TECHNICAL MEASURES TO CONTROL NOISE

M F Russell

Lucas Industries Noise Centre, Lucas CAV Ltd. Acton, London, W3 7SS

INTRODUCTION

Lucas CAV became interested in noise in the 1950s during a feasibility study into quieter diesel power units for passenger cars. Several methods for controlling noise radiated from the engine surfaces have been demonstrated, and noise control features have been built into certain ranges of Lucas CAV products. This work gave an insight into the generation of noise and the various techniques for controlling it. This technology has been greatly expanded to encompass the plant and equipment used in Lucas factories.

In the 1960s a few measurements were made when new items of plant and equipment were judged to be noisy subjectively but recommendations were difficult to apply because the plant was usually in service before the investigations started. To prevent excessively noisy plant from becoming a serious problem, a Company purchase standard was introduced which placed limits on the noise emitted by new plant and equipment.

The Company standard on Noise of New Plant and Equipment, which was first available in 1969, specified a maximum permissible sound level for the new plant, a method of measurement and a procedure to be followed when purchasing new plant. After much discussion, a procedure was evolved to fit in with the Company's operating systems and which required the minimum extra resources and training. For such a standard to work, the specified sound level must be achievable and the total noise from the worst typical array of acceptable plant must not constitute a significant risk of hearing impairment.

This paper describes how the margin between noise from single items of plant and arrays of plant was established; and briefly discusses the propagation of sound in large factory spaces. It describes, by means of case studies, the control of noise at source which the Company noise standard for new plant has encouraged. The paper concludes with an assessment of the effectiveness of the policy so far.

MAXIMUM PERMISSIBLE SOUND LEVEL FOR NEW PLANT

Before 1970, the available criteria for hearing impairment due to occupational exposure to noise were in the form of octave band spectra. The levels quoted were at, or close to, Noise Rating 85 which is equivalent to 87 to 90dB(A) for a wide variety of typical factory noise spectra. The original Company proposal for a maximum permissible sound level for new plant was Noise Rating 82 so that the noise exposure of an operator working between two such machines would not exceed the existing criteria. However for plant acceptance tests it was highly desirable that a single figure criterion should be used rather than an octave band spectrum, because Lucas companies were purchasing over 800 items of new plant per annum. It was felt that a simple test procedure giving a single figure assessment was likely to be more successful than one requiring frequency-selective measurements. In 1970 Burns and Robinson (1) proposed a procedure for estimating the risk of hearing impairment from occupational noise based on A-weighted sound levels. It was decided to revise the draft standards so the exposure in the "worst typical" cases could not exceed 90dB(A) (continuously or recurrently) when all the plant installed in a workshop complied with the Company noise standards.

TECHNICAL MEASURES TO CONTROL NOISE

An examination of the worst typical cases was made by studying arrays of plant which were known to be noisy, and calculating the cumulative sound level at an operator's ear position as each individual item of plant in an array is switched on. Efforts to calculate the "reverberant" sound level using the classical acoustic theory gave estimates which were up to 10dB(A) higher than measured reverberant sound levels in typical Company factories. Calculated values of directly-radiated sound were combined with measured levels of "reverberant" sound to give the results shown in Fig 1. The three curves show the cumulative sound level at an operator's position as each item of plant is added to the array for three sizes of plant:-

(a) "Large" machines are assumed to act as effective barriers to directly radiated sound from plant in the array on the far side to the operator's workstation. In typical arrays of large automatic lathes, presses etc., an operator may be close to only three machines. For the purpose of the calculation, such large items were assumed to cause sound levels of 85dB(A) up to a distance of approximately 2m from the projected plan, all around the machine.

(b) Small single spindle auto's, small presses and other items of plant, which are low enough in height to allow directly-radiated sound to reach the operator from all machines in an array, give rise to a higher cumulative level. Cylindrical radiation was assumed close to the source, barrier effects were incorporated using Maekawa's formula (2) and the operator's ear was assumed to be 0.8 metre from the principal noise source of one item of plant. The worst typical array was assumed to be a double-row, with 1.7 metres between plant centres in each row (interleaved stock tubes for automatic lathes). For the purpose of this calculation it was assumed that each machine (and its stock tube) generated a sound level of 85dB(A) at the operator's position and at all points one metre outside the projected plan and 1.5 metres above the floor level.

