Proceedings of the Institute of Acoustics

VIBRATION MEASUREMENT OF POWER HAND TOOLS USED IN THE SHIPBUILDING INDUSTRY

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1. INTRODUCTION

Modern shipbuilding techniques involve various forms of metal working and as a result many types of power hand tools (pneumatic or electrical) are used. High levels of vibration transmitted to the hands, arms and shoulders of operators using such tools, however, can cause a number of medical conditions commonly grouped together under the term Hand Arm Vibration Syndrome (HAVS).

In order to asses the vibration exposure of tool operators, vibration tests are carried out to identify those tools which pose the greatest risk of inducing HAVS, and those which can be used without exceeding acceptable daily vibration doses.

This paper discusses various aspects of the measurement procedures that have been employed to measure tool vibration exposure of personnel in the shipbuilding industry. In addition, advice is given on solving problems that have been encountered during the measurement process, and how the results of the tests are interpreted and compared with the Health and Safety Executive limits.

Please note that all tools covered in this study were used horizontally and all operators were right handed.

2. INSTRUMENTATION

The instrumentation used to measure hand arm vibration outlined in this study consists of the following:

Bruel & Kjaer 2231 modular precision sound level meters
Bruel & Kjaer BZ7116 human vibration modules
Bruel & Kjaer 2522 human vibration units
Bruel & Kjaer 4374 accelerometers and associated cables
University of Southampton ring mounts
Bruel & Kjaer 4294 calibration exciter

The above instrumentation allows measurements of overall frequency weighted acceleration vibration levels in the x, y and z directions relative to the hands to be made in accordance with BS 6842 [1].

The main reasons why this instrumentation was chosen are as follows:

- It was required that the measurement system to be used should cause as little disruption to the needs of production schedules as possible. It was therefore decided that a portable measurement system was required so that "on the job" measurements could be taken on the shop floor rather than having a static system or test rig to which tools would be taken away from production for testing.

- Since Bruel & Kjaer 2231 sound level meters were already being used on site in the measurement of airborne noise, it was decided that it would be cost effective to base the measurement system around these instruments.

- University of Southampton ring mounts were chosen over other accelerometer attachment systems that are directly fitted to the tool because of the time that would be saved in not having to attach and then detach the accelerometers from the tool itself. Nelson [2] has shown that acceleration readings taken with accelerometers mounted on such rings are comparable with those obtained using other measurement systems.

- It was also decided that two sets of measurement equipment would be obtained so that vibration measurements for both hands of the tool operator could be made simultaneously. In addition to providing corresponding data on both hands at the same time, the time taken to conduct the tool tests would be less than if measurements were taken on each hand separately.

3. MEASUREMENT PROCEDURE

In order to be consistent in the way that hand arm measurements are taken, it has been found useful to outline the measurement procedure to be followed in the form of a checklist as follows:

- For the tool itself, make a note of the tool manufacturer, the model type, speed of rotation, any special attachments (bit size, drill size, vibration damped handles, etc), and the tool orientation (horizontal, vertical, etc). For the operator, record his/her name, job title and whether they are left or right handed. Also record the details regarding the medium on which the tool will be used (steel, aluminium, etc).

- Load the vibration module into each sound level meter, and attach the human vibration units and accelerometer cables.

- Check the calibration of the system by placing each accelerometer on the calibration exciter in turn. It has been found useful to use double-sided sticky tape to attach the accelerometers to the calibrator for ease of attachment and removal. The calibrator provides a signal of 10 ms^{-2} at 159 Hz and the calibration of the instrumentation is checked with the vibration frequency weighting option on the sound level meter switched off. The use of sticky tape does not affect the accelerometer response characteristics at the frequencies of interest [1, 3]. The calibration level of the sound level meters can be adjusted if necessary using 3 potentiometer screws on these units. Once a year all of the instrumentation is checked against a nationally traceable standard.

- Mount the accelerometers on the ring mounts using beeswax. Again this is used for ease of attachment and removal and does not affect the accelerometer response characteristics at the frequencies of interest [1, 3]. Although beeswax has been found to be suitable in attaching the accelerometers, experience has shown that sometimes the accelerometers can be physically knocked off during testing. In order to prevent the accelerometers from being damaged, a small amount of sticky tape can be wrapped over the ring mount, loose enough not to press on the accelerometers but sufficient to catch them if they become detached.

