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HSE CONTRACT RESEARCH REPORT No. 28/1991

# INVESTIGATIONS OF MACHINERY NOISE REDUCTION AT SOURCE

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ISVR, Southampton University
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Price £20 00

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Techniques of noise reduction in many machines by palliative means have long been documented. The work described here is intended to demonstrate the benefits which can be achieved in convenience and cost effectiveness by preceding the noise control measures with a proper diagnosis of the sources of noise generation and then addressing them by engineering means. On two sample footwear manufacturing machines noise reductions of between 4 and 10 dB(A) are obtained with no compromise on accessibility or machine function.



This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

## Introduction

1. The effects of high noise levels in industry, ranging from annoyance with the attendant reduction in concentration and efficiency to noise induced hearing loss are well documented. That efforts to reduce such levels should be taken has also long been acknowledged. Both employers and machinery manufacturers are finding increasing legal weight behind the exhortations to action, with gradually increasing statutory requirements on the manufacturers. Duties falling upon machine manufacturers were included in the Health and Safety at Work etc Act 1974 (the 1974 Act) and have been restated and amplified in the Noise at Work Regulations 1989 (the Regulations). Additional duties will arise as a result of the implementation of the EEC Machinery Safety Directive, due by December 1992.

2. The duties on employers stated in the Regulations also amplify those of the 1974 Act and include the requirement to "...reduce, so far as is reasonably practicable (other than by the provision of personal ear protectors), the exposure to noise....". That duty might involve reducing the noise emission of a machine by palliative measures (enclosures etc), engineering effort to reduce the actual generation of noise in the working process, a change in the method of use of a machine or even the adoption of a completely different production process.

3. Past emphasis on palliative treatments will need to change as the noise control effort progresses and new quieter machines are required by industry. Similarly the continuing cost pressures on all sectors of industry must be taken into account in assessing the limits of "reasonable practicability". **As part of their continuing effort to encourage both users and manufacturers to make proper use of existing technology, the Health and Safety Executive wanted to show how noise reduction at source can be a better and cheaper option if proper investigation and analysis of machine operation and noise generation is applied.**

4. Two machines in use in the footwear industry were selected to illustrate some of the techniques and the benefits which could come from their application The work was carried out by staff of The Wolfson

Unit for Noise and Vibration Control (now known as ISVR Consultancy Services), a part of the Institute of Sound and Vibration Research at Southampton University, and with the active cooperation of the Shoe and Allied Trades Research Association. There follows a summary of the research results which provided noise reductions of between 4 and 10 dB(A) at the operator position.

5. Within the footwear industry a number of workers are subject to daily equivalent personal noise exposure, $L_{EP,d}$, in excess of 90 dB(A). At this "second action level" as defined in the Regulations there is now a duty on the employer to reduce the noise emission of machines if this is possible. The daily exposure of 90 dB(A) equivalent has long been regarded as a trigger level, above which positive actions would be needed.

6. Much of the necessary work to reduce noise emissions must take the form of detailed attention to individual machine types and a careful appraisal of the processes and operating regimes of these machines in order to reduce noise for operators and those nearby.

## The Source of the Problem

7. The noise exposure of operatives in the footwear manufacturing industry varies considerably but the majority of their exposure is attributable to the operation of the various machines involved in the shoe manufacturing process. The range of machines needed to cover the production of welted and unwelted shoes, some stitched some stuck, some highly automated some virtually hand made, is large and their potential for generating noise covers a wide range. In addition the layout of factories is not standardised and the density of packing machines and operatives together varies, with the attendant variation in the noise exposure attributable to the operation of nearby machines.

8. Some background noise exposure results from the operation of heating systems, extract fans, ancillary items such as air compressors, trolleys for internal transfer of work in progress and similar sources not

specific to the footwear industry These sources should not be forgotten as they can quickly become important when a few individual machines have been subject to detail attention.

9. The noise exposure of an operator is likely to be dominated by the noise from his or her own machine, though that cannot be taken to mean that reduction of that noise source alone will ensure an adequately low exposure level for that operator. Within the range of machines in the footwear industry the main sources of noise generation will be from the operation of mechanisms driven continuously (normally by electric motors) or intermittently (frequently pneumatically powered and perhaps subject to automatic sequencing after operative initiation of the work cycle).

10. Within the first category the mechanisms vary but many of them, for instance sewing machines and the rounding and channelling machine described later, involve a combination of rotary and reciprocating elements to fulfil their task. The versatility of these machines may be achieved by the use of adjustable elements in the mechanism. Though continuously driven the function of the machine may be impulsive in nature.

11. In the second category, of which the insole attacher described later is a good example, the operation is almost entirely impulsive and the operative noise exposure may be made up from the contributions of a large number of sources, none of them markedly greater than the others.

12. In virtually all machines there exists a potential for increased noise output as a result of wear, poor setting, operator abuse and lack of maintenance.

## Noise Reduction on a New Machine - the Unifast Insole Attacher

13. The Unifast insole attacher was chosen as an example of the intermittent operation machines in current production. The tests and noise reduction effort on this machine would be directed to isolating the noise sources and showing how they could be reduced by attention to design details which could be incorporated on new machines, but also

offered as a retrofit package or incorporated when machines were refurbished. The machine is illustrated in figure 1 and its operating sequence is as follows:

The operative places the inverted last into the machine and positions the insole on the last bottom.

