Relevant test methods for establishing sound power levels of powered hand tools[a)]

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High rates of noise induced hearing loss among construction workers provides the motivation for providing noise exposure level information to users and purchasers of powered hand tools. This paper describes relevant sound power level test methods necessary to estimate a tool user's noise exposure. The data are summarized here while detailed test results are posted on a National Institute for Occupational Safety and Health (NIOSH) website database, searchable by tool types, make, and model. The tools database also links directly to the NIOSH Hearing Protector Device Compendium, recommending the appropriate hearing protection for the given noise exposure. Measuring the sound power level in both the loaded and unloaded conditions and reporting the greater value is appropriate for the intended use of providing the relevant data to be used in making purchasing decisions and choosing correct hearing protection. While these researchers tested tools in both the loaded and unloaded conditions, much of the testing in the loaded condition required development of test jigs, methods, and procedures not detailed in existing test standards. It is recommended that efforts be initiated to develop standardized test jigs and methods, such as detailed here, so noise emission levels of power tools can be determined in a relevant and uniform manner from lab to lab.

Primary subject classification: 72.4; Secondary subject classification: 12.5.1

1 INTRODUCTION

In November 2003, the National Institute for Occupational Safety and Health (NIOSH) began A-weighted sound power level (L_{WA}) testing of powered hand tools used in the construction industry. This effort was motivated by high rates of noise induced hearing loss (NIHL) among construction workers and the need to provide noise exposure level information to the users and purchasers of powered hand tools. This paper focuses on describing relevant L_{WA} test methods necessary to estimate a tool user's noise exposure. All test results are posted on a NIOSH internet website database, accessible to the public, and searchable by tool types, make, model, etc.[1]. The database also includes a link to the NIOSH Hearing Protector Device Compendium. This provides convenience in choosing appropriate hearing protection for a given noise level[2].

Noise induced hearing loss is related to noise level, proximity to the harmful sound, time of exposure, and individual susceptibility. This disease is one of the most common occupational illnesses in the world. Occupational hearing loss is a permanent illness, with no recovery currently possible. Hearing loss severely impairs the quality of life, and in its most severe degree, presents a handicap that prevents the worker from being able to communicate effectively at work and at home. The effects of NIHL may be immediate hearing loss that is permanent and/or may be accompanied by tinnitus. Tinnitus is a ringing, buzzing, or roaring in the ears or head. Hearing loss and tinnitus may be experienced in one or both ears. Tinnitus may continue constantly or intermittently throughout a lifetime. The effects of hearing impairment also have serious consequences to the individual's ability to

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[a)] The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH). Mention of company names of products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC), NIOSH.

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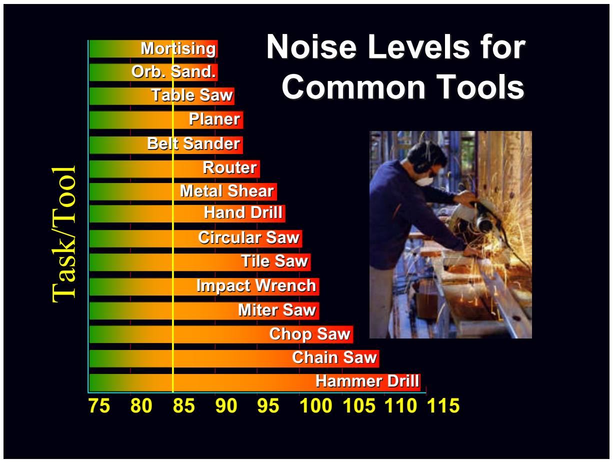


Fig. 1—Tools and tasks vs. Noise level demonstrate carpenters' noise exposure[8]. Sound pressure level in A-weighted dB measured at typical operator's ear distance.

