TEST METHODS AND SOME OF THE PROBLEMS INVOLVED IN MEASURING THE VIBRATION OF HAND-HELD PNEUMATIC TOOLS

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ABSTRACT

With the advent of the draft ISO "Guide for Evaluation of Human Exposure to Hand-Transmitted Vibrations," manufacturers of pneumatic tools, who had been working on the vibration problem of their tools, applied the Guide's test methods with mixed results. These manufacturers formed the working group sub-committee 8A of PNEUROP (the European Trade Association for Compressors and Pneumatic Tool Manufacturers) and planned a program to produce a test method and installation that would give consistent and meaningful results. With the use of such a test, criteria could be drawn to establish vibration limits, because doubts had been raised concerning the reliability of figures obtained by earlier test methods.

This paper presents the work done to date and gives an example of one method to reduce vibration. The "D.C. Shift" in the taped signal from an accelerometer has been investigated and found to be the result of extremely high accelerations at frequencies far above those that could affect that hand-arm system. The use of mechanical filters to avoid this phenomenon is described.

INTRODUCTION

This paper attempts to demonstrate the united effort of several European manufacturers of pneumatic tools to take corrective action that will reduce vibration levels in these tools.

Vibration Induced White Finger (VWF), under one of its several titles, has been investigated in considerable detail over the past 65 years. Most of the published documents, however, look at the subject from the clinical, physiological, or subjective psychological points of view; only within recent years have engineers been concerned with the subject to any marked degree. More recently, proposed safe limits of vibration have been drafted and published by official bodies: Technical Committee 108 of the International Standards Organization (ISO) deals with mechanical vibration and shock, and its subcommittee No. 4 with human exposure to vibration. In May 1973, this subcommittee published a draft proposal entitled "Guide for the Evaluation of Human Exposure to Hand-Transmitted Vibration," which was revised in March 1975 and in September 1975.[1]

The British Standards Institution followed with a somewhat similar "Draft for Development" in November 1973, revised in February 1975.[2] These two documents have, of necessity, been based on the available medical information, largely obtained from investigations of workers using chain-saws and pedestal grinders. These documents have had a two-pronged effect on the manufacturers of portable powered tools.

Firstly, the manufacturers have had to make measurements and examine means of reducing vibration levels at the tool-hand interface; and, secondly, the users of hand-held tools are now asking the manufacturers to state these levels, measured in accordance with the proposed standards. These developments have caused some concern among European manufacturers, who are well aware that many of their products are likely to produce vibration levels in excess of those in the draft proposals.

It must be noted that both documents aim at specifying guidelines for vibration exposure below which damage to the human hand-arm system is unlikely to occur. They are not intended to provide comprehensive testing data.

In fact, at a meeting of ISO Technical Committee 108, subcommittee 4, at Southampton in the U.K. in September 1975, subcommittee 3 of Technical Committee 118, which deals with compressors and pneumatic tools, was given and accepted the task of developing and establishing the methodology for testing and, where necessary, further specifying requirements for instrumentation, always with reference to Technical Committee 108.

BACKGROUND

At the time these draft standards were published, the situation prevailing at the plant of the Consolidated Pneumatic Tool Company at Fraserburgh in Scotland was probably fairly typical of that in many companies.

The Research & Development Department was well-equipped with general instrumentation (e.g., a sound-level meter and octave-band filter) as well as a good deal of expertise on noise-level measurement, but none in the field of vibration. The need to develop such expertise and obtain the necessary equipment was clear, and orders were placed for accelerometers, amplifiers, and a 4-channel FM tape recorder.

An exploratory meeting, held in February 1974, included Professor William Taylor of Dundee University and a representative of the University of Salford, Mr. David O'Connor, who had had some experience in vibration measurement on chain saws and pedestal grinders. Certain tools were selected for measurement on the basis that they were typical of a high proportion of the factory output or that they were used in situations where VWF had been suspected. The University of Salford agreed to cooperate in these initial measurements by providing the equipment and the personnel, so that some comparisons could be made when the Company's own instruments were delivered.