Operation of the control lever causes a single pneumatic cylinder to lift the last towards the two hammer cylinders, making contact with the hammer faces and pressing them into the cylinders.

Internal valving in the cylinders is operated by the inward movement of the hammers and causes an internal piston to be fired pneumatically downwards, contacting the upper end of the hammer and delivering a blow which forces the insole onto captive spikes on the last.

Releasing the operating lever allows the last lift cylinder to exhaust and the spring return on the last lift mechanism draws it clear of the hammers and allows the last with insole attached to be removed.

A nominal throughput of 250 pairs per hour is expected for the machine.

14. Noise measurements obtained at a notional operator's ear position with the machine, a "used" but serviceable one, working in an anechoic chamber separated the contributions from the last lift mechanism and the two hammers, by selective operation of the hammers, and gave the following results, corrected to a throughput of 250 pairs per hour:

| | $L_{eq}$ dB(A) |
|---|---|
| Last lift only | 78.5 |
| Last lift and toe hammer | 83.7 |
| Last lift and seat hammer | 84.5 |
| Last lift and both hammers | 86.0 |

If the work rate were maintained from the duration of the samples used to a full day, then the value for $L_{eq}$ quoted above would become valid as $L_{EP,d}$. Under factory conditions with a partially reverberant surrounding and other similar machines in the vicinity the actual operator exposures would be higher by typically 2 to 4 dB(A), confirming that the insole attacher certainly comes above the first action level and may in some cases give rise to levels above the second action level (1). The increase should be closer to the lower figure because the operator is necessarily very close to the sources of noise on his own machine.

15. This machine gave a useful diagnostic insight into the design, both subjectively and by partially dismantling the hammer sub assemblies. It was clear that the noise from the last lift could be reduced if its lift and drop were at a more controlled speed or were cushioned at each end of the travel. Though this would make only a small change in the overall noise emission it would be subjectively welcome. The hammers both produced noise from the effects of their impulsive operation on the machine frame and from the air exhaust. Though the main hammer exhausts were through a form of silencer, this was subject to progressive deterioration and there was also a subsidiary exhaust at the base of the hammer, which for the seat hammer was in direct line of hearing of the operator and quite close to ear level.

16. A second series of tests was carried out on a new machine, situated in the maker's works. Again the results quoted are corrected to a work rate of 250 pairs per hour, but because of the different acoustic environment they cannot be used to give a "new versus old" comparison with those quoted in 14 above. The tests used the machine as designed and then fitted with a package of alterations devised as a result of the tests on the first machine and agreed with the manufacturer as practicable for new build and retrofit. These consisted of:

Revised hammer top mountings as indicated in figure 2. These were designed to be more robust than those previously fitted (which were in any case known to have a short life) and also to be effectively fail safe

Revised bottom mountings for the hammers, figure 3, incorporating an exhaust air collection chamber from which the air could be piped to a silencer inside the main machine body.

A small extension for the seat hammer cover, removing the direct line of sound from the auxiliary air exhaust to the operator's ears.

No action was taken in respect of the last lift, as this new machine showed a sensibly slow rise and fall of the last lift mechanism and therefore did not create the impact noise experienced on the first one tested.

17. The sound levels measured with the standard and modified machine parts using the same set of operating conditions as before were:

| | Standard $L_{eq}$ dB(A) | Modified $L_{eq}$ dB(A) |
|---|---|---|
| Last lift only | 68.0 | 68.0 |
| Last lift and toe hammer | 86.4 | 83.2 |
| Last lift and seat hammer | 81.7 | 79.1 |
| Last lift and both hammers | 87.9 | 83.7 |

Once again some allowance in the absolute values might need to be made for industrial use in more reverberant surroundings, but it would appear likely that the modified machine in "as new" state would give rise to an operator exposure below the first action level. The acoustic conditions should have only a very small effect on the difference observed between the standard and modified machine noise.

18. Several qualitative observations were made on this new machine and are worthy of record as they have an influence on the noise generation and durability.

The operation of the last lift was much more controlled on the new machine than on the old one previously studied. This was due to the correct fitting and adjustment of the air regulator for the lift and restrictor for the lowering phase. It would appear that on the old machine poor maintenance or deliberate "adjustment" outside the manufacturer's instructions were responsible in part for the excessive rattling from the operation of the last lift. This feature is all too common in machines found in service and certainly not restricted to the footwear industry.

One aspect of the rattling on the old machine came from the heel support which only rested in the lifting arm. On the new machine it was restrained and this provided noise reduction as well as operational improvement.

19. It was revealed in discussions with the machine makers that the hammer was developed from a nail gun used in the furniture industry. The internal arrangement of a large piston contacting a slender piston rod which then contacted the even slenderer nail is correct for the transference of energy in an impact process. However as used in this application the slender piston rod contacts a hammer carrier with a much greater cross sectional area and this will tend to result in the energy being transferred as a series of impacts or at best a single impact with a considerable fluctuation within its force-time history, thus leading to additional noise generation. It was outside the scope of the investigation to go deeper into the design of the machine, but this observation would suggest that there could be benefit from some internal redesign of the lower part of the hammer to improve energy transfer and increase efficiency.