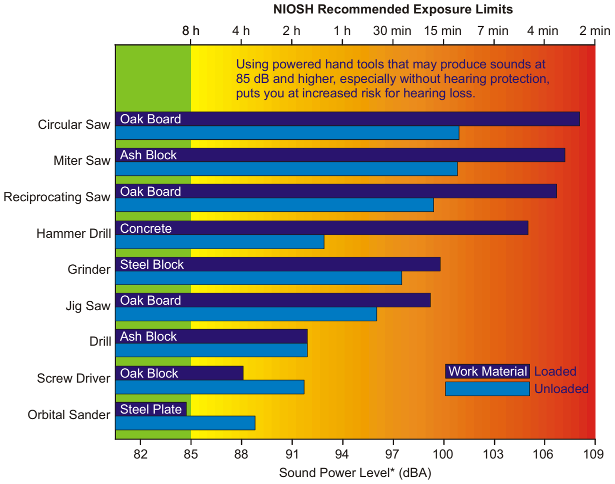
communicate in social and family settings, recognize auditory warnings, and may lead to added job stress and decreased job performance[3–5]. Persons with NIHL are also more prone to workplace accidents as a consequence of the inability to hear audible warnings and impaired speech perception[6].

Up to 50% of construction workers exhibit a hearing disability by age 50. A 1995 NIOSH health hazard evaluation (HHE) revealed that carpenters aged 25–35 years have the hearing equivalent of a 55-year-old worker who has not been exposed to excessive noise. By age 55, most carpenters need a hearing aid[7]. Figure 1 shows the A-weighted sound pressure for various tools being used by carpenters[8]. These noise levels are in terms of the A-weighted sound pressure levels at the operator's ear for typical tool-to-ear distances.

Given these sound pressure levels are in excess of the NIOSH recommended exposure limit (REL) of 85 A-weighted dB and OSHA's permissible exposure limit (PEL) of 90 A-weighted dB, it is little wonder the 55-year old carpenter suffers an occupationally related NIHL. Other studies have shown between 16% and 50% of all construction workers suffer significant NIHL[9–13]. Recent studies conducted at the University of Washington found that 40% of the noise exposure measurements made on carpenters and laborers were over the PEL established in the State of Washington—85 A-weighted dB for 8 hours[14]. Twenty-four percent of the measurements made on those who work in the so-called "quiet" trades, such as electricians, were also over this PEL. A number of studies have shown workers' general noise exposures from powered hand tools range from 81 A-weighted dB to 113 A-weighted dB[8,13,14]. Although, these previous studies focused on personal, task-based, and area noise level measurements, they did show that power tools were a major contributor to worksite noise.

Department of Defense figures for 2006 show that compensation to civilian workers for hearing loss cost \$34.7 million. \$14.1 million was spent in 2006 just by the Navy to compensate their civilian workforce for hearing loss[15]. For instance, the Puget Sound Naval Shipyard (PSNS), having 6000 workers, has had an annual incidence rate of significant hearing loss of 14%. Conservatively, at least 1 in 10 workers at this shipyard alone will experience a hearing loss principally due to noise exposure. NIOSH recently visited PSNS and preliminary measurements found time-averaged A-weighted sound pressure levels (L_{eqA}) of 108 to 115 A-weighted dB for activities such as carbon arc welding, 93 to 104 A-weighted dB for chipping hammer operations, 110 to 116 A-weighted dB wood planer running, and shipyard area noise exposures of greater than 90 A-weighted dB near sand blast and dust recovery units. Lastly, Veterans Administration estimates annual cost of hearing loss compensation to be over \$1 billion per year[16].

The importance of relevant L_{WA} level testing is to accurately enable the estimation of sound pressure level exposures to tool operators. Non-existent or inappropriate noise emission test method standards have led to a void of accurate noise emission data. Accurate data could be used by tools users and purchasers to make informed decisions about both the tools they purchase and the appropriate hearing protection they use. There are thousands of powered hand tools on the market. These tools are used in hundreds of different acoustical environments by thousands of tools users. It would be impossible to gather sound pressure level exposures for all the various permutations and combinations of power tool use and the environments in which they are used. However, it has been shown the L_{WA} can be effectively used to estimate a workers' A-weighted sound pressure level (L_{PA}) exposure across all tool use environments and conditions[17]. Reference 17 describes several methods for translating measured L_{WA} levels for powered tools into predicted sound pressure levels at the operator's ears. For instance, the most conservative approach would simply be to use the value of the measured L_{WA} level, in decibels, without adjustment, as the estimated L_{PA} the tool operator would be exposed to. Generally, this would indicate the upper bound to the noise exposure levels that a worker may expect from the given tool, and against which the worker might want to be safely protected. This method, as described in Ref. 17, is especially useful when describing handheld power tools or other devices being



*Sound power level is equivalent to sound pressure level when evaluating noise exposures associated with powered hand tool use.