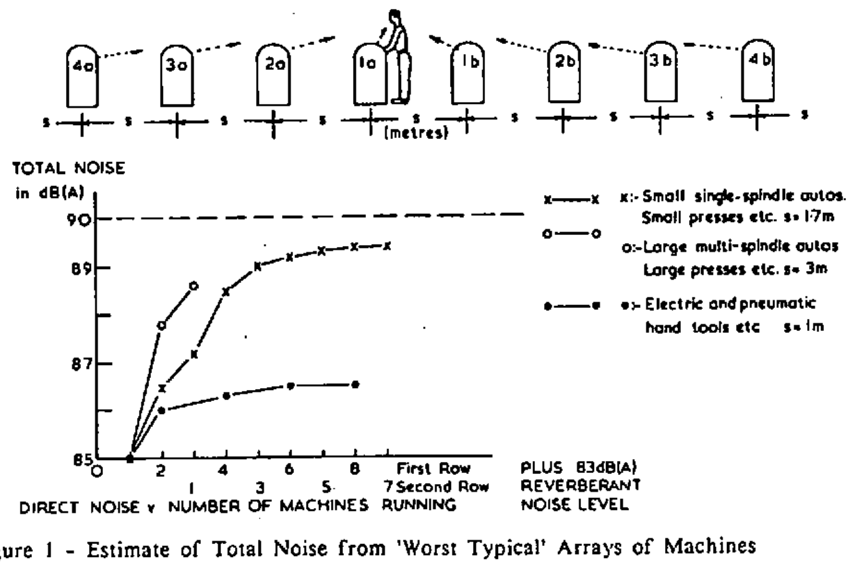

Figure 1 - Estimate of Total Noise from 'Worst Typical' Arrays of Machines

TECHNICAL MEASURES TO CONTROL NOISE

(c) Hand tools, such as hand-held or bench-mounted pneumatic drills, chisels or electric drills, are often held so that the principal sound source is approximately 0.3 metre from the operator's ear. The closest possible spacing on an assembly line is 1 metre between centres. For the purpose of this calculation the machines were assumed to be small omnidirectional sources, each individually producing 85dB(A) at the operator's ear position.

The total direct and "reverberant" sound is shown to the right of Fig 1 by short horizontal lines; and it is clear that if plant is to be installed in densely-packed arrays, approximately 5dB(A) margin is required between the maximum permissible sound level of a single item of plant and the sound level to which an operators ear is exposed.

It was intended that Company production engineers, works engineers and the plant engineers would measure the noise emitted by new plant during the acceptance tests. These tests cover a wide range of performance and safety issues. An additional margin of 2dB(A) was added to allow for acoustic conditions at the test site (which was not usually the final site), industrial grade sound level meter tolerances, and variations in microphone position. As a result of this study, the maximum permissible sound level for new plant was set at 83dB(A), to be measured while the plant was operated at the noisiest normal working condition within the manufacturers specification.

Before this standard was issued, serious thought was given to the possibility of limiting the maximum permissible sound level for new plant to achieve 85dB(A) in Company factories when all the plant was operating normally. Such a requirement would would have reduced the maximum permissible sound level for new plant to 78 or 80dB(A). Experience at that time showed clearly that most plant manufacturers were not able to modify their existing designs sufficiently to comply with an 80dB(A) requirement; and consequently the standard would fail because it could not be implemented.

Sound Power v Sound Pressure

From time to time the new plant noise purchase standard, and the other noise standards, are reviewed. In view of the increasing volume of international standards specifying methods for measuring sound power for all types of machinery (from microcomputers to tower cranes), serious consideration was given to incorporating a sound power limit into Lucas standards. With the aid of a computer-based analyser which has been described in a previous paper (3) the sound level was measured at a large number of microphone positions around 5 machines (a large lamination press, two lathes, a fuel injection pump tests bench and a compressor).