20. Ultimately the wisdom of using a compressed air impact system might be questioned. The effort in manual last attachment, with a small hammer wielded in one hand 17 times a minute would not be classed as hard physical labour. The insole attacher has an air consumption rated at between 0.7 and 1.0 cubic feet per minute free air delivery which would require between 200 and 280 watts of installed compressor power (based on a conversion rate of 3.5 cfm raised to 80 $lbf/in^2$ per kW). Electro-magnetic actuation for small impact presses is now becoming available and there may be scope for the adoption of such an operating system

## Noise Reduction on an Old Machine

21. The old machine chosen for this exercise was a Universal Rounding and Channelling Machine (URC), sometimes known as a sole edge trimmer, and it is well known as a high noise generator. This employs a reciprocating knife which cuts on its forward face (much as a chisel onto a paring block) through the thickness of a welt or sole to clean up the profile around a shoe. The design of this machine goes back many years and it is long since out of production, however the relative resilience of the welted footwear trade has been responsible for a continued demand for the machine and a small number are recycled.

22. The machine is illustrated in figure 4 with the major operating items indicated. In use a shoe is put to the machine, sole side inwards, with the clamp and feed on the top of the welt, the welt to upper join being pressed up onto the tip. The knife moves back and forth, cutting through the leather onto a brass insert in the clamp and feed lever. With an additional motion the clamp advances the shoe when the knife is retracted and the channelling knife, when fitted, cuts the slit in the sole of the shoe which will later be sealed over the stitching.

23. The throughput can vary with the size of the shoe and the length of the welt. In normal use the machine is running continuously and shoes will be taken from a rack, processed and replaced. When a rack has been completed the machine will be left running whilst the rack may be taken to the next operative, and a replacement collected. Thus where there are a number of machines grouped together the noise exposure will be a combination of the noise from an operator's own machine working and idling whilst taking shoes from the rack, and from his neighbours' both working and idling.

24. In a factory survey undertaken by SATRA following the results of this laboratory investigation, the time in handling a rack of shoes was found to be 7 minutes, of which 3 minutes were occupied in rounding whilst 4 minutes were machine idling time (2).

25. This machine has the characteristics mentioned in the introduction in taking a uniform (rotary) motion and then modifying this with mechanisms to provide a diversity of speeds and reciprocating motions. Some of the mechanisms are quite slow running as exemplified by the cam used to vary the width of the trimmed welt around the profile of the shoe whilst the knife will be operating at a rate of 900 strokes per minute with the normal pulley ratios.

26. As received the machine was known to be in a worn state, and it was found that there was an insignificant difference between the noise when cutting leather and when idling. With the aid of a variable frequency supply to the motor it was established that the noise was rising approximately with the fourth power of speed, indicating a moderately impulsive loading characteristic though not having quite the explosive violence of diesel engine combustion noise. Subjectively the noise was characterised by a rattling and as the graph, figure 5, shows, the addition of some lubrication, by means of the sight glass oiler visible in figure 4, did produce some worthwhile noise reduction at lower speeds though progressively less at higher speeds.

27. The nature of the mechanism was not particularly convenient for the progressive removal of parts for diagnostic purposes, since items tended to be driven one from another. Hence the removal of a heavy item from the end of a drive line would give a noise reduction if it had been rattling itself or if a weaker link in the line were worn and rattling in response to the inertia loads. Some results were however obtained both by manually restraining and removing those parts of the mechanism which could conveniently be approached. All results were obtained under anechoic conditions without cutting, and with the microphone placed at a typical operator's ear position.

| Condition | Sound level dB(A) |
|---|---|
| As received | 89.9 |
| Feed clamp restrained | 88.9 |
| Feed clamp and channelling knife block restrained | 86.3 |
| Channelling knife slide removed | 87.3 |
| Feed assembly removed | 84 8 |

28. The mechanism is a complex one and a full description would be out of context here. It should be noted however that it contained not only shafts and sliders for the cutting knives, but also cams having profiles on both faces and edges to impart movement in two directions to, for instance, the clamp and feed shoe which is mounted on the end of a shaft driven by two cam followers to both reciprocate and have a small rotational oscillation. Examination showed that in the majority of running fits where the typical dimensions were in the 15 to 30 mm range, diametral clearances had increased from an anticipated 0.15% to over 0.5%, a change which would justify the description "worn" but which had not rendered the machine unserviceable.

29. To evaluate the effects of these degrees of wear, the machine was returned to the manufacturers for a standard rebuild. As mentioned earlier it had not been returned from its previous users because it was considered unserviceable, nonetheless it would have been subject to some refurbishment before being passed to a new user. The state in which it was finally presented for testing should therefore represent that in which it would have been returned to service.

30. When retested at its standard operating speed of 900 rev/min at the cutting head, the sound levels found at the operator's position were 85.9 dB(A) idling and 80.2 dB(A) when cutting. These represent reductions of 4 and 9.7 dB(A) respectively and can be described as significant.

31. The retest results indicated that the basic machine design, in good running order and properly lubricated, need not be a source of excessive noise generation. The scope of the investigation did not however extend to any long term work to assess the rate at which the "as new" noise performance would deteriorate in normal use. There is hearsay evidence that the rattling characteristic of a worn machine was apparent on a particular machine a relatively short time after a rebuild, but there was no comparable experience of the performance of that machine immediately after the rebuild.

32. In many respects the URC provided a good example of a class of machine where some fundamental redesign of the <u>parts</u> of the mechanism, but not the kinematics which control its successful function could give benefits in noise reduction and long term durability, the latter likely

also to give better long term noise stability Such a process would have been inappropriate for such a small number of machines in service but similar cam designs were redesigned and the results reported as part of the SERC specially promoted programme on high speed machinery, where a sweet wrapping machine was the object of attention (3).

