

## Hand–Arm Vibration in a Group of Hand-Operated Grinding Tools

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### ABSTRACT

Vibration acceleration was triaxially and basicentrically measured, and digital-audio-tape-recorded with each axis separately evaluated using both the ANSI S3.34 and ACGIH hand-arm vibration (HAV) guidelines, for two pairs of pneumatic handheld grinders commonly used in metal fabrication operations including shipyards. Each tool pair consisted of a new and used grinder of the same model, performing the same simulated grinding tasks using new small grinding wheels, carbide burrs, wire brushes, and flap wheels. The results of this limited study showed, primarily, that the HAV standards were not exceeded, but there was a consistent tendency for the acceleration levels to increase between new and used tools, ranging from 11% to 66% on the Z-axis, 13% to 66% on the Y-axis, 44% to 58% on the X-axis, when tasks involved using grinding wheels and carbide burrs (hard implements). The results were mixed when using disposable wire brushes and flap wheels (softer implements). The overall results suggest the need for and implementation of a regular tool vibration monitoring and maintenance program as a primary element to help maintain tool acceleration levels to a minimum. © 2002 Wiley Periodicals, Inc.

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### 1. INTRODUCTION

Metal fabrication operations, such as automobile assembly and shipbuilding, are extremely labor intensive and often require the use of powered, vibrating hand tools. It has

been estimated that approximately 2 million U.S. workers are exposed to hand-arm vibration (HAV) through the use of such tools (Pelmear & Wasserman, 1998). The various trades within these operations may use an assortment of tools in the performance of the work tasks including vertical, angle, and die grinders; needle guns; chipping hammers; and reciprocating saws. For example, in shipyards, workers use a variety of grinders and needle guns to smooth welding beads that have joined two pieces of steel, to remove the weld slag, or to custom fit matching components. Tile workers use chipping hammers to remove terrazzo tile from the decks of washrooms and kitchen areas. Ship repair and ship breaking operations use reciprocating saws to cut out sections of bulkhead, decking, and other metal components in order to remodel or remove compartments within a vessel. These tools may be used individually or in combination anywhere from minutes up to 8 hr a day depending on the assigned task, the trade involved, and the type of work being performed at the facility.

Unfortunately, the development of both hand-arm vibration syndrome (HAVS), also known as vibration white finger, and carpal tunnel syndrome (CTS) has been linked to the prolonged use of vibrating hand tools among a variety of occupations (National Institute for Occupational Safety and Health [NIOSH], 1997). Bovenzi (1998) reported a relative risk for HAVS of 10.3 for shipyard workers and 18.6 for shipyard caulkers when adjusted for age, smoking, and drinking habits and compared to referents with no HAV exposure. HAVS is a neurovascular disorder that results in numbness and tingling in the fingers, loss of finger coordination and dexterity, and may be accompanied by blanching of the fingers. This disorder is progressive on prolonged exposure to HAV, and generally irreversible even on avoidance of further exposure to HAV. Letz, Cherniack, Gerr, Hershman, and Pace (1992) found a monotonically increasing prevalence of the higher severity symptoms with increasing exposure to HAV among shipyard workers. Approximately 71% of the full-time pneumatic grinders reported HAVS vascular complaints compared to 33% for workers exposed to HAV on a part-time basis. As a part of HAVS, finger blanching can be triggered by exposure to cold, nicotine, or both, due to the vasoconstrictive effects. In a study of shipyard workers, NIOSH (1987) found 70% of the grinders, 25% of the welders, and 10% of the shipfitters reported finger blanching.

Conversely, CTS is a disorder of the median nerve as it passes into the hand, resulting in numbness and tingling in the thumb and first three fingers of the affected hand. Due to a number of similarities in how the disorders are presented initially, differential diagnosis between HAVS and CTS is difficult in the early stages of the disorders. To complicate matters further, CTS may in fact occur concurrently with HAVS (Pelmear & Wasserman, 1998).

A major objective of this small pilot study was to vibration test under simulated work conditions, a small sample of pairs of same model/same manufacturer pneumatic powered tools, keeping other variables constant (i.e., all new tool implements, identical air pressure, same work tasks, same workpieces, one experienced operator, etc.) with the operational hypothesis that during normal tool use the vibration levels would rise over time and usage, and that this rise was in part due to normal tool "wear and tear" and tool maintenance. Four conventional pneumatic grinding hand tools commonly used in shipyards and other metalworking industries were vibration tested. The tools tested were: (a) two 14,000 rpm angle grinders of the same model, one new and one used and (b) two 18,000 rpm die grinders of the same model, one new and one used. All tools tested were made by the same U.S. manufacturer and are shown in Figures 1a and 1b. These four pneumatic grinders are typically operated from a 90 psi air supply and are used to grind