The press was equipped with a "roller drive" mechanism to feed strip from a magazine coil into the press as required. This drive was relatively quiet, so by treating it as part of the same machine as the press, it provided an excellent opportunity to study the effect of the microphone array upon the precision of the sound power estimate. The "reference surface" described in British and International Standards (4,5) was taken as the imaginary rectangular box which just enclosed both the press and the roller drive mechanism. The "measurement surface" was the rectangular parallelepiped with surfaces 1 metre outside those of the "reference surface". The press noise was recorded and analysed at 85 microphone positions on the measurement surface. From this bank of data, several likely combinations of microphone position were chosen to calculate estimates of the sound power. These estimates varied with the number of microphone positions as shown in Fig. 2. Fig. 3 shows a sketch of the press and the optimum measurement positions.

TECHNICAL MEASURES TO CONTROL NOISE

The table below compares the estimates of sound power level using the microphone arrays specified in ISO standards 3744 (4) and 3746 (5) with estimates from other microphone arrays which are easier to use on the factory floor. It should be noted that the error introduced by measuring at a small number of positions is less than the accuracy tolerance of IEC 651 Type 1 Sound Level Meters. There seems to be a strong possibility that the microphone arrays specified in the ISO documents are not optimised and those specified in ISO 230 part 5 on machine tool noise seem to be better.

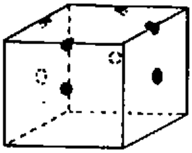

Figure 4 - A Simple Microphone Array, to provide a sufficiently accurate estimate using 8 positions

Table 1 Sound Power Estimates (dB(A)) for several machines

M/C	All Points	ISO 3744	ISO 3746	4 Corners 2 Heights	As in Fig. 4
Compressor	102.1 (70)	102.1 (17)	102.4 (8)	101.9 (8)	102.5 (8)
Large Press	103.8 (85)	103.3 (17)	102.9 (8)	103.2 (8)	102.0 (8)
Lathe	100.8 (41)	100.9 (9)	100.6 (8)	100.9 (8)	100.7 (8)
Small Lathe	94.1 (43)	93.6 (8)	95.2 (8)	92.5 (8)	93.7 (8)
Pump Test Bench	104.0 (16)	104.5 (8)	104.4 (8)	103.1 (8)	104.7 (8)

Note The number of measurement positions is shown in brackets.

Having explored some of the other aspects of sound power measurement and its use to specify noise of machine tools, there seemed to be no real advantages for the interpretation and calculation of operator exposure. Therefore the Company standard for noise of new plant for use inside factories specifies the maximum sound pressure level at the operator's workstations.

IMPLEMENTATION OF PLANT PURCHASE STANDARD

One of the most intractable noise problems faced by Lucas Companies has been the high speed, high capacity presses which stamp out laminations for electrical machines. The material for laminations is brittle and a large capacity press is required to produce the toothed pattern to accommodate the windings. Many laminations are required for each machine so high speeds are essential for economic manufacture.

TECHNICAL MEASURES TO CONTROL NOISE

Noise from presses is greatly influenced by the design of the tooling, which is usually ordered from a different supplier. Responsibility for complying with any noise limit is divided between the press supplier, the tooling supplier and the manufacturer of safety guards. As a result it is difficult to ensure that new presses comply with Company noise standards before they have been installed within Company premises.

When the "Noise of New Plant and Equipment" standard, and other noise standards, were issued, "awareness" courses were run by the Lucas Industries Noise Centre and by individual Lucas companies. To provide the resources needed to implement the standards separate intensive courses were run by the Noise Centre on "Noise Measurement" and "Noise Control". By the mid 1970s, over 200 engineers had attended the "Noise Measurement" Course which included a closely-supervised practical session, and over 1700 engineers had attended the "Noise Control" Course. A special combination of these courses is run by Lucas Industries Noise Centre for the Institution of Mechanical Engineers ("Practical Noise Control").

CONTROL OF SOUND PROPAGATION IN FACTORIES

It has been evident for many years that reverberent sound levels predicted by the classical acoustic theory do not agree with the actual measured levels at some distance from noise sources in large factory spaces. In an effort to develop a more appropriate calculation Wilson (6) measured the attenuation of sound with distance in two similar large factories, one of which had an acoustically absorbent ceiling. The measurements were made with a small sound source which was omnidirectional up to 2kHz, and within 5dB of omnidirectional up to 4kHz. The A-weighted results are presented in Fig 5 and the rates of attenuation of sound with distance are summarised in the table on the next page.