34. Of more practical application to the URC would have been the adoption of intermittent operation particularly in the light of the high noise produced, whether as new or worn, when the machine was idling. In use a foot pedal has to be depressed to open the clamp mechanism before the welt of the shoe is inserted into the cutter, and this action could be used to activate the drive motor. When a shoe is being processed the clamp is kept partly open by the thickness of the material, but when the shoe is removed the clamp returns, spring loaded, to its rest position. The most practical solution therefore appears to be the inclusion of a microswitch to the clamp mechanism to disable the motor when the clamp is closed. By reducing noise generation when the machine is not cutting the operator exposure reduction with an as new machine should be a little over 10 dB(A), giving a nett level even in factory conditions of less than the 85 dB(A) first action level.

34. The SATRA study noted above calculated the effect of providing a shut down facility for just one of a group of machines at a 2.6 dB(A) reduction for that machine's operator, with an additional benefit available if all the machines were to be so equipped. This would provide noise reduction with a halving of electricity consumption and a reduction in the rate of wear on the machine, surely an example of noise control without a financial penalty.

35. It was noticeable when the URC was observed in production that its noise spread over quite an area of the factory visited - it seemed naturally to be surrounded by quieter activities - and its contribution to the noise exposure of those other than its operators should not be ignored. Since the noise generation is centred in the compact region of the working head, it is perhaps one of the most amenable machines for a local enclosure, for which purpose a commercially available telephone hood might provide a very economical source of supply.

## Conclusions

36. Both these machines demonstrated that worthwhile noise reductions could be achieved without modifications which would in any way compromise their operational convenience. By examining the sources of noise generation, solutions could be found which did not require the adoption of inconvenient covers or enclosures.

37. Both machines when examined in the state that they had come from use in the industry showed signs of neglect and abuse. Time and again poor or deliberately incorrect setting of machines is found to have contributed to increases in noise emission, and the introduction of public executions for errant setters and maintenance supervisors is long overdue.

38. In the case of the Unifast insole attacher the modifications proposed would have a small effect on the cost of the initial machine build, but in service this might be offset by the enhanced durability, particularly of the revised hammer top mounting. The effective cost of the noise reduction could therefore be claimed to be negligible.

39. For the URC there would be an on cost to the operator if it were necessary to return machines for major rebuilding at more frequent intervals. It is difficult to gauge the true figures, but on the basis of the number nominally in use and those refurbished annually a working life of around 10 years would appear to be involved. There is no useful information on the possible reliability benefits to be obtained from having more frequent overhauls, but if the machine tested was representative there is no significant evidence of failures repaired by the user which would have relevance to noise generation.

40. For both machines there exists the prospect of changes which would in the long term provide energy saving. In the case of the URC the potential for intermittent operation might reasonably be expected to give a longer effective working life for a very small investment. The conversion of the Unifast from pneumatic to electromagnetic operation would need further economic assessment.

## Acknowledgements

The authors would like to acknowledge the assistance provided by the Shoe and Allied Trades Research Association, Regent Rebuilds Ltd and the British United Shoe Machinery Company for their practical help in selecting and supplying machines for test and useful comment during the project.

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2. "Reducing Shoe Machinery Noise" SATRA Bulletin, November 1988.

3. Design and Development of High Speed Packaging Machines. A A Fogarasy et al. Paper presented at I Mech E Conference on "High Speed Machinery", London 24th November 1988.