Fig. 2—A-weighted sound power level (A-weighted dB) vs. tool tested in the loaded and unloaded condition[18].

operated in close proximity to the operator's ears. Other approaches would subtract a certain number of decibels (generally in the range of 4–12 dB) from the measured L_{WA} level to predict the L_{PA} level. In any event, providing L_{WA} for powered hand tools will give the public much-needed information. Knowledge of potentially dangerous noise levels can be a significant factor in prevention of NIHL.

Figure 2 shows the differences in noise emission levels when testing in the loaded and unloaded conditions[18]. In only three cases (hammer drills, drills and screwdrivers) either higher or equal L_{WA} were found using the test condition as specified in ANSI S12.15[19]. In five cases (circular, miter, and reciprocating saws, grinders, and orbital sanders), the lower L_{WA} test condition is the standard's recommended test condition, thus providing information inappropriate for determining noise exposure estimations and worker protection needs.

In one case (jigsaws) there is no recommended test condition, however the tool is louder in the loaded condition. In general, standards currently underestimate noise exposures to tool and machinery operators and therefore, many of the existing standards for evaluating noise levels for tools and machinery must be revised to provide appropriate test conditions for determining NIHL risk.

There are numerous ISO standards that specify how to set-up and operate the measurement system for gathering sound power levels and sound pressure levels of machinery and equipment. Likewise, many European test standard series focus on electrical safety and product quality of specific powered hand tool types and do not specify relevant test conditions when accomplishing noise level testing[20]. Yet, ISO standards are the standards tool manufacturers follow for gathering data and they use European test standards for setting up the test conditions of the tool. For example, ISO 3744 is a widely used a general noise emission level test standard, yet there is no specific guidance provided for setting up relevant loading conditions for noise emission level testing of a specific power tool[21]. The test or loading condition for establishing electrical safety characteristics may not be considered appropriate for relevant sound level testing. For instance, while an eddy current brake may be useful in accomplishing some tests under "load," the brake certainly would not provide typical noise characteristics of a circular saw cutting through a piece of oak board. Similarly, while the ANSI S12.15 test standard specifies test methods and loading conditions for noise emission testing of some powered hand tools[19], the standard provides recommended test conditions having unrealistic loading in actual tool operation simulation. The test conditions specified in ANSI S12.15 may result in sound power levels that are lower than those from more representative modes of tool use. Relevant noise level test conditions, those conditions typical of tool use, are usually not specified in any existing standards. Thus, the recommended test conditions do not provide appropriate noise level information to tool users and purchasers. Previous NIOSH studies found that noise levels from tools in the loaded condition—in contact with material, such as wood or metal—were 4.1 dB louder, on average, than noise levels from the same tools that were not in contact with material[22–25]. This more than doubles the workers noise exposure and/or more than cuts in half the allowable amount of time they can work in that environment (Assumes NIOSH Recommended Exposure Limit of 85 A-weighted dB with a 3 dB exchange rate). These results further indicate that some industry noise standards are not effective or appropriate in determining noise exposures and risks. The presentation of new relevant test methods presented in this paper can be used in existing standards revisions to provide L_{WA} information that can be used to effectively estimate workers' noise exposure.

Finally, standards revisions to provide appropriate test conditions might also include recommendations for affixing noise rating labels to the tools producing hazardous noise levels (greater than A-weighted 80 dB sound power level). The labels will provide the appropriate information directly to the tool user. Figure 3(a) shows an example of a proposed noise rating label to be used in disseminating the noise emission level of a product (here stating the A-weighted sound power level, L_{WA}, in decibels). The Noise Reduction Ratings (NRR) label, such as that shown in Fig. 3(b), is already

Noise Rating 102 A-WEIGHTED DECIBELS

(LOWER SOUND POWER LEVEL RATING MEANS QUIETER PRODUCT)
THE APPROXIMATE RANGE IN SOUND POWER LEVEL
FOR (PRODUCT) IS FROM 80 TO 108 A-WEIGHTED DECIBELS

GENERIC TOOLS INC.
123 MAIN, ANYWHERE ANYSTATE
MADE IN USA

MODEL
GENERIC 007

Federal law prohibits removal of this label prior to purchase

EPA LABEL REQUIRED BY U.S. E.P.A. REGULATIONS 40 CFR Part 211, Subpart A

Noise Reduction Rating 30 DECIBELS

THE RANGE OF NOISE REDUCTION RATINGS
FOR EXISTING HEARING PROTECTORS IS
APPROXIMATELY 0 TO 35.
(HIGH NUMBERS DENOTE GREATER EFFECTIVENESS)