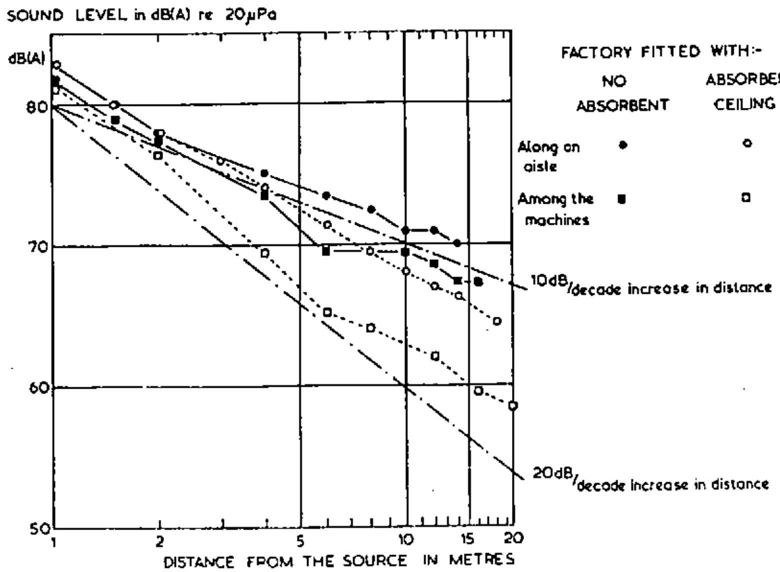

Figure 5 - Propagation of Sound in Large Factories

TECHNICAL MEASURES TO CONTROL NOISE

Line of measurements made :-	Rate of sound attenuation with distance in Lucas GFD factories	
	Reflective Ceiling	Absorptive Ceiling
along an aisle	3dB/(2 x dist)	4.5dB/(2 x dist)
across machine lines	3.75dB/(2 x dist)	5.5dB/(2 x dist)

No evidence of a reverberant sound level was found; but additional measurements with octave-band filtered random-noise showed vestiges of standing waves in broad aisles. It seems that scattering of sound by the machines reduced the influence of standing waves at heights up to 2 metres. In the factory without the acoustically absorbent ceiling, the rate of decay of sound along an aisle suggests a cylindrical radiation pattern, as if the source and its images in the reflective floor and ceiling approximated to a line source.

For large factories such as the 80m x 60m x 10m high workshops in which the tests were made, it seems that constant decay rates with distance give better working approximations to the sound propagation than the classical direct plus reverberant sound levels. These results have rather serious implications for the "correction for acoustic environment" which is specified in sound power test codes based on ISO 3744 and ISO 3746 (4,5).

A practical application for Wilson's working approximations occurred when two new lamination presses were to be installed in a Company workshop with other, quieter plant. There was considerable concern about the noise caused by these presses in neighbouring areas of the workshop, as well as concern for the noise exposure of the operator and setter. The presses were installed in a workshop with an absorbent-lined roof, which effectively controlled the sound reflected towards the operators of neighbouring plant.

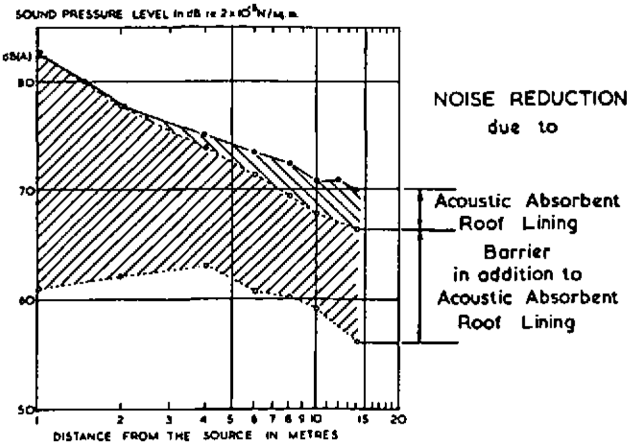

Figure 6 - Effect of Barrier in Factory Lined with Acoustic Absorbent

TECHNICAL MEASURES TO CONTROL NOISE

The workshop was equipped with a sprinkler system for fire fighting, a large ventilation system, area lighting and light cranes, all of which would have to be duplicated inside any acoustic enclosure. Hence control of sound propagation by an absorbent-lined barrier was a much more attractive proposition. The reductions achieved in this workshop are shown in Fig 3, using the small sound source used for previous measurements. Even when both presses are running, the noise is barely discernible in the rest of the workshop, where the total sound level from all the other plant rarely exceeds 85dB(A). If either the barrier or the absorbent ceiling had been used alone, the noise from the presses would have caused complaints.