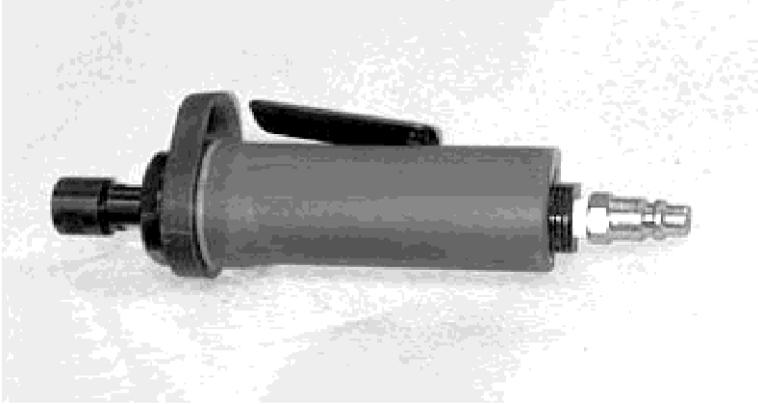


Figure 1a Pneumatic die grinder used in vibration testing.

metal and remove metal slag from structures. All tools tested and typical steel plates containing rough welds and other metal slag were provided for testing by a major domestic shipyard.

## 2. U.S. HAND-ARM VIBRATION STANDARDS/GUIDES

There currently exists in the United States a number of standards and guides related to HAV, including:

- American Conference of Government Industrial Hygienists–Threshold Limit Values (ACGIH–TLV) for HAV first issued in 1984 (ACGIH, 2001).
- American National Standards Institute (ANSI) Document S3.34: Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand issued in 1986 (ANSI, 1986).



Figure 1b Pneumatic angle grinder used in vibration testing.

- National Institute for Occupational Safety and Health (NIOSH) Criteria for a Recommended Standard for Occupational Exposure to Hand-Arm Vibration issued in 1989 (NIOSH, 1989).
- International Standards Organization, ISO/DIS 8662-4:Grinding machines. This draft International Standard was issued in 1993 (ISO, 1993).

The first three standards cited earlier are used for safety and health purposes. The ACGIH-TLV and ANSI S3.34 establish fixed daily HAV exposure criteria and were used in this study. The ACGIH HAV standard and the ANSI S3.34 evaluation criteria are not identical, but considerable overlap does occur. In most situations when one of these standards has been exceeded, the second is often exceeded as well. The NIOSH criteria document does not establish a fixed limit for HAV exposure and was not used in this study. ISO 8662-4 is used by manufacturers, but not for health purposes. This standard is restricted to using only a single vibration measurement axis, rather than three mutually orthogonal axes, and does not permit the evaluation of the tool during normal on-the-job work tasks. Thus ISO 8662-4 was not used in this study.

### 3. HAV MEASUREMENTS

Since mechanical vibration is by definition a vector quantity containing both magnitude and a direction, both ANSI S3.34 and ACGIH HAV standards require that three mutually perpendicular (triaxial) acceleration intensity measurements be measured using the international consensus coordinate system shown in Figure 2, where the linear Z-axis is motion along the length of the hand-arm; the linear Y-axis is motion across the metacarpals; the linear X-axis is motion through the hand (Wasserman, 1987).

Both the ACGIH HAV standard (given in Table 1) and the graphical ANSI S3.34 criteria (shown in Figure 3) require that triaxial root-mean-square (rms) acceleration intensity measurements be obtained, separately recorded, and "weighted" with each of the three axis results being separately evaluated for each measurement position on the tool being tested. In order to satisfy the evaluation criteria of both the graphical ANSI S3.34 and the numerical ACGIH standards, a separate  $\frac{1}{3}$  octave Fourier spectrum analysis is first

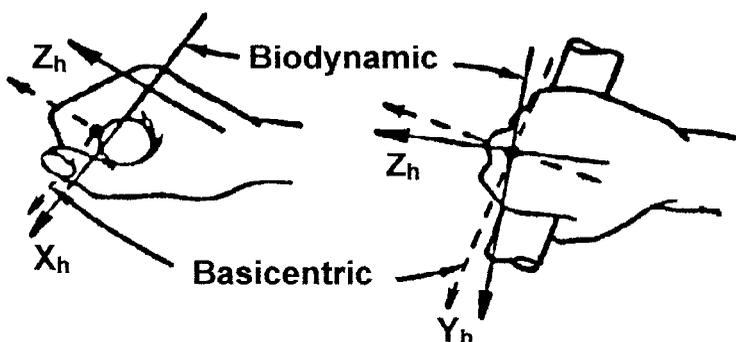


Figure 2 Hand-arm vibration vector coordinate systems.