ABC Protective Equipment
123 Main Street
Anywhere, USA

MODEL ABC1

Federal law prohibits removal of this label prior to purchase

EPA LABEL REQUIRED BY U.S. E.P.A. REGULATIONS 40 CFR Part 211, Subpart B

(a) (b)

Fig. 3—(a) provides hazard rating while (b) provides the protection rating. These two labels demonstrate the utility of having both ratings readily available through labeling.

widely used to demonstrate the effectiveness of various hearing protection devices. A worker may know the NRR for their particular hearing protection device (hearing protection devices are all typically labeled with their NRR). However, because noise emitting equipment is not labeled with sound levels, the worker has no idea what noise levels they are protecting themselves against. Again, note that the authors are making this point for handheld tools and equipment used in close proximity to the operator's ears. This point is valid only for handheld equipment.

If a worker is given a hearing protection device with a NRR of 30 dB, as shown below, that worker should know that they may then be protected for noise exposure levels on the order of 100–115 dB. However, without a noise level emission label, that worker could actually be under protected or may be unnecessarily overprotected (for machinery or tools emitting less than 100 dB).

The following describes the test setups and methods used by NIOSH researchers in gathering L_{WA} data appropriate for estimating noise exposure's of workers using those power tools.

2 LABORATORY MEASUREMENT SETUP

2.1 Lab Facilities Setup

L_{WA} testing was performed in a hemi-anechoic chamber at the University of Cincinnati. The hemi-anechoic chamber has a stainless steel floor and sound absorbing wedges on the walls and ceiling. The hemi-anechoic chamber reference box is limited to 1 cubic meter centered in the 2-meter radius measurement hemisphere. The chamber is described in detail in the project's study protocol[26].

2.2 Measurement Equipment

The data acquisition system used 11 LD 2541 free-field condenser microphones with PRM900 preamplifiers (Larson Davis, Provo, UT). A hemispherical measurement surface is used for L_{WA} measurements in accordance with ISO 3744. Ten microphones were arranged at a 2-meter radius from the center of the hemisphere for the sound power level determination. In addition to the sound power measurement, a simultaneous noise exposure (i.e., sound pressure level) measurement was made. One microphone, noted as the "11th" microphone, was located in the nominal hearing zone of the tool operator for estimation of noise exposure to the tool operator. The distance between the tool and nominal hearing zone changed slightly from tool to tool but tended to be on the order of 0.5 meter. A desktop computer based multi-channel data acquisition system PXI-1042Q chassis having two 8-channel PXI-4472 acquisition boards (National Instruments [NI], Austin, TX), gathered data from each of the eleven microphones simultaneously. The digitized signals were processed using NI's Labview software and stored for post processing in a Matlab binary data file (MathWorks, Natick, MA).

Power consumption and rotational or reciprocating speed of the power tools were recorded during testing. Environmental conditions of the hemi-anechoic chamber were recorded each day testing was conducted. A model 382860 electrical power meter (Extech, Waltham, MA) measured the electrical power, voltage, and current. The RS-232 serial connection for the power meter transferred the data to the computer for storage. A model ACT-3 tachometer (Monarch Instruments, Amherst, NH) measured the rate of rotation in revolutions per minute (RPM) or the speed of a reciprocation in strokes per minute (SPM) for the device under test. The data were transferred to the computer by an RS-232 serial connection. A model Perception II multi-condition meter (Davis Instruments, Hayward, CA) measured the barometric pressure, temperature, and humidity. The microphones, power meter, tachometer, and multi-condition meter were calibrated in accordance with manufacturer's instructions and National Institute of Standards and Technology (NIST) traceable for quality assurance.

2.3 Data Acquisition

Each of the eleven microphones is connected to a T-Junction Box. Each T-junction has three connections: 1) microphone, 2) Larson Davis 2900B power supply, and 3) the PXI-4472 board. The PXI-4472 boards are located in the PXI-1042Q chassis. The chassis and computer have National Instruments data transfer cards NI PXI-8330 MXI-3, having a 50 kHz sampling and data transfer rate from the chassis to the computer. Figure 4 shows the system flow diagram from the microphones to the computer.