During this interim period, a letter was sent to the Senior Medical Officers of 15 large concerns known to use vibrating pneumatic tools, asking questions similar to those referred to in the 1960 survey of Pecora, Udel, and Christman.[3] Replies were received from three, two of which indicated that VWF was no problem. There is little doubt that this reticence stems from a desire to avoid at all costs any additional trouble on the shop floor.

There is also some evidence to support the belief that even when an operator has early symptoms of VWF, he does not recognize them as such. He merely accepts that they may be due to a combination of his age and his work and takes no action. He does not in any case want to change his work unless the matter is very serious, probably fearing that such a change might affect his earnings.

At a recent course on safety given by the British Department of Employment in the Scottish factory of Consolidated Pneumatic, the lecturer, when asked what steps should be taken against VWF, said he had not heard of the disease. Perhaps this is indicative of the gravity of the problem in British industry.

It is certainly a fact that in a recent report (March 1975)[4] to the U.K. Secretary of State for Social Services, an Industrial Injuries Advisory Council found the disease "inappropriate for prescription" under the National Insurance (Industrial Injuries) Act of 1965, largely on the grounds of "difficulty of diagnosis" and "triviality of disablement in the majority of cases." This means in effect that a sufferer has no automatic right to compensation, but must take legal action against his employer to seek compensation. In fact, there is one recorded case in the U.K., in which an employee of an auto company sued his employers. The company admitted liability, and the case was settled out of court, the plaintiff accepting damages.[5]

An analysis of existing information carried out by the Max Planck Institute for Occupational Physiology in Bad Kreuznach, Germany,[6] found that several factors contribute to the incidence of VWF:

- temperature,
- the nervous system,
- noise (even alone, noise causes shrinkage of blood vessels in fingers), and
- percussion/vibration.

Tool manufacturers can have no influence on the first and second of these, and only a limited influence on overall noise, although much has been achieved in this field as far as the tool is concerned. The measurement of vibration must, therefore, form the basis of the approach.

FIRST MEASUREMENTS

By arrangement with the University of Salford, measurements were made in the three axes on six tools, viz., a demolition tool, an impact wrench, a pneumatic grinder, a 200 Hz electric grinder, a paint scraper, and a pneumatic rotary drill.

Except for the paint scraper, there was no evidence that any of these tools induced VWF—they were taken merely as being typical of the Company's range of products. However, the paint scraper, which is a 7,000-beats-per-minute percussive tool in which the handle mass is relatively low, is used by a customer with a blunt chisel as a weld-dresser. The men involved in this work are known to have some of the VWF symptoms (tingling and blanching of one or more fingers).

Instrumentation (Figure 1) consisted of a triaxial compression-type piezoelectric accelerometer, a sound-level meter, an FM tape recorder, and an oscilloscope. Calibration of the system was carried out acoustically