TABLE 1. ACGIH Threshold Limit Value for Exposure of the Hand to Vibration in Either X, Y, or Z Directions

Total Daily Exposure Duration <sup>a</sup>	Values of the Dominant <sup>b</sup> , Frequency-Weighted, rms, Component Acceleration Which Shall Not Be Exceeded. $a_k, (a_{keq})$	
	m/s <sup>2</sup>	g
4 hr and less than 8	4	0.40
2 hr and less than 4	6	0.61
1 hr and less than 2	8	0.81
Less than 1 hr	12	1.22

<sup>a</sup>The total time vibration enters the hand per day, whether continuously or intermittently.

<sup>b</sup>Usually one axis of vibration is dominant over the remaining two axes. If one or more vibration axis exceeds the Total Daily Exposure, then the TLV has been exceeded.

(Courtesy of ACGIH)

required for each vibration axis measured, each spectrum is displayed graphically, for each axis as used with ANSI S3.34. Next, a total weighted value of rms acceleration for each axis spectrum is calculated and separately used with the ACGIH HAV standard in Table 1.

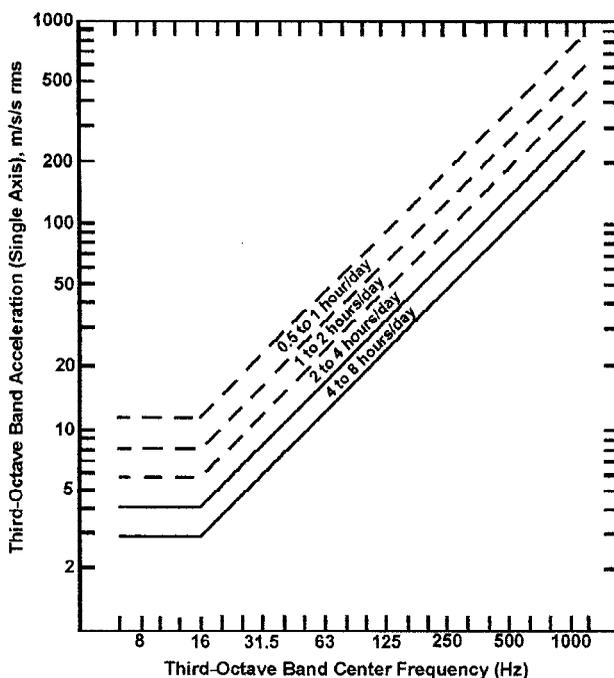


Figure 3 ANSI S3.34–1986, vibration exposure zones for the assessment of hand-transmitted vibration.

Both the ACGIH HAV numerical standard and the graphical ANSI S3.34 criteria require triaxial rms acceleration “intensity” measurements be obtained for each of the three measurement axes (see Equation 1) and then separately recorded.

$$a_{rms} = \left( \frac{1}{T} \int_0^T a^2(t) dt \right)^{1/2} \quad (1)$$

where

$a_{rms}$  = root-mean-squared acceleration intensity in meters per second squared

$T$  = measurement period, or time, in seconds, and

$a$  = measured acceleration in meters per second squared.

After recording each data axis, it is next necessary to separately convert “time domain” data into corresponding “frequency domain, Fourier spectra” (Equation 2) in order to satisfy the evaluation criteria for both ANSI S3.34 and ACGIH HAV standards.

$$F(t) = a_0 + a_1 \sin \dot{u}t + a_2 \sin 2\dot{u}t + \dots + a_n \sin(n)\dot{u}t \\ + b_1 \cos \dot{u}t + b_2 \cos 2\dot{u}t + \dots + b_n \cos(n)\dot{u}t \quad (2)$$

where

$a_0$  = zero hertz (or DC ) term, usually zero,

$a, b$  = acceleration amplitude values of each sinusoid at specific frequencies that comprise the spectrums, and

$\dot{u}$  = rotational frequency  $2\pi f$ .

Next, the HAV “weighting function” (Equation 3) is separately overlaid for each calculated Fourier spectrum and displayed graphically for each axis when using ANSI S3.34. When using the ACGIH HAV standard, Equation 3 is used to separately calculate a “total weighted value” of rms acceleration for each axis spectrum and then one separately compares each resulting value to the Table 1 values of the ACGIH HAV standard as described below.

$$a_{wo} = \left( \sum (W_f a_f) \right)^{1/2} \quad (3)$$

where

$a_{wo}$  = overall weighted acceleration in meters per second squared,

$W_f$  = weighting factor as tabulated in ANSI S3.34–1986 Table B1 for specific third-octave band center frequencies, and

$a_f$  = third-octave band rms acceleration values in accordance with 8.3.5 and 8.3.6 of ANSI S3.34–1986