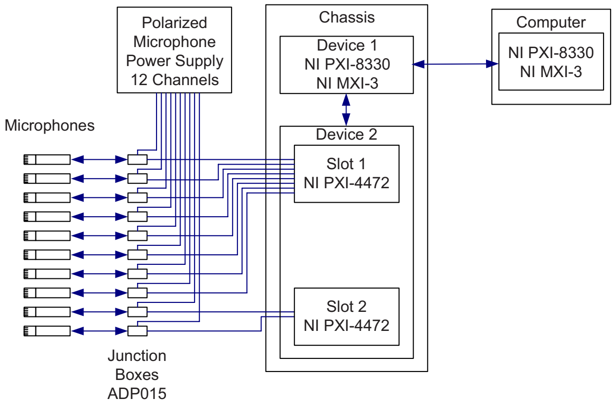


Fig. 4—Data acquisition system signal flow diagram.

The sound pressure data were acquired simultaneously from each of the eleven microphones in real-time. The data from the ten-microphone array was processed to calculate sound power and saved in the frequency domain as weighted and unweighted sound pressure levels. Sound pressure data from the 11th microphone was saved in the frequency domain and as a time series and as a wave file. Data analysis are detailed in the project protocol[26].

2.4 Calibration

The 11-microphone/preamp pairs were calibrated during each series of measurements, usually weekly. The microphone/preamp pairs were sent out for factory calibration annually. A reference sound source model RSS400 (Campanella Associates Columbus, OH) was used each day to determine the environmental correction term, K_2, for the sound power measurements of the power tools. The K_2 value was always less than 2 dB and also confirmed the microphone calibration had not shifted. The calibrations were done in accordance with ISO 3744.

2.5 General Measurement Setup

Each device under test, or powered hand tool, was mounted in the hemi-anechoic reference box volume. For much of the unloaded testing, the device under test was suspended with bungee cords from a steel structure as shown in Fig. 5. For loaded testing, a work bench or short table was used to mount a workpiece for cutting, drilling, sanding, etc.

Each device under test of the same type, but different model, was oriented in a similar direction for each measurement position so that the directivity could be compared within tool types. The directivity was assessed in accordance with ISO 3744. If the difference was greater than the number of microphones, then additional microphone positions were needed. By rotating the tool 180 degrees and acquiring another set of sound power measurements, the number of microphones could be effectively increased to 20. In such a case, the two tool positions were labeled position 1 and position 2 respectively.

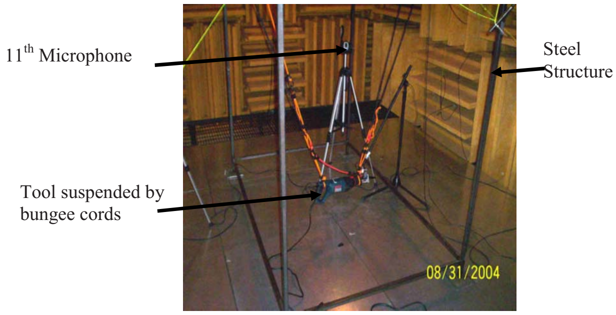


Fig. 5—Reciprocating saw suspended by bungee cords at the nominal height of the RSS's fan wheel.

3 TOOL SETUP SUMMARIES

Each tool is measured in both the unloaded and loaded conditions; however the test jigs, procedures, and results can be quite different for the two conditions. For the loaded condition, the test jigs and procedures for each tool type are illustrated. In the loaded condition, the tool types are presented based on the type of contact between the tool bit and the work piece. There are three types of tool-bit work piece contact: continuous contact, bladed saw contact, and impulsive contact. The contact type is useful in understanding the relationship between the unloaded and loaded L_{WA}.

Typically a hard wood such as oak or ash was chosen to provide a limiting condition on noise production when loading certain tool types such as saws, wood drills, or screwdrivers. The tools contact with a harder material is expected to produce more sound than using a softer material. Thus the sound level tests are conservative in nature and "fail safe" if using the test results to choose hearing protective devices.