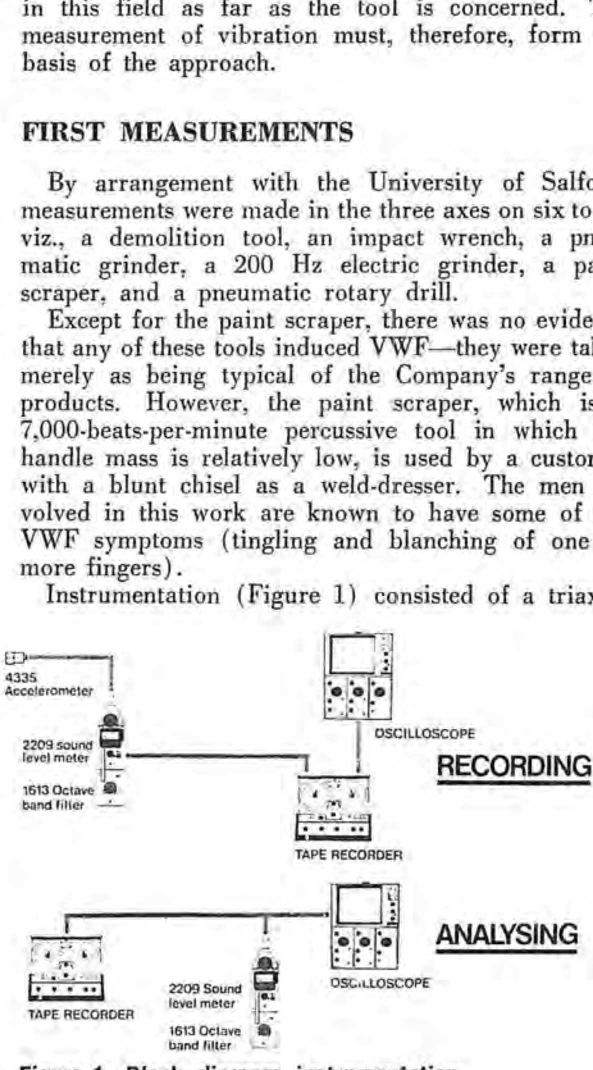

Figure 1. Block diagram instrumentation.

by feeding a pistonphone output into the sound-level meter by means of a microphone.

During this work it was noticed that, in the case of the paint scraper, the position of the baseline on the oscilloscope was inconsistent, i.e., there appeared to be a D.C. shift (Figure 2). Analysis of the tape

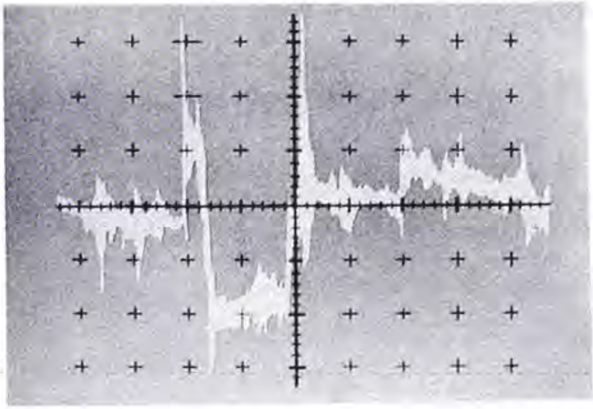

Figure 2. D.C. shifts.

showed exceptionally high acceleration levels at the lower frequencies; in the 31.5 Hz band, they are of a magnitude of 360 m/s², which corresponds to improbable displacements, viz., 0.4 in. It was certain that in some way these unreal displacement values and the D.C. shifts were associated, and the transducer was suspected.

The University of Salford approached the accelerometer manufacturers, Brüel and Kjaer (B & K), who were aware of the problem.[7] According to their textbook, the cause for accelerometer zero shift is still in some doubt; it is likely because of either a shift in orientation of some of the piezoelectric domains due to stress concentrations or a slight alteration in the contact area between the piezoelectric discs and the accelerometer base. Apparently, D.C. zero shift occurs under conditions of very high acceleration and is made manifest by a small, slowly decreasing output from the accelerometer after the cause has ceased.

On the paint scraper, acceleration transients upwards of 4,000 m/s² have been observed on the oscilloscope at frequencies well outside the range being measured for VWF investigation (30 to 40 kHz), and it is undoubtedly these transients that cause the disturbance of the D.C. level and the apparent high acceleration levels at low frequencies.

There appear to be two approaches to the problem without radical design change to the accelerometer. The first is to reduce the size of the piezo disc in order to reduce the mass carried by the mount. This necessarily reduces the output, too, and thus an early limit is set on the application of this method by the instrumentation existing in most companies.

The second approach is to filter out the offending high frequency, high level accelerations before they reach the piezo disc. B & K have produced some prototype mechanical filters for this purpose that are presently being evaluated at various universities and manufacturing establishments. These filters consist of two approximately ½-inch-diameter metal discs that are bonded to a plastic disc about 3/32 inch thick; they are interposed between the measuring point and the accelerometer. They exhibit a flat frequency response to about 2 kHz, rising some 5 dB at around 4 kHz, and then falling rapidly to about −25 db at 10 kHz.

Although this filter clearly minimizes the troublesome signals, there still remains a problem with high frequency high amplitude components from percussive tools such as the paint scraper referred to. It may be that the only answer in this case is the use of a low mass, low sensitivity transducer, although a redesigned B & K filter appears on first trials to have eliminated the problem (Figures 3-5).