NOISE CONTROL CASE STUDIES

Application of Close Shielding to Production Plant

In well-built box-frame presses, much of the sound is radiated from the apertures which open onto the tooling including:-

a) front and rear apertures for installing and setting the tooling
b) side apertures for stock ingress and scrap egress
c) apertures for product egress below the tooling

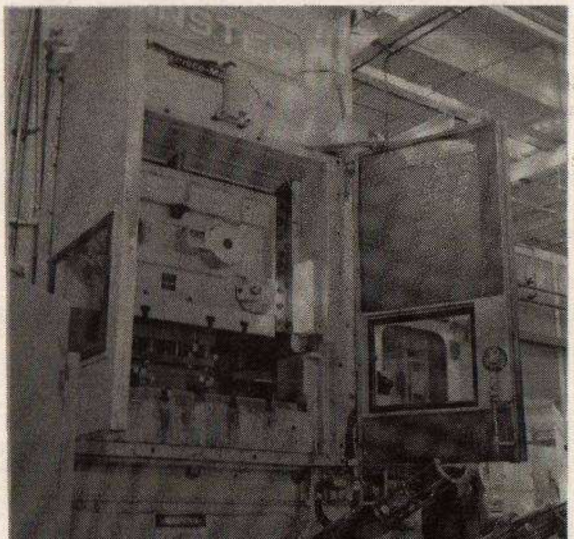

Figure 7 - Close Shields to Control Noise from a 150 Ton Lamination Press

It is possible to design the safety guards for presses so that they also reduce the noise radiated via the major apertures in the press frame. If additional covers (or lined ducts) are fitted over the other apertures which open onto the tooling, it is possible to contain the noise from this area. Reductions of 9dB(A) or more have been achieved with lamination presses and a bar-cropping press. However when treating a new type of press it is advisable to assess the contribution to the total noise which is radiated from the tooling and associated surfaces before specifying this treatment.

TECHNICAL MEASURES TO CONTROL NOISE

The construction of sound-attenuating guards and covers was developed from the "close shields" which were applied to crankcase and water jacket panels of diesel engines when it was not possible to modify the block casting (7). Fig 7 shows the close shields fitted to one of the high speed lamination presses which were mentioned in the previous section. Large glazed areas on both sides of the press allow the operator to observe the tools during operation. On the inside, the shields are lined with mineral wool acoustic absorbent which is protected by plastic film and perforated steel sheet. This has proved sufficient to prevent any increase in sound level in the enclosed space which might otherwise detract from the shielding effect. These shields have been in use for 8 years without needing any maintenance.

In addition to the treatments described, most of the tools used in these presses have multiple punches which can be staggered to reduce the impulsive loads applied to the press. The sound level has been measured at the operators ear position, and with various tools in use, the measured sound levels range from 81.5 to 88 dB(A).

It is possible to apply the techniques developed for reducing the structure response of diesel engines (7,8) to many production machines. An example of this approach occurred when manufacturers of a centre lathe could not meet the Company Standard for noise of new plant and equipment, even with improved gear manufacturing methods. The maximum permissible sound level was exceeded when the lathe was running at high speeds with very light loading due to noise from the main gearbox. When the surface vibration and noise radiation from the centre lathe were examined by the method described in an earlier paper (5):-

1. The main gearbox casting had several normal modes with natural frequencies close to gear machining frequencies.

2. The main gearbox radiated noise radiated noise directly towards the operator, and into a central cavity within the pedestal, from where it escaped via several small holes.