All tool tests had at least 10 seconds of averages (i.e., two 5-second averages, ten 1-second averages, etc., based on the operating cycle time of the particular tool). Only the orbital sanders had significant contributions at or below 160 Hz (requiring at least 30 seconds of averages or data in accordance with ISO 3744). The continuous noise characteristics of the orbital sanders allowed for 4 repetitions of fifty 1-second averages.

3.1 Unloaded Test Condition

All of the types of tools are measured at unloaded conditions. At unloaded conditions, the tool is running at full speed without a load applied to the tool bit, blade, wheel, etc. Each of the tools except for the miter

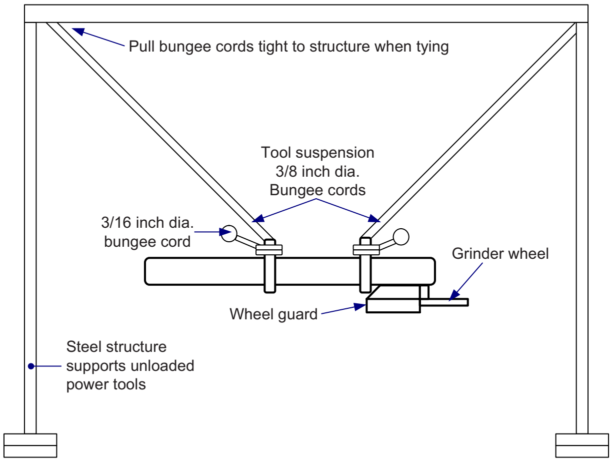


Fig. 6—Bungee cord attachment technique.

saws were suspended in the free-free condition using bungee cords as illustrated for a grinder in Fig. 6. The bungee cords were supported from a steel frame. ISO 3744 is non-specific about tool locations and heights, in the unloaded condition there is no tool operator and therefore no ergonomic considerations for the tool location and height.

3.2 Loaded Test Condition

All of the types of tools are measured at loaded conditions with a test jig designed for that tool type. In the loaded condition the power tool is running at full speed and interacting with a work piece. If the power tool has multiple modes, then the tool was set to the full speed in the chosen mode. The interaction of the power tool and the work piece causes both the power tool and the work piece to emit noise. Since work piece noise emissions can be a relevant source of noise exposure, materials are selected that are a limiting case for noise emissions. The size of the work piece that can be tested is limited by the size and strength of the support structures. Another consideration for the support structure that holds the work piece is the ergonomics of the tool motion. Some tools are easier to use near the floor and other tools are easier to use on a work bench. The different height support structures used were a short table (workpiece nearer to the floor) and a work bench (workpiece tends to be waist height).

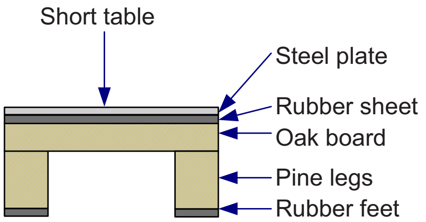


Fig. 7—Short test table for mounting test jigs for power tools.

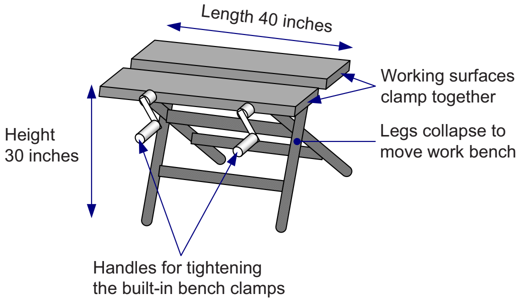


Fig. 8—Portable work bench for testing power tools.

The safety and health of the tool operator is an important consideration when testing in the loaded condition. For several tool types, the test jigs were mounted on a short test table as shown in Fig. 7. The test table had a $12 \times 12 \times \frac{1}{4}$ inch steel plate top and rubber feet to absorb vibrations.

Other tools were tested using the portable work bench (Black and Decker Workmate 550 Portable Project Center and Vise). Figure 8 shows a diagram of the work bench.

3.2.1 Orbital sanders (continuous contact tools)

Tool-bit work piece interaction noise was considered an important component of the tool noise. Materials typically used with a particular tool at a construction site were used when operating the device under test at loaded conditions. The materials, test jigs, and other conditions will be detailed below by tool type.