### 3.1. ACGIH-TLV HAV Evaluation Criteria

Each weighted axis vibration total acceleration value is separately compared to Table 1 values of: 4 m/s<sup>2</sup> for 4 to 8 hr daily HAV exposure, 6 m/s<sup>2</sup> for 2 to 4 hr daily exposure, 8 m/s<sup>2</sup> for 1 to 2 hr daily exposure, and 12 m/s<sup>2</sup> for up to 1 hr daily exposure. After evaluating each axis, “if one or more axis exceeds the Total Daily Exposure then the TLV has been exceeded.” The vibration axis containing the largest weighted acceleration magnitude determines the maximum permissible daily exposure time a worker can operate the given tool. The genesis of the ACGIH HAV standard is keyed to minimizing the possibility of finger blanching in HAV-exposed workers (i.e., Stage 1, Taylor–Pelmear, and Revised Stockholm medical classification systems; Pelmear & Wasserman, 1998).

### 3.2. ANSI S3.34 Evaluation Criteria

The HAV time-dependent limits of the ANSI S3.34 document are shown in Figure 3. The vertical axis of Figure 3 shows acceleration magnitude in m/s<sup>2</sup> (*Note: 1g = 9.81 m/s<sup>2</sup>*). The horizontal axis shows vibration frequency extending from 5.6 Hz to 1400 Hz (in  $\frac{1}{3}$  octave bands) over the “weighted range” of the time-allowable curves. Figure 3 also contains a series of exposure time-weighted (“elbow-shaped”) parallel curves containing four daily exposure zones: 4 to 8 hr/day, 2 to 4 hr/day, 1 to 2 hr/day, 0.5 to 1 hr/day. As with the aforementioned ACGIH HAV standard, triaxial rms linear acceleration measurements are obtained and recorded, with each axis separately analyzed and subjected to a Fourier spectrum analysis. The three vibration spectra are then separately compared to these “weighted curves” shown in Figure 3. For any of the three measurement axes, if one or more Fourier spectral peaks touches, intersects, or both, with one or more of these weighed time dependent curves, then ANSI S3.34 has been exceeded for that daily vibration exposure time.

## 4. INSTRUMENTATION SETUP AND TOOL TESTING

Figures 4a and 4b show diagrams of the instrumentation setup used to obtain, measure, record, monitor, and analyze the vibration emanating from the vibrating hand tools tested; Table 2 lists the equipment used in this study. For each of the four grinders tested, a very small mass triaxial crystal accelerometer system with built-in preamps was mounted on a metal threaded cube welded to an automotive hose clamp and rigidly secured to the tool. This accelerometer system was used to measure each of the three directional vibration accelerations at a location very close to where the tool operator’s hand grips these one-handed tools. Next, each of the three accelerometer preamplifier outputs were tape recorded on a special instrumentation digital audio tape (DAT) system. The DAT then drives a digital signal processor analyzer connected to an IBM laptop PC, such that the fidelity of the multichannel recorded acceleration data were continuously monitored. The X-, Y-, and Z-axis vibration channels were each given a cursory Fourier spectrum analysis. For postdata processing, complete Fourier spectrum analyses, including averaging, calculation of weighting functions, and so forth, were performed using proprietary software programs in MATLAB format, using a Dell workstation computer. After final analysis, the vibration spectrum for each channel was plotted on a chart recorder–plotter. Each vibration channel of the system was calibrated (with reference to gravity) using a Robotron 11032 vibration calibrator. Air pressure (90 psi) used to power the air tools was obtained

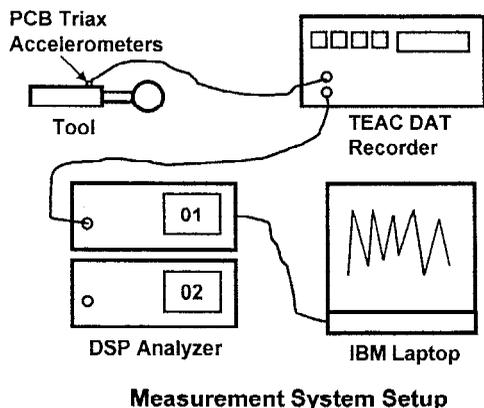


Figure 4a Vibration measurement system schematic.

and regulated from a mobile Atlas–Copco XAS60 air compressor unit. The tool testing took place at the Institute for the Study of Human Vibration laboratory, University of Tennessee in Knoxville. The operator for all four tools tested was a professional master machinist with more than 25 years’ experience.