- Place the ring mounts over the operator's middle fingers (and gloves) and tape the accelerometer cables to the tool operator's arms in order to prevent the cables snagging on the tool when it is operated. In instances where sparks or dust are likely to be present, then the sound level meters should be covered with a clear plastic bag to prevent possible damage.

- In order to protect the personnel taking the measurements from physical injury, it is usually necessary for protective clothing to be worn (overalls, ear defenders, protective glasses, etc). In certain cases it will be necessary for personnel to stand well back from the process being investigated (eg shot blasting) and consequently longer accelerometer cables will be required. To date, accelerometer cable lengths of between 1m and 5m have been used depending on the type of test, without degradation of the accelerometer signal.

- The tool operator is then instructed to hold tool in normal manner, ensuring that the ring mounts are gripped on to the tool, to start the tool and to put the tool to the job.

- Measurements are then commenced. Measurements are taken after the tool is put to the job to minimise the possible occurrence of DC shifts, caused by the impact of putting the tool to the job, which would be exhibited as large intermittent increases in the measured levels.

- After an appropriate time stop the measurements. From experience it has been found that tool running times of about 2 minutes in duration are sufficient for the instrumentation to record the required weighted frequency range of vibrations without causing undue tiredness on the part of the tool operator. Although the vibration level recorded by the instrumentation is determined over the whole of this testing period, it has been found useful to allow the instrumentation to log the average vibration level every 30 seconds as an additional precaution in identifying the possible occurrence of DC shifts.

- After completing the measurement period, allow the tool operator to remove the tool from the job and switch off the tool. Again measurements are stopped before the tool is removed from the job to minimise the possible occurrence of DC shifts

- Further measurements are then taken after allowing the tool operator a short time of rest. In some cases the tool operator may wish to put the tool down and flex his/her fingers before continuing.

4. TYPICAL RESULTS

During the study described here and many other investigations, it has been found that there can be a considerable variance in vibration levels between tools of the same type and also when different operators use the same tool. Factors that contribute to this variance include: how the operator holds the tool, the degree of push force used, the tool orientation and the condition of the tool and work piece.

In order to obtain the vibration levels exhibited by a tool type, average levels from a number of tests using different operators and different tools of that type are determined. The mean and standard deviations of two different angle grinders are shown in Tables 1 and 2 after 5, 10 and 15 measurement samples using different operators and different tools of that type.

Table 1 Frequency Weighted Vibration Measurements for Angle Grinder 229 mm disk 6600 rpm

No. of Runs	No. of Different Tools	No. of Different Operators	Left Hand (ms^{-2})			Right Hand (ms^{-2})		
			x	y	z	x	y	z
1-5	1	2	4.0±1.2	4.0±1.8	2.5±0.9	3.1±0.9	2.0±1.1	1.8±0.7
1-10	2	5	3.1±1.2	3.3±1.7	2.0±0.9	2.8±1.1	2.0±1.0	1.6±0.5
1-15	2	5	3.4±1.2	3.6±1.6	2.2±1.0	3.1±1.1	2.4±1.0	1.7±0.5

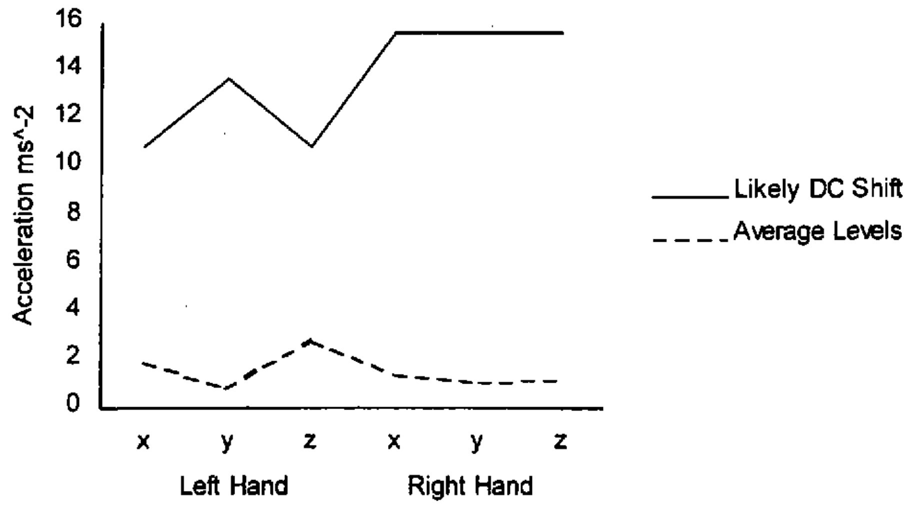
Table 2 Frequency Weighted Vibration Measurements for Angle Grinder 178 mm disk 8600 rpm