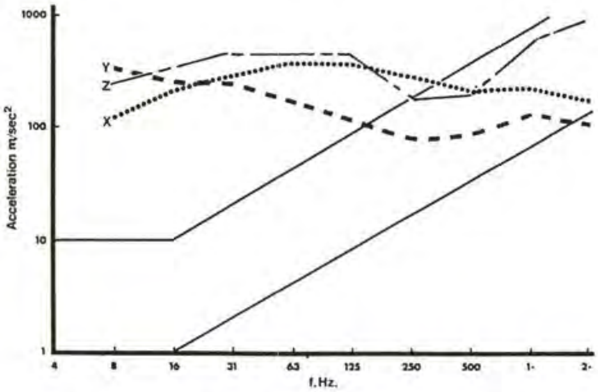

Figure 3. Vibration level measured to British Standards Institution draft for development using octave analysis CP.75 with no filter. High accelerations at low frequencies are shown.

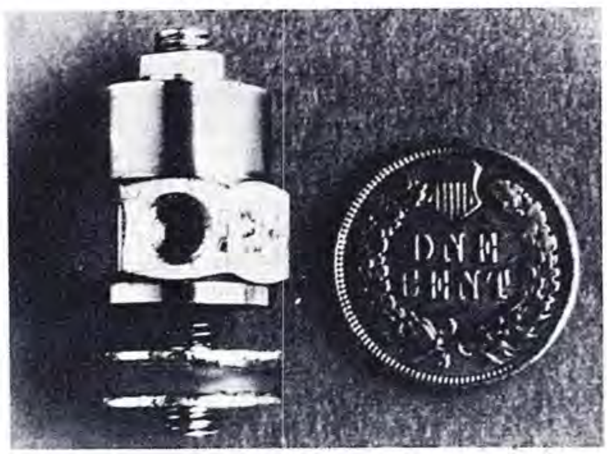

Figure 4. Mechanical filter, transducer.

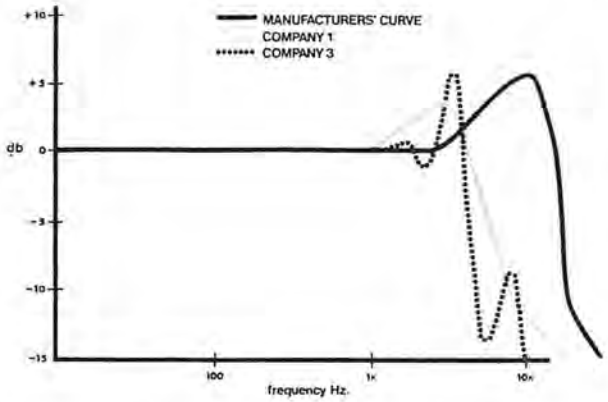

Figure 5. Performance of mechanical filter.

PNEUROP

It has already been mentioned that the introduction of the proposed measurement standards caused some activity among the users and manufacturers of vibrating tools, and the work of the European manufacturers in this field is being coordinated by PNEUROP.

PNEUROP is the association of European trade associations concerned with compressed air equipment (Figure 6). Its work is of a technical nature,

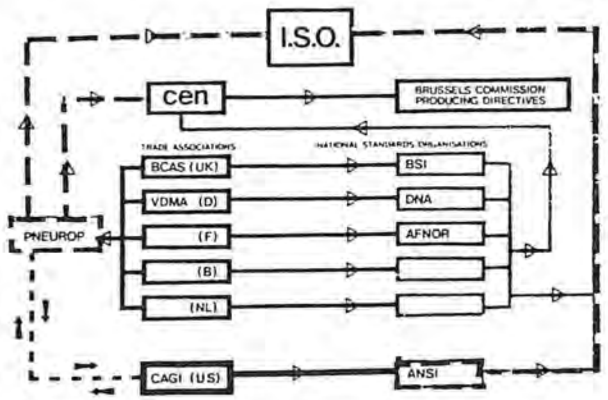

Figure 6. Function of PNEUROP in standardization.

and it has some 14 technical committees dealing with the many facets of the industry. PNEUROP's members, one of which is the British Compressed Air Society, send delegates to their National Standards Institutions on the Technical Committees of the International Standards Organization (ISO). PNEUROP itself sends observers to ISO, especially to those committees where the basic draft has been drawn up by PNEUROP. PNEUROP and the Compressed Air and Gas Institute (C.A.G.I.), the U.S. trade association, have a very close two-way liaison, and members of C.A.G.I. take an active part in PNEUROP technical committees.