Per ANSI S12.15, an 8-pound wooden block/sand bag weight was saddled to the top of the orbital sander. Figures 9–11 show the saddled weight design. Two v-notch wooden blocks were clamped to the top of the orbital sander as illustrated in Fig. 9. A plastic bag filled with sand rested on the top of the sander as shown in Fig. 10. Clamps were used to hold the v-notch blocks to the sander while two bungee cords were used to hold the two clamps together.

Figures 10 and 11 show how the orbital sander motion was constrained. Four horizontal bungee cords

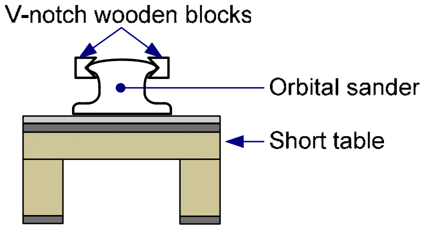


Fig. 9—Test table design and placement of v-notch blocks to orbital sander.

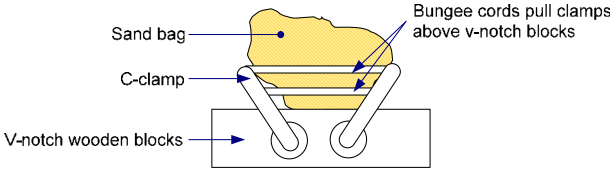


Fig. 10—Orbital sander saddled weight design.

were attached from the steel structure to the C-clamps. The tension and length of the horizontal bungee cords were adjusted until the orbital sander remained level and close to the center of the test table while operating. The orbital sanders tested in this study were typically small and low-powered; more powerful orbital sanders may require an operator to hold the sander in position.

3.2.2 Belt sanders (continuous contact tools)

Figure 12 shows the belt sander test setup for a loaded sound power measurement. ANSI S12.15 does not specify a loading condition for portable belt sanders. The sander was tested by having the operator press the sander against an oak board. The belt sander is louder in the unloaded condition and hence was tested in both loaded and unloaded conditions. During testing, the dust bag was attached to the belt sander. Since the unloaded condition is louder, the unloaded L_{WA} is reported in the database.

3.2.3 Screw drivers (continuous contact tools)

L_{WA} was measured by driving a test screw (#12 wood screw, $3\frac{1}{2}$ inch long, galvanized steel) into a 4-inch thick wood block until the screw head was flush with the block surface. Any clutch slip noise was not included in the L_{WA} measurement as not all screw drivers produce a clutch slip noise. The wood block with dimensions $4 \times 10 \times 11$ inch was assembled by connecting four 1-inch oak boards together with large wood screws. The oak block was resiliently mounted on a short table placed on top of the work bench. The short table setup is detailed in previous INCE proceedings[23]. 5/32-inch diameter pilot holes were drilled and counter bored for all test screws. Before testing, each test screw was tightened approximately $\frac{1}{2}$ to $\frac{3}{4}$ inch deep. While holding the screw driver tightly, the tool operator pushed down with nominal force against the screw and when ready, pulled the variable speed trigger to full speed for data acquisition. In general, the screw was driven into the wood block in 1 to 2 seconds. The screwdrivers did not need to come to full speed before driving the screw because the screwdriver bit must be in contact with the screw before and during operation of the screw driver. Figure 13 shows the setup for the screwdrivers. This test was repeated at least 5 times to ensure a minimum of 10 seconds of data was captured.

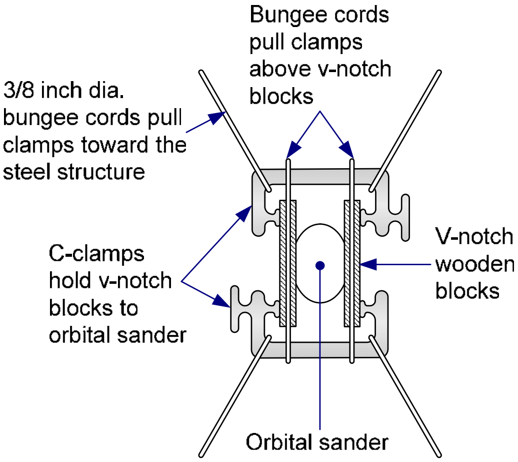


Fig. 11—Test jig for connecting orbital sander to steel structure to constrain motion.