**4.1. Vibration Tool Testing**

Each test run consisted of a minimum of one full minute duration of continuous vibration data, triaxially obtained as required by the HAV standards, and DAT-recorded. Each tool complete with implements weighed approximately 2 to 3 lb and was operated using one hand. All vibration test runs were videotaped. In order to simulate actual shipyard conditions, all test workpieces supplied by the shipyard were pieces of actual heavy shipyard metal structures (HY-80 steel). These test pieces in turn were securely mounted to a very large mass iron/steel floor-mounted table workbench for rigidity. New grinding, deburring, sanding, and wire brush implements were used each time a tool was tested. Before testing, each tool was properly lubricated. The experienced tool operator wore protective

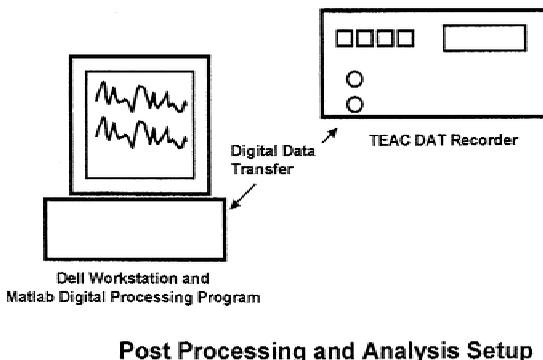


Figure 4b Signal processing system schematic.

TABLE 2. Equipment Used in Vibration Study

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Measurement Setup
TEAC DAT Recorder
Transducers: Model PCB 356B11, s/n PC3668, type triaxial
IBM Laptop: s/n 78-M1358, interface to DSP analyzer
DSP Siglab 2042: s/n 11332, monitoring test signals
Postprocessing
TEAC DAT Recorder: Same unit as above, with digital recording of each test run
QuikVu ISA card: s/n 000336, for transferring digital data from TEAC to PC
Dell Workstation: s/n 9GYWI, data processing machine
Matlab: digital processing software

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eyewear, antivibration gloves, and hearing protection while operating these tools. The vibration tests were conducted in accordance with the HAV standards using the basicentric measurement coordinate system (Figure 2), where the measurement of vibration is taken directly from the tool, versus the biodynamic measurement coordinate system, where vibration measurement is taken indirectly over a knuckle of the hand (Pelmeur & Wasserman, 1998).

The vibration testing runs consisted of the following (NIOSH, 2001):

- Testing a used 14,000 rpm angle grinder using a new grinding wheel—removing welds.
- Repeat testing a new, same-model 14,000 rpm angle grinder using a new grinding wheel—removing welds.
- Testing a used 18,000 rpm die grinder—individual test runs for removing slag, using the following tool implements:
  1. carbide burr
  2. wavy knot style wire end brush
  3. crimped wire end brush
  4. flapper sanding disk
- Repeat testing a new, same-model 18,000 rpm die grinder—individual test runs, removing slag, using the following tool implements:
  1. carbide burr
  2. wavy knot style wire brush
  3. crimped wire end brush
  4. flapper sanding disk

## 5. TOOL TESTING RESULTS

Tables 3 through 7 compare, by axis, weighted vibration acceleration data to the ANSI S3.34 HAV standard. Two examples of the actual tool vibration spectra are given where the ANSI S3.34 standard is overlaid on the spectra: one where the standard is exceeded (Figure 5) and one where it is not (Figure 6). Further, the results given in Tables 3 through 7 are derived from each tool test run and the corresponding spectral graph. Each of these tables identifies and summarizes: the tool being tested and the activity (e.g., grinding,

TABLE 3. 14,000 rpm Pneumatic Angle Grinders With Grinding Wheels Removing Welds

Direction	Weighted Acceleration	Exceeds: ACGIH-TLV	ANSI S3.34
Used Angle Grinder at 90 psi			
X	0.76	NO	NO
Y	1.53	NO	NO
Z	4.06	(8 hr) YES	NO
New Angle Grinder at 90 psi			
X	0.48	NO	NO
Y	0.96	NO	NO
Z	2.45	NO	NO

*Note.* Frequency range: 5.6–1,400 Hz, acceleration (rms) in  $m/s^2$ .

sanding, etc.); the vibration frequency range of 5.6 to 1,400 Hz ( $\frac{1}{3}$  octave band Fourier spectrum analysis); direction/measurement axis; and which (if any) curve in the ANSI S3.34 standard has been exceeded. Also Tables 3 through 7 compare, by axis, weighted numerical test results to the weighted ACGIH HAV numerical standard given in Table 1. The largest weighted value determines the maximum permissible daily HAV exposure using that tested tool.

## 6. DISCUSSION

As stated previously, the operational hypothesis of the study that during normal tool use the vibration levels would rise over time and usage due to normal tool “wear and tear” and tool maintenance has in part been borne out. Referring to Table 8, it can be clearly seen that for the angle grinders performing the same tasks that:

TABLE 4. 18,000 rpm Pneumatic Die Grinders With Carbide Burrs Removing Slag

Direction	Weighted Acceleration	Exceeds: ACGIH-TLV	ANSI S3.34
Used Die Grinder at 90 psi			
X	1.28	NO	NO
Y	1.82	NO	NO
Z	1.71	NO	NO
New Die Grinder at 90 psi			
X	0.89	NO	NO
Y	1.16	NO	NO
Z	1.54	NO	NO

*Note.* Frequency range: 5.6–1,400 Hz, acceleration (rms) in  $m/s^2$ .