3. Small sheet metal covers radiated significant contributions to the noise.

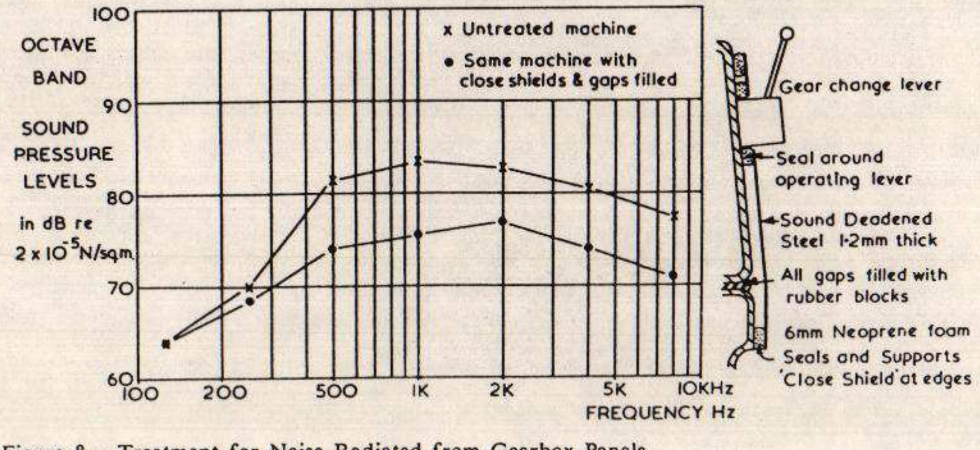

Figure 8 - Treatment for Noise Radiated from Gearbox Panels

TECHNICAL MEASURES TO CONTROL NOISE

Two interesting results came out of these tests:-

1. Providing that the microphone positions were distributed uniformly over the measurement surface, and preferably not at the corners and edges of the measurement surface, the precise placement of the microphones was not important.

2. To achieve < ± 1 dB(A) error due to microphone placement alone, the estimate of sound power should be made from 12 microphone positions; if ± 1.5 dB(A) is adequate, 8 microphone positions will do.

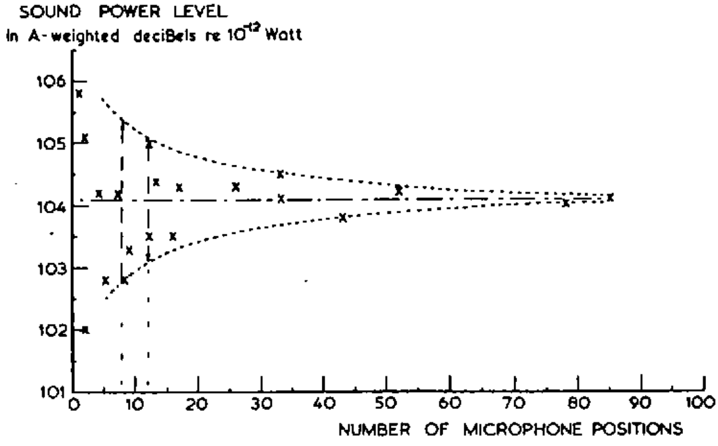

Figure 2- The Number of Microphone Positions Affects Precision of Sound Power Estimates