UNIFAST INSOLE ATTACHER UNDER TEST

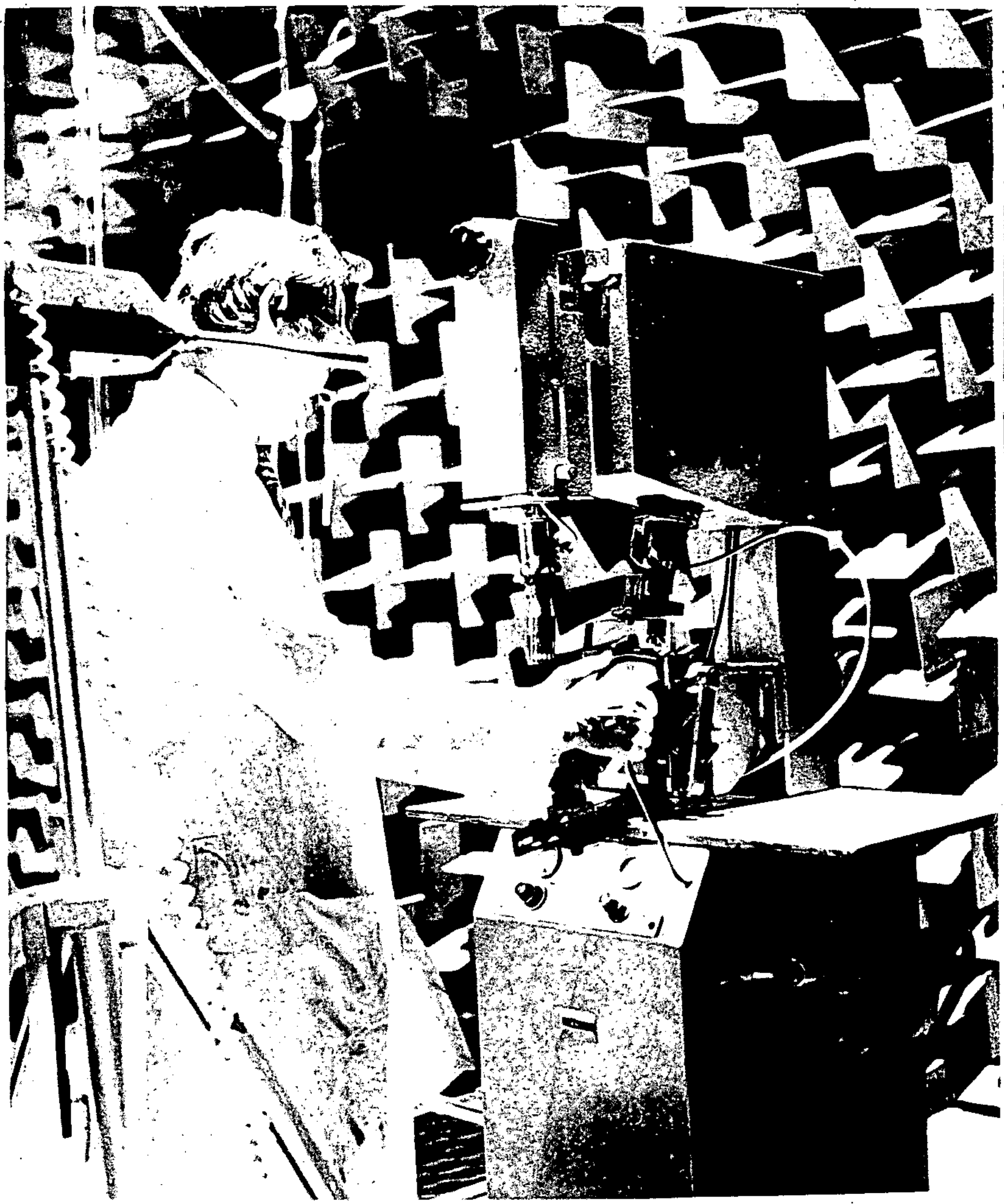
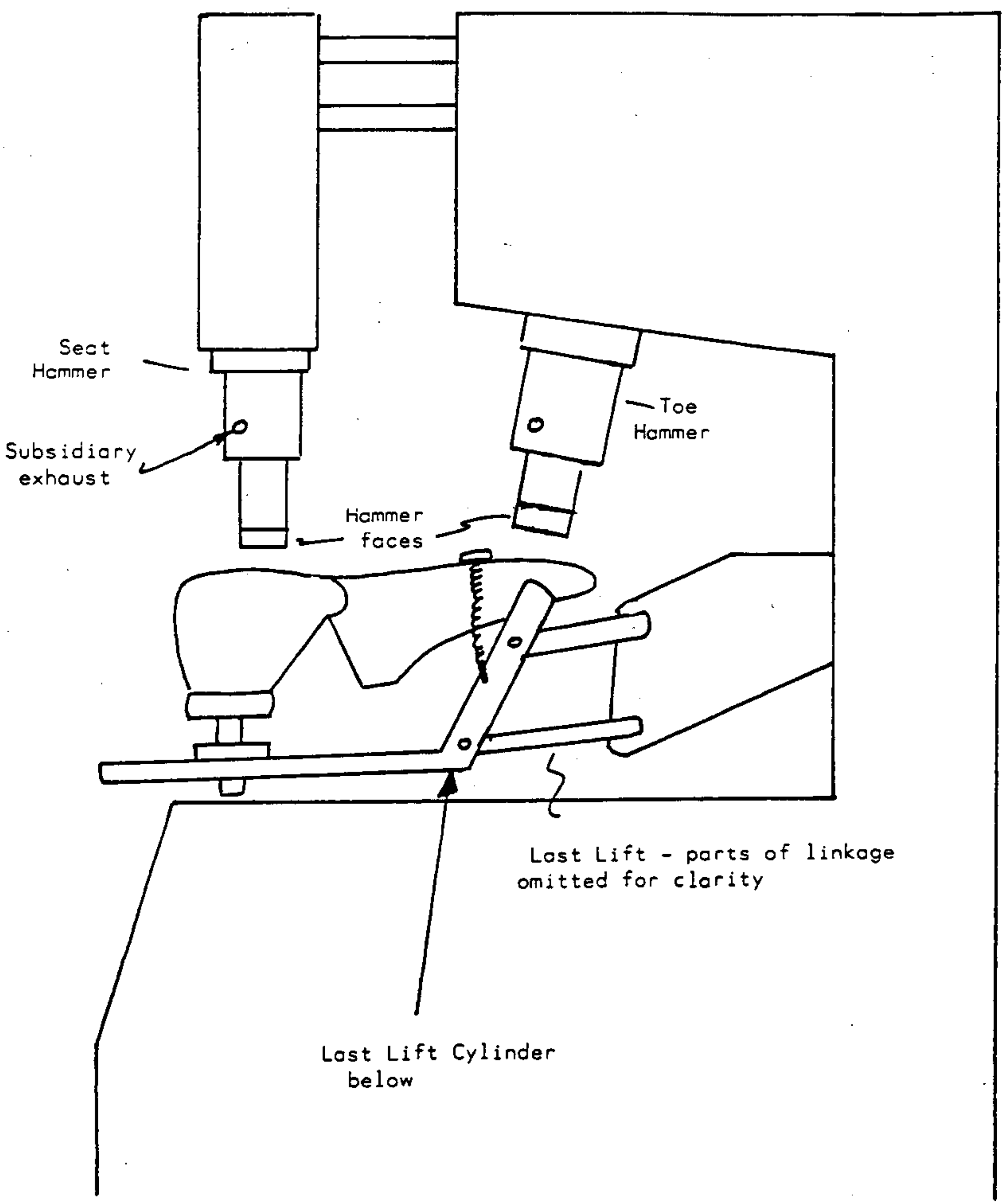