TABLE 5. 18,000 rpm Pneumatic Die Grinders With Wavy Knot Style Wire Brush Removing Slag

Direction	Weighted Acceleration	Exceeds: ACGIH-TLV	ANSI S3.34
Used Die Grinder at 90 psi			
X	1.28	NO	NO
Y	2.35	NO	NO
Z	2.10	NO	NO
New Die Grinder at 90 psi			
X	1.32	NO	NO
Y	2.08	NO	NO
Z	2.36	NO	NO

Note. Frequency range: 5.6–1,400 Hz, acceleration (rms) in  $m/s^2$ .

1. The new tool did not exceed either the ANSI or ACGIH HAV standards,
2. The same model used tool did just graze the 4 to 8 hr/day ACGIH standard in the Z-axis, which would limit that tool's use to less than 4 hr/day, and
3. The acceleration levels all increased, ranging from 58% to 66% in the three measurement axes with the acceleration on the Z-axis beginning to exceed the standards.

This same occurred when the new and used die grinders both used carbide burrs to remove slag. In this case, neither HAV standard was exceeded for either tool, but the acceleration levels for all three measurement axes increased from 11% to 44%. An important observation in these two examples is that both the grinder wheel and the carbide burr permit a constant–steady feed force as applied by the tool operator, from

TABLE 6. 18,000 rpm Pneumatic Die Grinders With Crimped Wire Brushes Removing Slag

Direction	Weighted Acceleration	Exceeds: ACGIH-TLV	ANSI S3.34
Used Die Grinder at 90 psi			
X	1.49	NO	NO
Y	2.53	NO	NO
Z	3.18	NO	NO
New Die Grinder at 90 psi			
X	3.66	NO	(4–8hrs) YES
Y	3.76	NO	(4–8hrs) YES
Z	3.73	NO	(4–8hrs) YES

Note. Frequency range: 5.6–1,400 Hz, acceleration (rms) in  $m/s^2$ .

TABLE 7. 18,000 rpm Pneumatic Die Grinder With Flapper Sanding Disk Removing Slag

Direction	Weighted Acceleration	Exceeds: ACGIH-TLV	ANSI S3.34
Used Die Grinder at 90 psi			
X	1.51	NO	NO
Y	2.07	NO	NO
Z	2.38	NO	NO
New Die Grinder at 90 psi			
X	1.20	NO	NO
Y	2.21	NO	NO
Z	1.66	NO	NO

Note. Frequency range: 5.6–1,400 Hz, acceleration (rms) in  $m/s^2$ .

tool to workpiece, because these two attachments are solid in material, and at any one point in time, a small, well-defined part of these attachments comes in contact with the workpiece.

In Table 8, such is not the case when using the die grinders with softer disposable implements such as both types of wire brushes and the flapper sanding wheels. In these cases, there were no significant acceleration level changes between the new and used tools performing the same tasks, probably due to the fact that simultaneously many tentaclelike projections from the wire brushes (and many flappers) come into varying degrees of contact–coupling with the workpiece. Therefore, it is difficult for the operator to

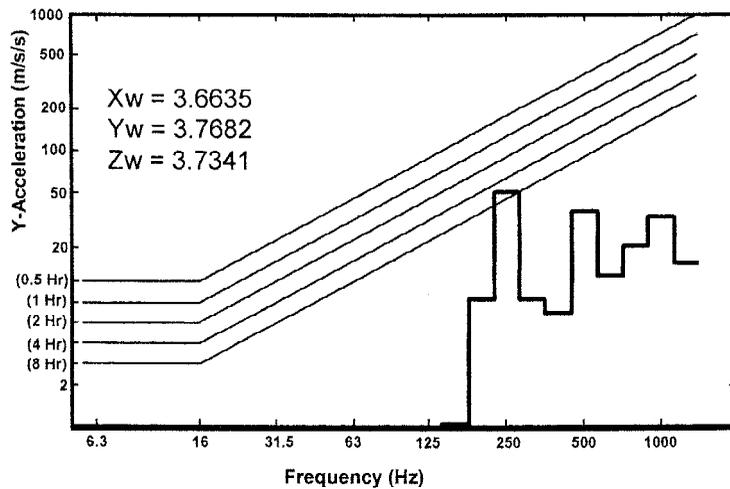


Figure 5 Example of an 18,000 rpm die grinder vibration spectra exceeding the 4–8 hr/day exposure zone in ANSI S3.34 for the Y measurement direction; tool working and removing metal slag with a new crimped wire brush implement at 90 psi.