Shortly after the publication of the proposed standards for the measurement of vibration, an "ad hoc" committee of PNEUROP's Subcommittee No. 8, which deals with noise levels, met in June 1974. This resulted in the first meeting of a Working Group on hand-arm vibration in the U.K. in January 1975.

At this meeting the proposed standards were examined, and their apparent shortcomings, as far as the pneumatic tool industry is concerned, were noted. There was general agreement among manufacturers that there had been a lack of technical participation as these standards were being drafted and that the matter was now serious and urgent. The Committee did not in any way oppose the standards; in fact, it agrees there is sufficient evidence to necessitate them, but several points require clarification. Examination of the documents reveals that much work must be done before meaningful measurements can be made, e.g.,

- The method of loading the machine under test must be specified.
- The method of holding the machine must be specified, and probably measurements must simultaneously be made of grip and static force.
- Repeatability of results will have to be determined, and test tolerances specified.

The objectives of the Working Group are thus defined.

Clearly, one of the first tasks of such a Working Group must be to investigate the spread of results obtained from tests, and a simple initial investigation was set in motion.

First Measurements by PNEUROP Working Group

At this stage, measurement in one axis only was attempted, and the equipment used in the author's company consisted of a B & K general-purpose accelerometer driving a B & K 2209 sound level meter and octave band filter.

In view of the D.C. shifts already referred to, it has become not only desirable but essential to monitor the signal—thus ensuring that neither D.C. shifts nor overloading occur. Because of this, an oscilloscope is always included.

The purpose of the tests to be undertaken was to establish the overall scatter in measurements taken by several engineers using different equipment on dissimilar but equivalent tools.

A number of companies were to take a "direct drive grinder" at random from their range, all of about the same horse-power, i.e., approximate commercial equivalents, with 6,000 rpm maximum rated speed. The vibration amplitude was to be measured on the bare machine and the machine and several wheels while working on various surfaces. Measurements were to be made at right angles to the handle and in the 125 Hz octave band only, that is, the band in which the rotational speed falls.

Only three companies actually participated, and the results from the bare machine are not encouraging. The acceleration (m/s^2) found by Company A was 0.25; from Company B, 0.25; and from Company C, 3.85. The overall tests made while working on different surfaces yielded levels ranging from 2.2 to 39.7 m/s^2. One company went further and used a number of operators, but failed to see any correlation between operator and vibration level. They concluded merely that the scatter was large.

This work, discussed at a subsequent PNEUROP meeting, led to agreement that the participating companies would carry out the following plan in an attempt to pinpoint the reason for the large scatter.

Firstly, each company would use the same grinder as before, and in the 125 Hz band only, measure the acceleration with 10 different wheels and with the same wheel mounted 10 times. The object was to obtain some indication of the scatter that resulted from the wheels, and to indicate whether the wheel manufacturers should be involved at this stage.

Secondly, a "round robin" test would be carried out. Each company would provide a grinder of similar hp and 6,000 rpm from its range, and these grinders would be sent to the participating companies where ⅓-octave analyses over the band 2 Hz to 2.5 kHz would be made on all machines. No wheel would be fitted to the machines for these tests, for the object was to establish the probable scatter of results with the use of different personnel and equipment, and involve the minimum of variables.

Thirdly, each company would take from its range a small percussive tool of similar performance having an air consumption of approximately 18 ft^3/min and measure the acceleration when used with a blunt and with a sharp steel. B & K mechanical filters were to be used in this test, which was intended to give some indication of overall scatter on a tool known to be difficult to load consistently.

Results of Round Robin Test

For the grinder part of this test, the machine was to be suspended by a cord as if it were grinding a horizontal surface, in an attempt to eliminate the effect of differing "grips" by an operator.

At Consolidated Pneumatic, the measurements were made by feeding an accelerometer output, via a sound level meter as preamplifier, to the tape recorder—the sound level meter being used in the linear mode. Before taping the signal, a note was made of the level in the octave band of the machine fundamental frequency (in this case, 125 Hz octave band) to check that the analysis was in the correct order of magnitude.