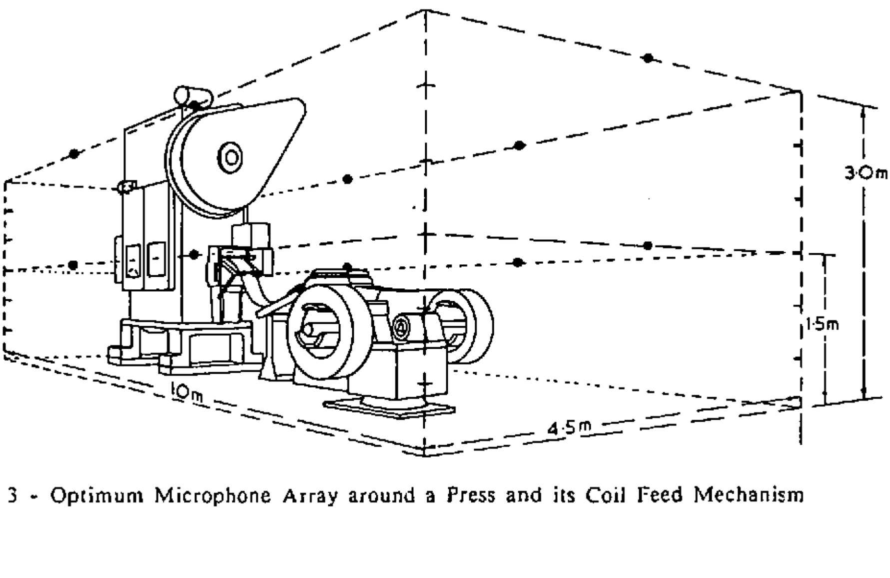

Figure 3 - Optimum Microphone Array around a Press and its Coil Feed Mechanism

TECHNICAL MEASURES TO CONTROL NOISE

A package of treatments was devised, which reduced the sound level at the operators position by 5dB(A), comprising:-

1. Thick gaskets to seal the small gaps between the pedestal components.

2. Constrained layer damping for the small sheet metal covers.

3. A close shield, resiliently mounted off the face of the main gearbox covering those areas of the gearbox and the top half of the pedestal which radiated most noise.

The package of surface treatments was relatively easy to apply to existing lathes and standard production machines, and design improvements could be substituted for these treatments as the lathe was developed. Fig 8 shows how this package reduced the noise by 5dB(A) to meet the Company requirements, with some margin for the likely variation in gear noise from production samples.

Noise control at source

A bandsaw, which had been purchased for cutting bar stock into discs for chucking autos, was found to emit a piercing screech when a new job required that it cut 75mm dia. bars of tough alloy steel. The sound level could reach 90dB(A) near the machine and the loud tone could be heard in the housing estate 200 metres from the works, particularly when the roller door of the delivery bay was open. During the preliminary measurements, the Noise Centre identified blade vibration as the cause of the noise and began calculating the various natural frequencies of the blade. A second machine had been ordered; and the suppliers, Addison Tool Co., were asked if they could reduce the noise of the new machine to meet Lucas Standards whilst cutting tough steel bar. The new machine was supplied with two ball bearings mounted on a turntable which could be rotated to lightly grip the blade on the tight side of the cut. This device damped the vibration in the blade. The reduction in noise was dramatic, as shown in Fig 9 and a similar device was fitted to the original machine. This is a very cost effective noise control treatment, and much to the credit of the machine manufacturers.

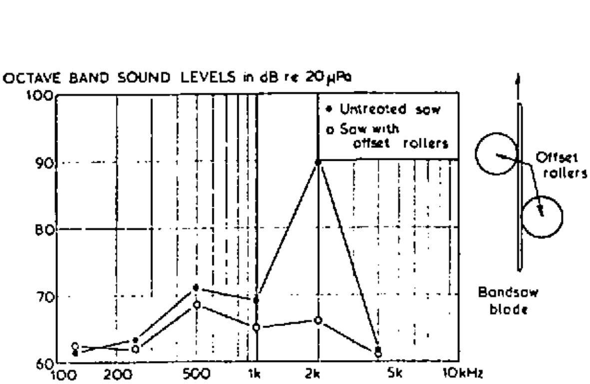

Fig 9 - Noise Reduction Obtained by Inhibiting Flexural Vibration of a Bandsaw Blade.

TECHNICAL MEASURES TO CONTROL NOISE

Milling Machine Noise was reduced by 9dB(A), by Company Reliability and Production Engineers when they were faced with a noise problem which varied in intensity with each batch of specially-purchased stock. The noise was radiated by the milling machine when it was used to slice small components from special hot-rolled bar stock. It was reduced by attaching a lead flywheel to the arbor of the milling machine, which both de-tuned and damped the torsional resonances. This solution cost a few pounds to implement, required no maintenance, created no obstruction to the access by the operator, caused no additional safety hazards, and was a great deal cheaper than the alternative local enclosure of the milling table. The flywheel and cutters are shown in Fig 10.