**Figure 1a**



Seat Hammer
Subsidiary exhaust
Toe Hammer
Hammer faces
Last Lift - parts of linkage omitted for clarity
Last Lift Cylinder below


Figure 1b

UNIFAST HAMMER TOP MOUNTING

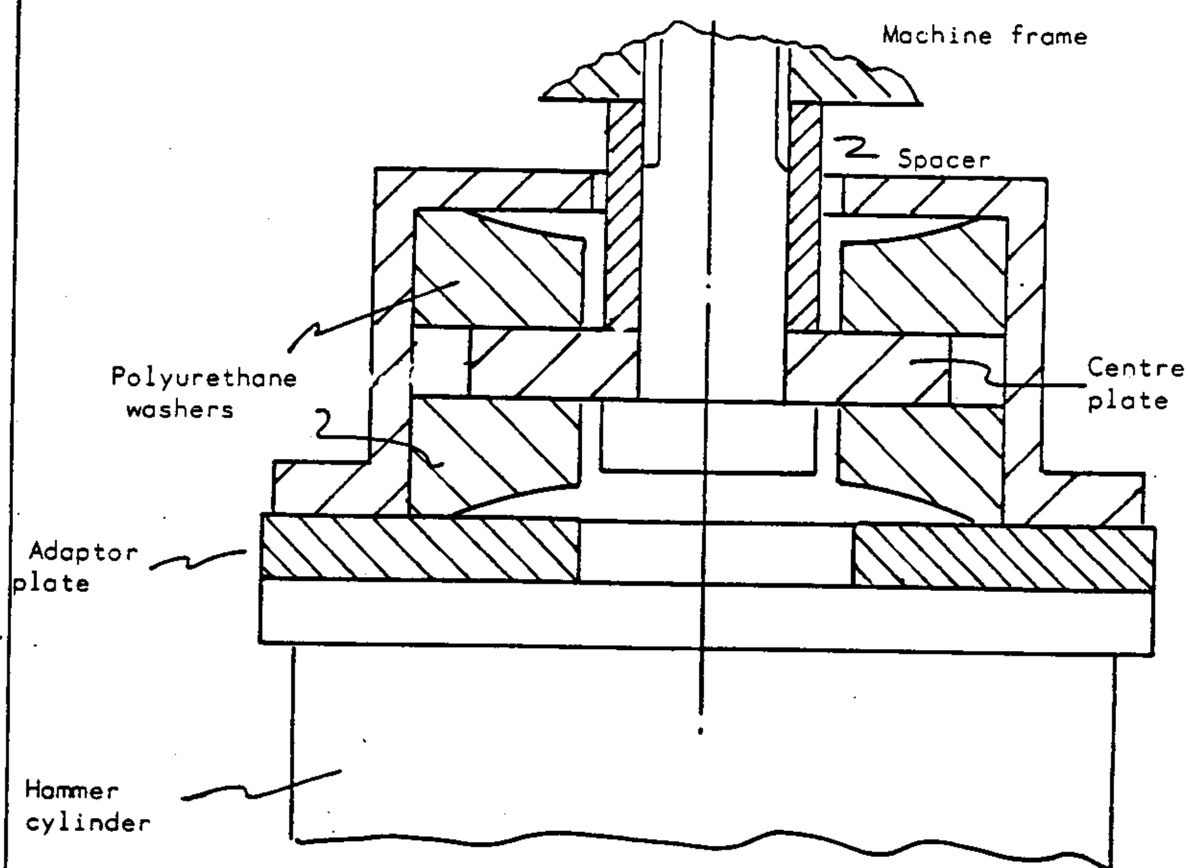