A 1/1 and ⅓-octave analysis was to be made using an analyzer and chart recorder. When this was attempted, two major errors came to light, and the tests had to be repeated.

1. The tape recorder was unsuitable for tape loops, and an insufficient length of tape had been recorded to permit the necessary combination of writing and chart speeds.
2. Frequencies in the 63 Hz band and below were "lost" in the noise base of the system. Subsequent examination of the accelerometer output showed an overall dynamic range in excess of 60 dB over the frequency band 32 Hz to 32 kHz, with a maximum at 16 kHz, well beyond the range specified in the proposed standards, and undoubtedly due to accelerometer resonance.

The tape recorder, as with most FM recorders of its class, had a dynamic range of 48 dB and had been adjusted to avoid overloading by what was now seen to be the very high level of 16 kHz component. Clearly, insufficient attention had been paid to the content of the input signal, and it was now evident that some filtering before recording was required merely to reduce the dynamic range of the signal. For the repeated tests, the B & K mechanical filter was used, and this proved to be very satisfactory. On some machines, however, the range was greater than 50 dB, which is the overall capability of the B & K analyzer/chart recorder combination. So two analyses were made of each tool: one with the signal level so adjusted that there was no overload of the chart recorder up to 2.5 kHz; and a second, having increased the recording level 10 or 20 dB, which caused overloading of the chart recorder at the higher frequencies but brought the lower ones out of the noise base.

This extremely wide dynamic range, which the acceleration/frequency signal spans, suggests that velocity might be a more satisfactory parameter to measure, but the mass, physical size, and cost of velocity transducers tend to render them less attractive for industrial purposes. I am not aware of one with an adequate frequency and/or amplitude range. Certainly a low-pass mechanical or electrical filter is essential to limit the dynamic range of the signal applied to the analyzing equipment, and this must be inserted as early in the system as possible following the accelerometer.

Let us look at the data obtained from the suspended grinder with no wheel mounted. For simplicity, only the levels in the 125 Hz octave band are shown in Table 1. The worst of the four machines is well with-

Table 1. Round robin tests of four machines by four companies; acceleration in m/s^2 at 125 Hz

Company	Machines			
	a	b	c	d
A	4	1.2	4	0.60
B	4	1.14	3.5	0.22
C, two	2.9	1.3	3.1	0.17
divisions	4.4	1.6	3.5	0.22
D	3.6	1.5	3.2	0.16

in the exposure boundaries, and all companies have produced acceptably similar results. Another octave analysis on 12 machines of the type used by one company in the round robin revealed this same sort of distribution.

However, the picture is somewhat different when wheels are mounted. In Table 2 are the results of the four companies' tests, each on its own grinder, with 10 new wheels fitted. The maximum single measurement made on any test was 55 m/s^2, which takes the machine (still doing no work) outside the 30-minute continuous boundary line.

Table 2. Machine with 10 different wheels; acceleration in m/s^2 at 125 Hz

Company	Mean acceleration	S.D.	Mean wheel bore, mm	S.D., mm
A	19.5	13.2	22.342	0.0203
B	19.5	14.2	20.194	0.0574
C	26.4	10.7	—	—
D	17.7	6.6	—	—

The situation is much the same for the same wheel mounted 10 times (Table 3). Here the maximum single measured level was 67 m/s^2. It should be noted that the wheel bore and spindle diameter were well within the specified tolerances for these parameters.

Table 3. Machine with same wheel mounted 10 times; acceleration in m/s^2 at 125 Hz

Company	Wheel	Mean acceleration	S.D.
A	a	11.5	1.9
	b	7.4	1.6
	c	47.0	9.3
B	d	16.6	2.8
	e	52.4	9.2
C	f	14.1	1.6

Two companies measured acceleration levels when the machine was grinding a mild steel block, using different operators, and the average results ranged from 15 to 28 m/s^2, again in the 125 Hz band (max. 56 m/s^2).