No. of Runs	No. of Different Tools	No. of Different Operators	Left Hand (ms^{-2})			Right Hand (ms^{-2})		
			x	y	z	x	y	z
1-5	1	3	0.8±0.3	2.1±0.6	1.3±0.6	1.7±0.6	4.1±1.7	1.2±0.4
1-10	1	3	0.9±0.3	1.9±0.7	1.1±0.5	2.1±0.7	3.8±1.3	1.2±0.3
1-15	2	4	1.1±0.5	1.7±0.9	1.3±0.6	2.4±0.8	4.0±1.4	1.3±0.3

As Tables 1 and 2 show, the standard deviations are significant compared with the mean levels confirming the degree of variance mentioned above. From experience, in order to obtain a reasonable representation of average vibration levels, a minimum of 2 tools of the same type should be used by at least 2 operators, with each operator using each tool 3 times giving a minimum total of 12 tool runs. It has been found that the time taken to perform this number of tests typically takes 45 to 60 minutes in total.

A typical example of the effects of a DC shift is shown in the following LARA (left and right axis) chart (Figure 1) for a 25000 rpm rotary file. This shows the levels measured during one particular tool run and the average levels of tests on this tool type (excluding the DC shift affected item) during the same testing period. It is possible in this case that the measurement process was commenced before the tool was put to the job and hence the apparent high levels were caused by a tool-job impact. Typically, measurements affected by DC shifts can be of the order of 10 times the average level for that tool.

Figure 1 Frequency Weighted Vibration Measurements for Rotary File with Rotary Burr 25000 rpm



It should be noted, however, that if the vibration levels exhibited by one particular tool of a tool type is consistently much higher than other tools of that type, then the cause may be due to a fault with the tool indicating that maintenance is required.

5. COMPARISON WITH LIMITS

BS 6842 [1] states that the vibration transmitted along each axis relative to the hand can be equally detrimental and that the approximate injury potential may be assessed in terms of the magnitude of the frequency weighted vibration in the dominant axis.

Based on the dominant axis measurements, the Health and Safety Executive have recommended [4] that programmes of preventative measures and health surveillance should be carried out where daily 8 hour hand exposure regularly exceeds a frequency weighted acceleration dose (AEQ) of 2.8 ms^{-2} as defined in BS 6842 [1]. The proposed, but not yet ratified, EU directive on Physical Agents at Work has defined a similar action level but at 2.5 ms^{-2} [5].

Table 3 shows average levels for each axis for a number of tool types, and the time taken (rounded down to the nearest minute) per day to reach an AEQ of 2.8 ms^{-2} based on the dominant axis vibration levels (underlined). The actual vibration dose that a person would receive per day would depend on how long the tool is used during a shift.

Table 3 Frequency Weighted Vibration Measurements and Exposure Times for Various Tools

Tool	Left Hand (ms^{-2})			Right Hand (ms^{-2})			No of Tool runs	Time to Reach 2.8 ms^{-2}
	x	y	z	x	y	z		
Angle Grinder 229 mm disk 6600 rpm	3.6	3.5	2.3	3.2	2.4	1.8	17	4 hrs 50 mins
Angle Grinder 178 mm disk 8600 rpm	1.2	1.9	1.4	2.5	3.9	1.4	16	4 hrs 7 mins
Surface Grinder 178 mm disk 8500 rpm	4.7	3.9	2.6	3.0	2.5	2.6	10	2 hrs 50 mins
Rotary File 22000 rpm	2.7	1.6	2.6	1.3	1.2	1.6	14	8 hrs 36 mins
Rotary File 18000 rpm	2.3	1.8	2.1	1.7	0.8	1.6	11	11 hrs 51 mins
Rotary File 25000 rpm	2.4	1.6	1.8	1.4	1.3	1.4	12	10 hrs 53 mins
Needle Scaler 1	3.6	9.5	4.7	2.4	8.8	2.8	11	41 mins
Needle Scaler 2	5.7	12.8	4.5	2.8	12.1	4.7	11	22 mins
Needle Scaler 3	1.6	3.3	1.5	1.6	1.1	0.9	10	5 hrs 45 mins