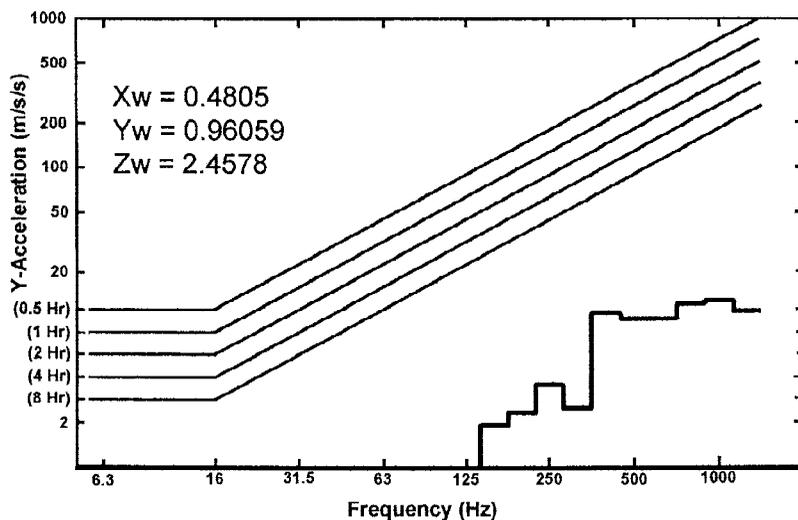


Figure 6 Example of a 14,000 rpm angle grinder vibration spectra not exceeding ANSI S3.34 for the Y measurement direction; tool working and removing metal welds with a new grinding wheel at 90 psi.

TABLE 8. Weighted Acceleration Level Trends ( $m/s^2$ ) by Axis for Tested Tools

Tool Type/Implement	Axis	New Tool	Used Tool	Trend (%)
<i>Hard Implements</i>				
Angle grinder with grinding wheel	X	0.48	0.76	Increase (+58.3%)
	Y	0.96	1.53	Increase (+59.4%)
	Z	2.45	4.06	Increase (+65.7%)
Die grinder with carbide burr	X	0.89	1.28	Increase (+43.8%)
	Y	1.16	1.82	Increase (+12.9%)
	Z	1.54	1.71	Increase (+11.0%)
<i>Softer Implements</i>				
Die grinder with wavy knot style wire end brush	X	1.32	1.28	Decrease (-3.0%)
	Y	2.08	2.35	Increase (+12.9%)
	Z	2.36	2.10	Decrease (-11.0%)
Die grinder with crimped wire end brush	X	3.66	1.49	Decrease (-59.3%)
	Y	3.76	2.53	Decrease (-32.7%)
	Z	3.73	3.18	Decrease (-14.7%)
Die grinder with flapper sanding disk	X	1.20	1.51	Increase (+25.8%)
	Y	2.21	2.07	Decrease (-6.3%)
	Z	1.66	2.38	Increase (+43.4%)

maintain a steady feed force from tool to workpiece. In fact, with the new tool using the crimped wire brush implement, the ANSI S3.34 curves were exceeded for 4 to 8 hr/day exposure, thus limiting the use of that tool to less than 4 hr/day when using a crimped wire brush. The corresponding weighted acceleration levels in each of the three axes came very close ( $3.66\text{--}3.76\text{ m/s}^2$ ) to exceeding the  $4\text{ m/s}^2$ , 4 to 8 hr/day exposures, again limiting this tool and implement to less than a 4 hr/day exposure.

## 7. STUDY CONCLUSIONS AND RECOMMENDATIONS

From this limited study of four tested tools, the following overall conclusions can be made.

### *14,000 rpm angle grinders:*

1. The new angle grinder did not exceed either the ANSI S3.34 or the ACGIH HAV standards.
2. The same model used grinder did just exceed the 4 to 8 hr/day ACGIH standard and thus, strictly speaking, this particular tool should be used for less than 4 hr/day.

In an effort to maintain the lowest vibration acceleration levels possible, and because of the increasing vibration acceleration levels from new versus used tools tested, it is suggested that the implementation of a regular tool maintenance program be considered, with regard to monitoring and reducing tool vibration levels, in cooperation with the tool manufacturer. If possible, this program should include the regular vibration testing and monitoring of tools performing under actual work conditions. Similar tool maintenance programs have been implemented with other vibrating tools used in other types of industries (Johnson & Wasserman, 2000). These vibration reduction maintenance programs appear to be effective, provided the new tools of the same model being monitored do not initially exceed either the ANSI S3.34 or the ACGIH HAV standards in either of the three measurement axes.