**Figure 2**

UNIFAST HAMMER BOTTOM MOUNTING

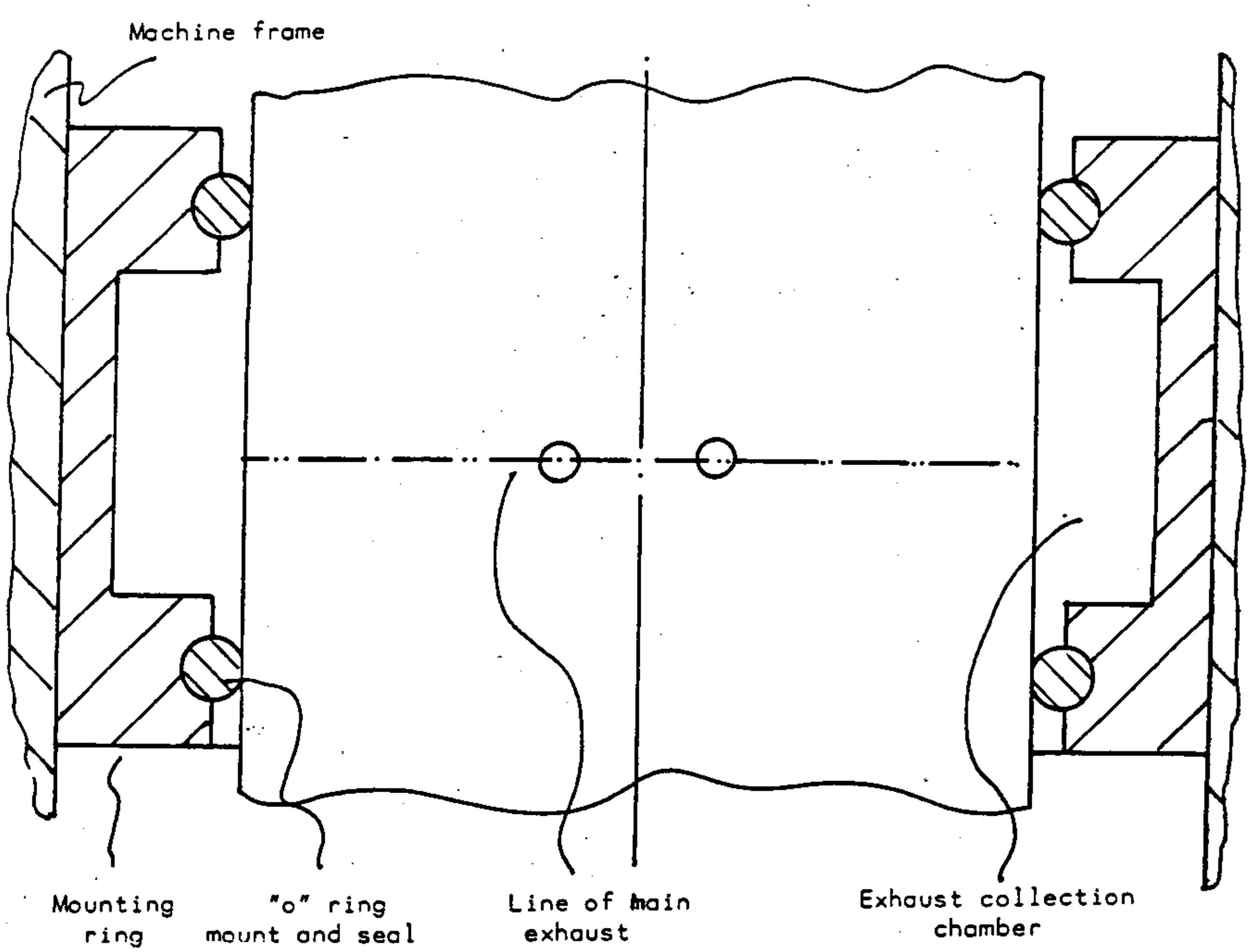



**Figure 3**

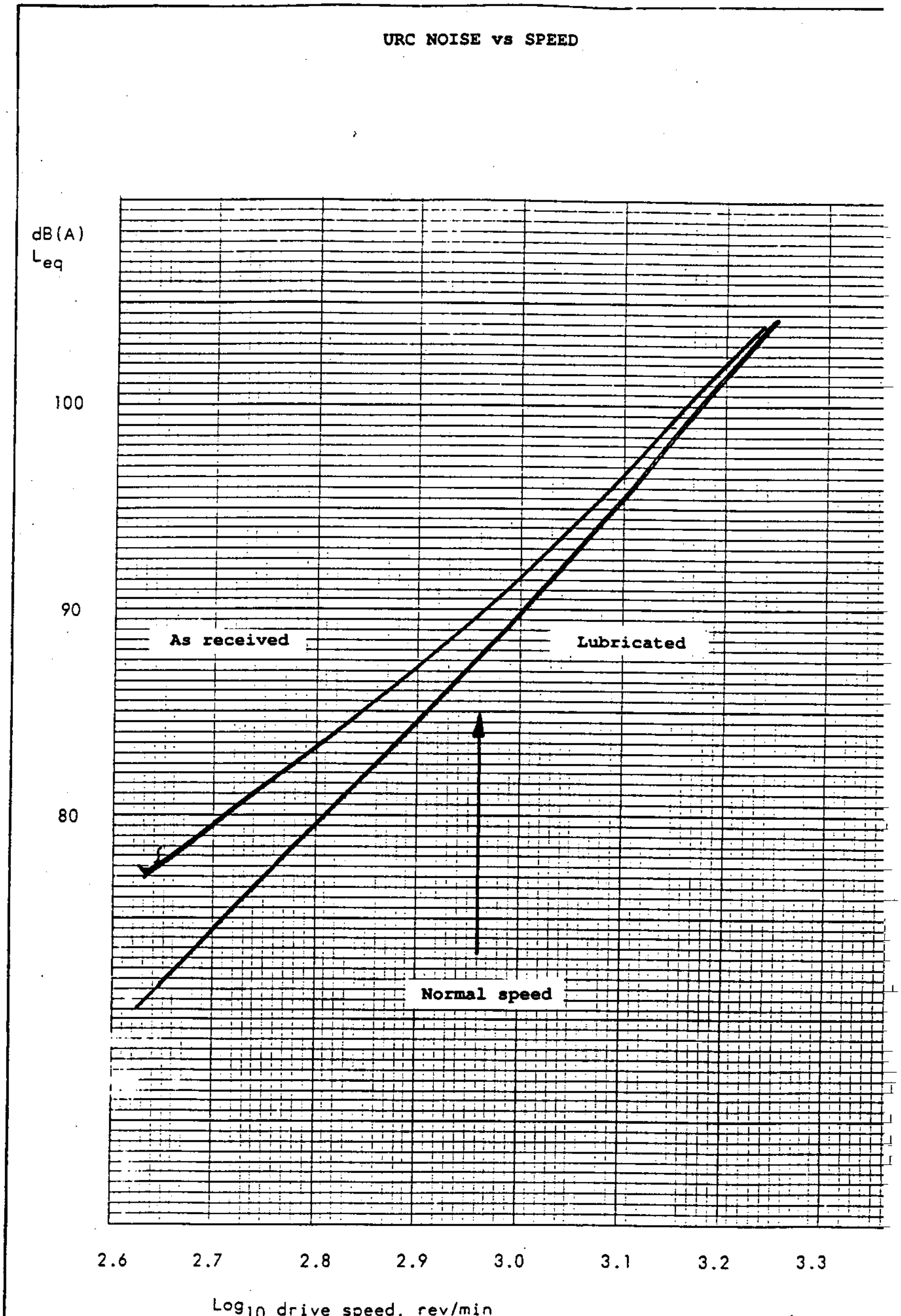

URC NOISE vs SPEED
dB(A)
Leq
100
90
80
As received
Lubricated
Normal speed
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