The percussive tool tests were carried out by three companies (Figure 7). The machines were, of course, of different types but similar in size and air consumption. A number of operators were used, and results in the 31.5 Hz octave band ranged from 11 to 32 m/s^2, well outside the 30-minute continuous boundary; the results of a typical test are shown. We know that this type of machine is often used for a large proportion of the working day, but we do not know the length or distribution of the periods of non-use. We know, too, that the users show VWF symptoms; such a machine must, therefore, be suspected.

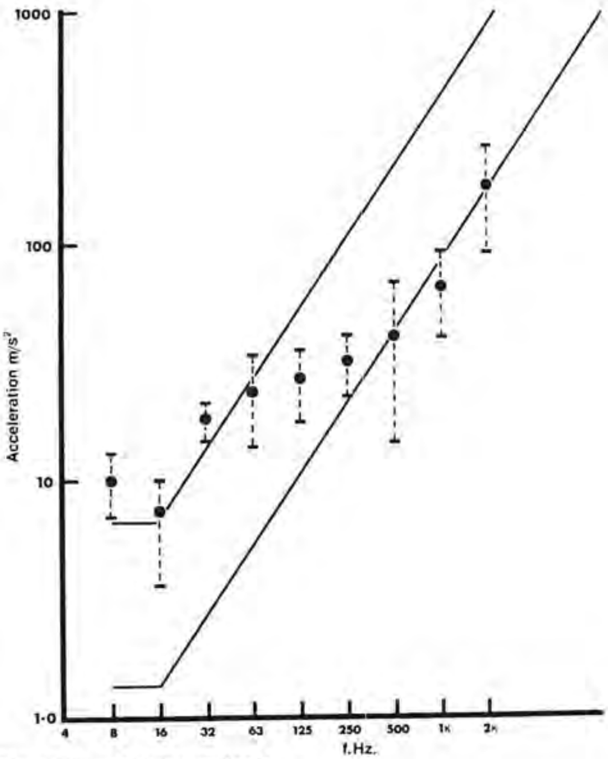

Figure 7. Percussive tools.

Although it is difficult for industry to provide the data necessary for correlation, I believe that these data can only be obtained by health surveys.

SUMMARY AND CONCLUSIONS

This series of tests has highlighted two major problems.

Firstly, we see that, in the case of the grinder, we have had to run it without wheel and without operator to obtain repeatable and meaningful data. It is going to take time before we have learned enough to be in a position to make measurements with any confidence under working conditions on a grinder, let alone on, say, a road-breaker.

Secondly, on power tools, particularly percussive ones, it will be necessary to reduce vibration levels to meet the currently proposed guidelines.

One simple approach to this end, for the higher frequencies at least, is the attachment, probably by bonding, of a soft plastic sleeve to the tool handle. Consolidated Pneumatic has produced some prototypes of the paint scraper referred to earlier with such a sleeve, but because of the D.C. shifts in the transducer, no reliable measurements have been made. Subjective impressions from the users of such tools indicate this to be a step in the right direction.

Manufacturers cannot afford to ignore this problem, and development of tools with vibration reduction in mind will undoubtedly take place concurrently with the work of developing test procedures and methodology in the field of vibration measurement. However, it is more than likely that for a long time to come, we will need to accept that these tools produce levels of vibration beyond the limits set by the draft proposals, and we must minimize the risk of damage, to some compromise level, by limiting the time of exposure.

The problem is less analogous to noise where hearing protectors can be readily used.

The final solution will, of course, have many economic problems, since the resultant tool is sure to be heavier, or clumsier, or have a lower working capability, or all three combined. There are more problems associated with percussive tools than with chain saws, for instance, because of the wider frequency scatter occurring with these tools.

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QUESTIONS AND ANSWERS

Question (D. Wasserman, NIOSH): Using this mechanical filter, did you find any difference on the grinders when you took measurements with and without it?

Answer: None whatsoever.

Question (D. Wasserman): So, it's only on the percussion tools that it was really required?

Answer: Yes, this is where very high acceleration levels occur. Three different companies simultaneously took measurements with and without the filter. There was no difference in the results.

PROCEEDINGS OF

THE INTERNATIONAL OCCUPATIONAL HAND-ARM VIBRATION CONFERENCE

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

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