### *18,000 rpm die grinders:*

1. With carbide burrs, neither the new nor the used die grinders exceeded either the ANSI S3.34 or the ACGIH HAV standards in any of the three measurement axes. However, in Table 8, there was an 11% to 44% increase in acceleration levels from the new to used tools. Thus, again, it is suggested that the implementation of a vibration tool maintenance program be considered to monitor and minimize increasing acceleration levels in these tools and implements.
2. With wavy knot style wire brushes, crimped wire brushes, and flapper sanding disks, neither the new nor the used die grinders exceeded either the ANSI S3.34 or the ACGIH HAV standards in any of the three measurement axes. However, the acceleration levels in Table 8 for both the wavy knot style wire brushes and the flapper sanding disks showed no increase. For the crimped wire brushes there was a decrease in acceleration levels between new and used tools, which may be attributed to the difficulty and disparity in maintaining constant feed forces on the workpiece using the softer, tentaclelike disposable tool implements. Again, it is prudent to

suggest, as a precautionary measure, that a vibration tool maintenance program be implemented where deemed necessary.

## 8. ADDITIONAL HEALTH CONSIDERATIONS

It is possible to minimize the affliction prevalence of occupationally induced HAVS (Pelmear & Wasserman, 1998) from vibratory tools, by using preventative measures that include using vibration-reduced power tools designed with the human operator in mind, together with the following:

1. Using full-finger protected antivibration gloves, which meet or exceed the international antivibration glove standard: International Standards Organization ISO-10819 (ISO, 1996).
2. Using good work practices (ISO, 1996; NIOSH, 1983; NIOSH, 1989; Pelmeare & Wasserman, 1998), which include:
  - Letting the tool do the work, holding it as lightly as possible consistent with safe work practices to reduce the coupling of vibration into the hand
  - Not using the tool any more than is necessary, and if possible at reduced tool speeds, if doing so would not expose the workers to more harmful vibration at a different frequency
  - Keeping hands warm and dry and not smoking when using vibrating tools
  - Seeking medical attention should signs and symptoms of tingling, numbness, and/or finger(s) blanching occur

## REFERENCES

- American Conference of Governmental Industrial Hygienists. (2001). *Threshold Limit Values for Physical Agents-Hand-Arm Vibration*. Cincinnati, OH.
- American National Standards Institute. (1986). *ANSI S3.34: Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand*. New York.
- Bovenzi, M. (1998). Vibration-induced white finger and cold response of digital arterial vessels in occupational groups with various patterns of exposure to hand-transmitted vibration. *Scandinavian Journal of Work, Environment and Health*, 24(2), 138-144.
- International Standards Organization. (1993). *ISO 8662-4: Hand-Held Portable Power Tools—Measurement of Vibrations at the Handle-Grinding Machines*. Geneva, Switzerland.
- International Standards Organization. (1996). *ISO 10819: Method for the Measurement and Evaluation of the Vibration Transmissibility of Gloves at the Palm of the Hand*. Geneva, Switzerland.
- Johnson, J., & Wasserman, D. (2000). Ergonomics & vibration in powered hand tools used in meat processing. *Journal of Low Frequency Noise, Vibration & Active Control*, 19(1), 1-15.
- Letz, R., Cherniack, M.G., Gerr, F., Hershman, D., & Pace, P. (1992). A cross sectional epidemiological survey of shipyard workers exposed to hand-arm vibration. *British Journal of Industrial Medicine*, 49(1), 53-62.
- National Institute for Occupational Safety and Health. (1983). *Current Intelligence Bulletin #38: Vibration Syndrome*. (DHHS [NIOSH] Publication No. 83-110). Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.
- National Institute for Occupational Safety and Health. (1987). *Hazard Evaluation and Technical Assistance Report: Electric Boat, Groton, CT*. (DHHS [NIOSH] Rep. No. HETA 87-348-2011). Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health.
- National Institute for Occupational Safety and Health. (1989). *Criteria for a Recommended Standard—Occupational Exposure to Hand-Arm Vibration*. (DHHS [NIOSH] Publication No. 89-106).

- Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.
- National Institute for Occupational Safety and Health. (1997, July). Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. B.P. Bernard (Ed.) (DHHS [NIOSH] Publication No. 97-141). Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.
- National Institute for Occupational Safety and Health, Division of Applied Research Technology, Engineering and Physical Hazards Branch. (2001). Hand-Arm Vibration in Shipyards. (Tech. Rep. No. EPHB 229-050). Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention.
- Pelmear, P., & Wasserman, D. (1998). Hand-Arm Vibration—A Comprehensive Guide for Occupational Health Professionals (2nd ed.). Beverly Farms, MA: OEM Press/Medical Publishers.
- Wasserman, D. (1987). Human Aspects of Occupational Vibration. Amsterdam: Elsevier Publishers.