be larger than for loudspeakers.

A third means of active control is to control the vibration of the cooling oil itself. This appears to have a distinct advantage in that the wavelength in oil is about 5 times that in air. This potentially reduces the number of sources required, as determined by condition (5), by a factor of 25. If we take S to be the inside surface of the transformer casing, equation (1) gives the pressure applied to casing. To eliminate the unwanted noise we must produce cancellation on S. S is very close to any actuators in the oil so condition (3) becomes the dominant condition. This shows that the actuator spacing must be small compared to the distance from the actuator to the tank casing. This condition is independent of frequency. Viewed another way, this condition tells us a minimum distance for monitoring performance of an active control system.

We can illustrate the effect of condition (3) with a simple model problem. Figure 3 shows line sources at positions $\underline{r}_j$ around a cylindrical core of radius 0.1m. The core vibrates radially to produce effectively a line monopole at the centre of the core. The strengths and phases of the surrounding sources are chosen so as to minimise the total radiation. The relative cancellation at a point $\underline{r}$, distance d from the core, is

$$20 \log_{10} \left| 1 - \frac{|\underline{r}| e^{-ik|\underline{r}|}}{N} \sum_{j=1}^{N} \frac{e^{ik|\underline{r} - \underline{r}_j|}}{|\underline{r} - \underline{r}_j|} \right| , \qquad (6)$$

where N is the number of sources. Reflections from the core have been neglected since it is small in a wavelength scale, reflections from the casing can be neglected if good cancellation is achieved.

This is shown as a function of distance d in figures 4 and 5. In figure 4 the frequency is 100Hz, in figure 5 it is 400Hz. At larger distances the cancellation is determined by the separation on a wavelength scale of the actuators from the effective position of the source, hence better cancellation is achieved at 100Hz. At small distances condition (3) begins to break down and the cancellation is the same at both frequencies. From these results we see that condition (5) becomes appropriate when d is greater than a wavelength.

The technique of controlling the vibrations of the oil shows considerable promise, although the reductions in system complexity are not as great as might have been imagined.

The use of loudspeakers to reduce the noise of transformers is limited by the large number of loudspeakers and control channels required, but this technique is now viable for control in specified directions.

In conclusion, the number of actuators required to produce good reductions is determined by

(i) the size of the source region on a wavelength scale;

(ii) the distance from the actuators to the region where reduction is required;

(iii) the range of directions over which reduction is required.

With the availability of multichannel periodic control systems, the viability of active control for transformer noise will be determined by the number of actuators and their power requirements.

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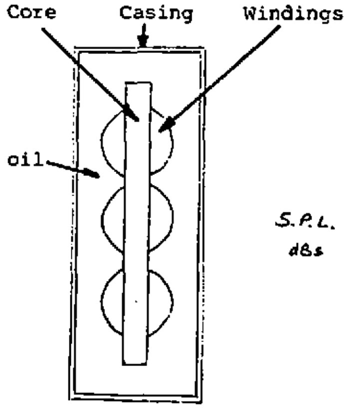

Figure 1

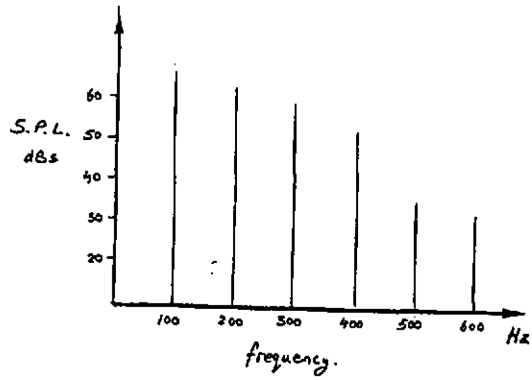

Figure 2

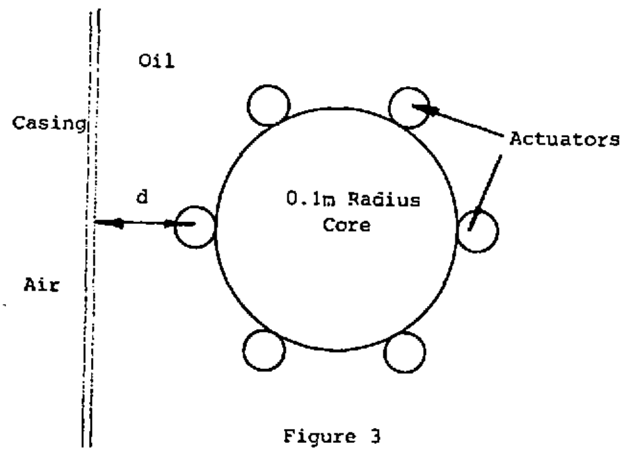

Figure 3

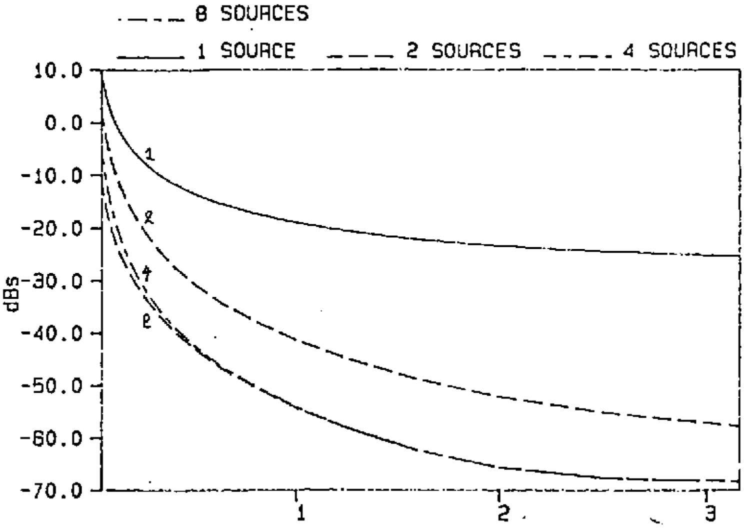

Figure 4

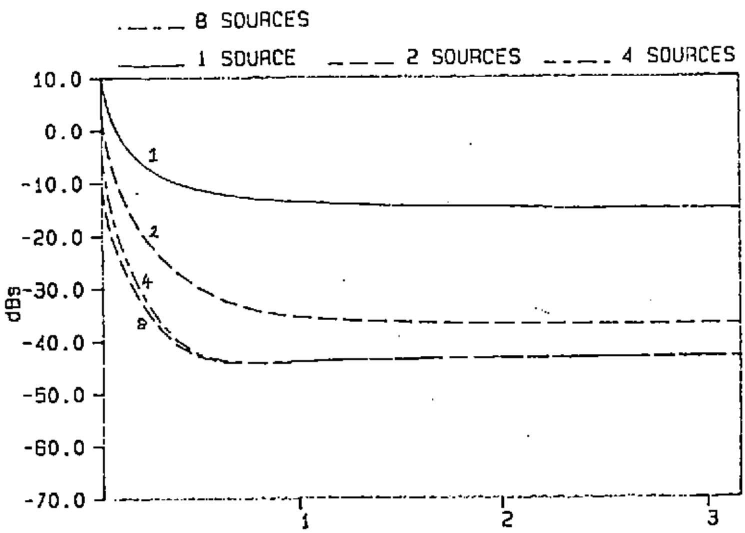

Figure 5