6. VIBRATION CONTROL

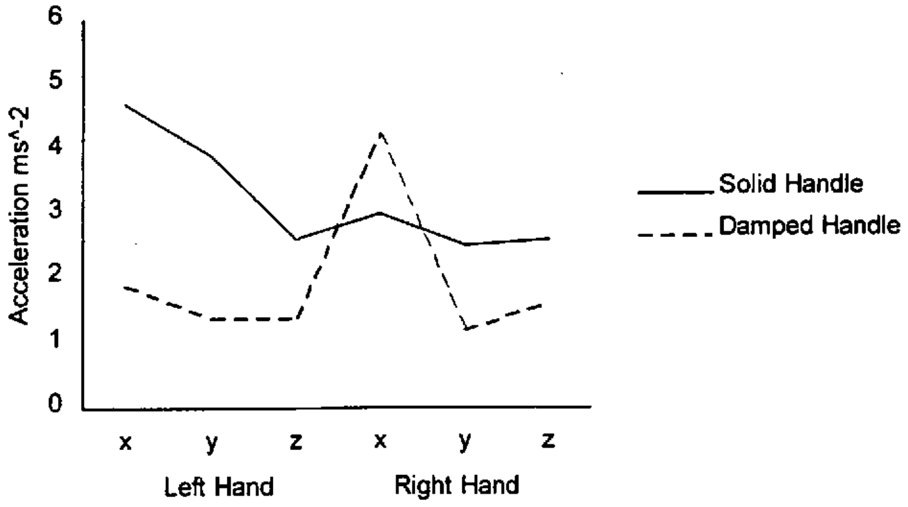
Having obtained the average frequency weighted vibration levels such as those indicated in Table 3, one can then instigate various forms of vibration control, namely:

- Replacing tools that exhibit high vibration levels with tools that cause lower vibration exposure. For example needle scaler 3 has now replaced needle scalers 1 and 2 which have been quarantined from use.

- Limiting the time tools can be used. Table 3 shows the extent at which tools can be used during a day up to the 2.8 ms^{-2} AEQ limit.

- Applying palliative measures to the tools. Vibration damped handles have been used with success on certain types of tools. For example the results on a surface grinder shown in the LARA chart in Figure 2 indicate that the dominant axis vibration level before treatment of 4.7 ms^{-2} (x-axis left hand) was reduced by 0.5 ms^{-2} (x-axis right hand dominant after treatment) by applying vibration damped handles. It should be noted, as found in other studies, that the application of a vibration damped handle, although reducing the dominant axis vibration, can also redistribute vibration to other axes.

Figure 2 Frequency Weighted Vibration Measurements for Surface Grinder 178 mm disk 8500 rpm



7. CONCLUSIONS

This paper has described how a practical system of measuring hand arm vibration has been used, how the results of the tests have been interpreted and compared with the Heath and Safety Executive limits, and how practical solutions in overcoming problems encountered during testing have been identified.

8. REFERENCES

[1] BS 6842:1987 "Guide to Measurements and Evaluation of Human Exposure to Vibration Transmitted to the Hand".

[2] "Vibration Measurements on Percussive Pneumatic Tools using Ring Mounted and Tool Mounted Accelerometers and Laser Doppler Velocimetry A Comparison of Methods" C M Nelson, UK Informal Group Meeting on Human Vibration, September 1986, University of Technology, Loughborough.

[3] "Mechanical Vibration and Shock Measurements" J T Broch, Bruel & Kjaer, October 1980.

[4] "Hand Arm Vibration" (HSG88) Health and Safety Executive 1994.

[5] Proposed EU directive on Physical Agents at Work 1993.