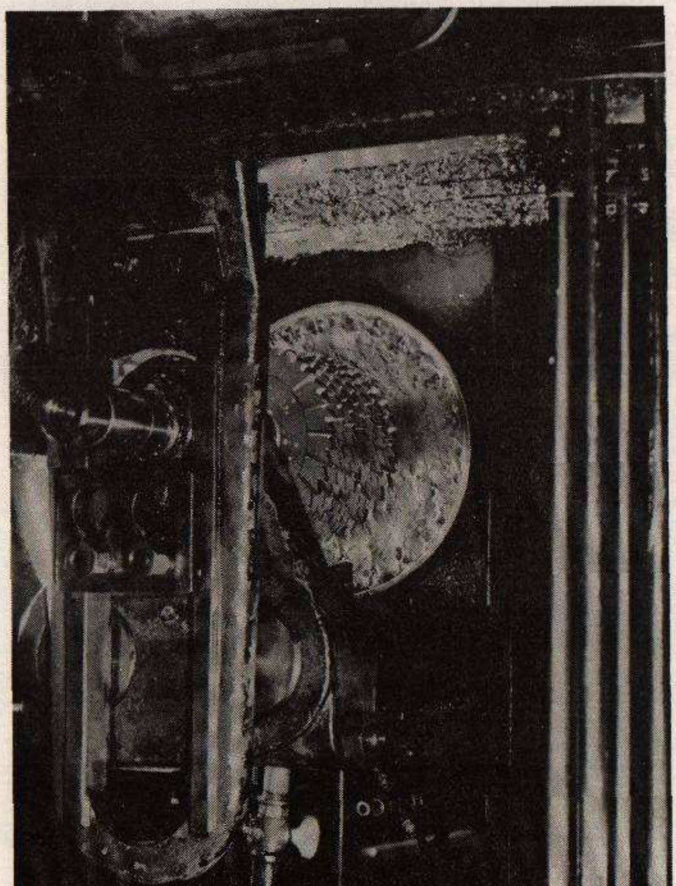

Figure 10 - Lead Flywheel Attached to Milling Cutter Shaft to Reduce the Noise

OVERALL EFFECT OF NOISE CONTROL STRATEGY

Although the control of noise from new plant and equipment is only one part of the overall strategy, it is the part that has had most influence on the actual noise levels in Company factories, because many machines were replaced during the 1970s. In addition some plant manufacturers have been able to comply with the Company requirements when reconditioning existing plant. Lucas Industries Noise Centre have made appropriate noise control technology available to Lucas plant suppliers' and providing education, training, consultancy, diagnostic measurements, advice on alternative noise control techniques and proposals for noise control designs. The best results have been achieved when there has been close cooperation between the Company engineers and plant suppliers' engineers as indicated in an earlier paper (9). In one particular factory one could walk from the area which was equipped before the noise of new plant was controlled in which the sound levels range from 87 to 90dB(A) to the area which was equipped later and hear an appreciable reduction in sound levels.

ACKNOWLEDGEMENTS

The author is grateful to the directors of Lucas Industries plc and Lucas CAV Ltd for permission to publish this paper. The control of noise in Lucas factories is the result of the coordinated efforts of production engineers, works engineers, suppliers of new plant and members of Lucas Industries Noise Centre. The author is pleased to have this opportunity to acknowledge their contributions.

REFERENCES

1. W Burns, D W Robinson "Hearing and Noise in Industry" HMSO 1970 SBN 11 760022 9.

2. Z Maekawa "Noise Reduction by Screens" Applied Acoustics 1 (1968) pp 157-173.

3. S Worley "A Better way to Measure Sound Power" Proc "Inter-noise 83" Vol II pp 1059/62 Institute of Acoustics ISBN 0-946731-02-0.

4. BS4196 Part 4 1981 ISO 3744 "Engineering Methods for Determination of Sound Power Levels for Sources in Freefield Conditions Over a Reflecting Plane" British Standards Institution.

5. BS4196 Part 4 1981 ISO3746 "Survey Methods for Determination of Sound Power Levels of Sources British Standards Institution.

6. P M Wilson "A Pragmatic Look at Sound Propagation in Real Factory Spaces" Proc Inst of Acoustics Conference on Noise Control in Factory Buildings.

7. M F Russell "Reduction of Noise Emissions from Diesel Engine Surfaces" Society of Automotive Engineers Congress Detroit Jan 1972 Paper 720135.

8. M F Russell "Towards Quieter Diesels" (I Mech E) Journal of Automotive Eng Vol. No 9 Dec 1970 pp 5-10.

9. M F Russell "Machinery Noise, the Users Viewpoint" Proc 17th Machine Tool Design and Research Conference Birmingham University 1976.