Log10 drive speed, rev/min

**Figure 5**

UNIVERSAL ROUNDING & CHANNELING MACHINE
WORKING HEAD ONLY

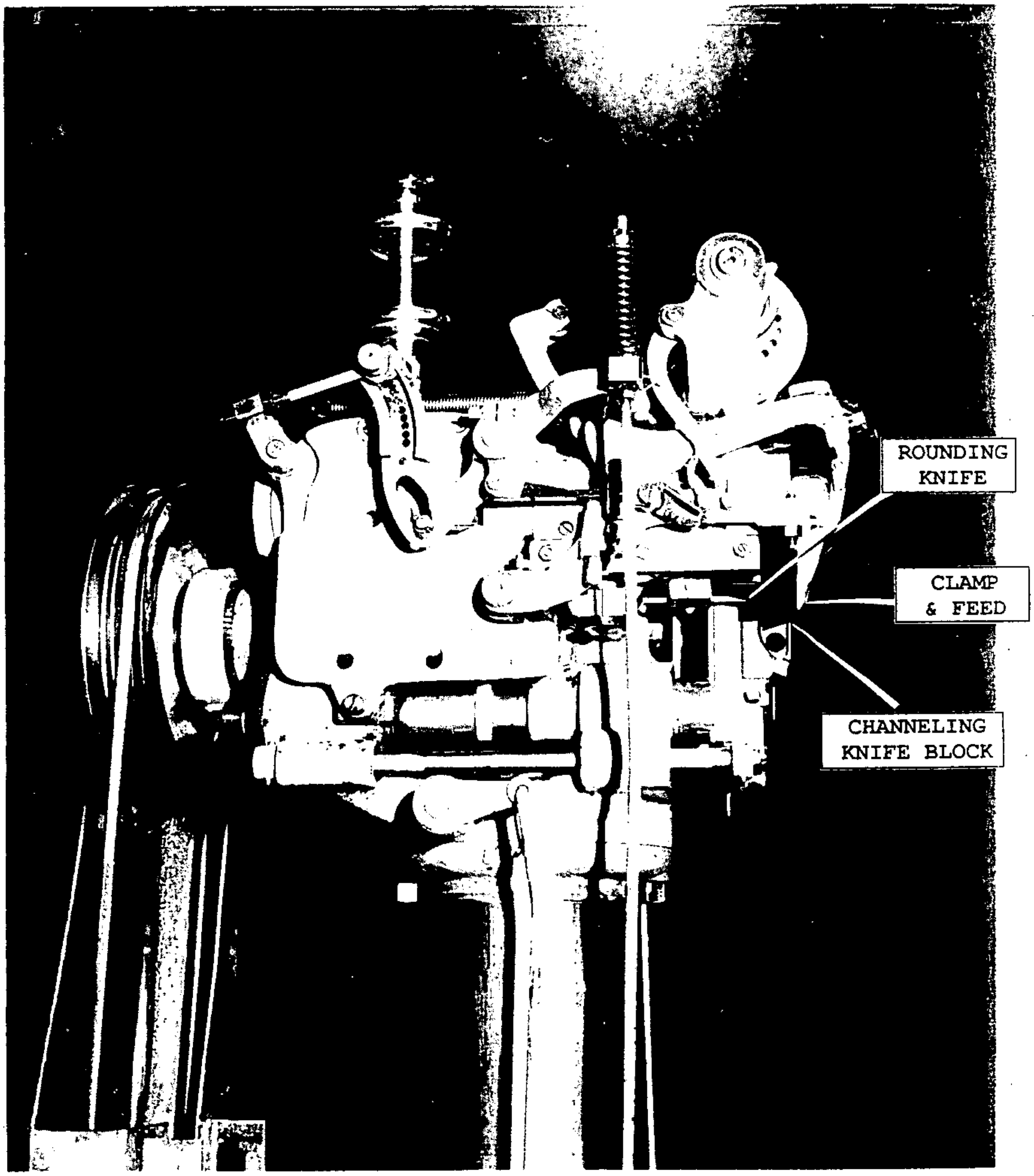



Figure 4

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ISBN 0 71 760369 5