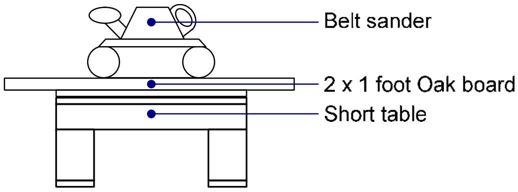


Fig. 12—Belt sander test jig design.

3.2.4 Drills (continuous contact tools)

A $4 \times 9 \times 48$ inch ash wood block was resiliently mounted on the work bench. Each drill was tested with a drill bit of the maximum rated size. The drill bits were standard two flute twist design, straight shank, high

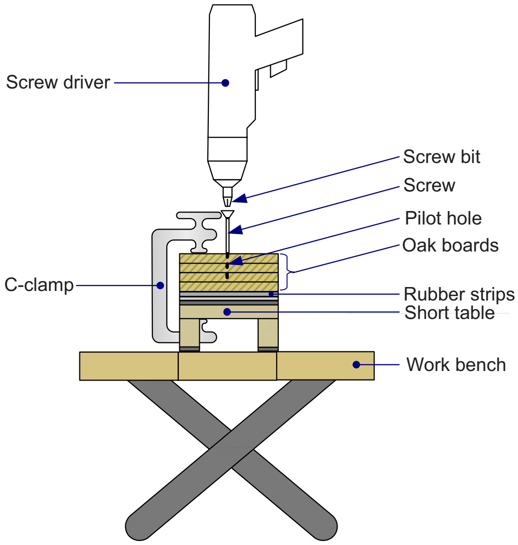


Fig. 13—Test jig for resiliently supporting a wooden block for testing screw drivers.

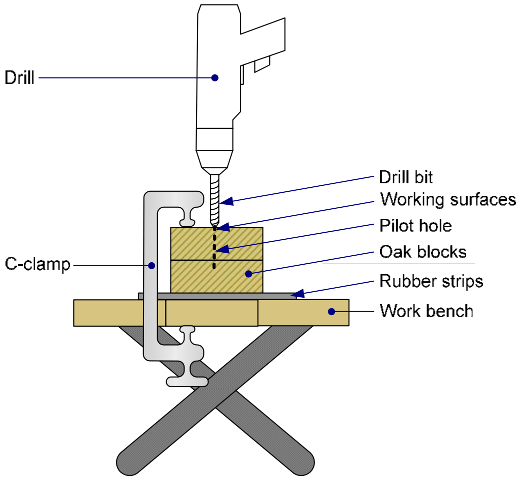


Fig. 14—Test jig for supporting a steel block to steel structure to constrain motion.

speed steel, polished bright finish, jobber length. Drilling started at an unaltered surface of the block at full speed. The hole was drilled to allow at least 10-seconds of data capture to include repeated averages as necessary. The drilling rate ensured no clogging or burnishing the drill. After drilling each hole, the drill bit was cooled with water and cleared of debris. Figure 14 shows the setup for the drills.

3.2.5 Grinders (continuous contact tools)

A 7/8×2×8 inch steel block was resiliently mounted to the portable work bench using rubber strips, 2×4 inch wooden blocks, and C-clamps. The grinder was held horizontally by a tool operator, with the grinding wheel flat against the 7/8 inch wide side of the steel block. The grinder was pressed against the steel and operated in 10-second data acquisition increments. After each set of incremental test runs, the steel block was cooled in a water bath to retain hardness. Figures 15 and 16 show the setup for the grinders.

3.2.6 Circular saws (toothed blade contact tools)

The circular saws were tested in two methods. In method 1, the circular saws cut through 1×12×48 inch rough-sawn oak boards. The tool operator communicated to the computer operator when to start the data acquisition, unfortunately it only took a few seconds to cut through the boards making synchronization of the data acquisition with cutting the boards difficult.

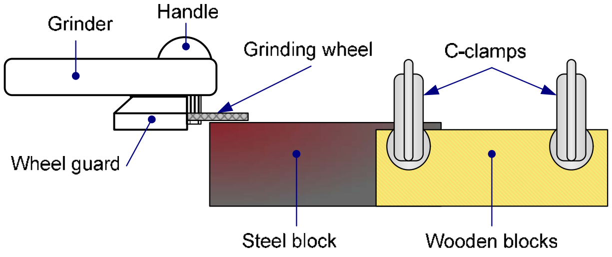


Fig. 15—Test jig for supporting a steel block to steel structure to constrain motion.

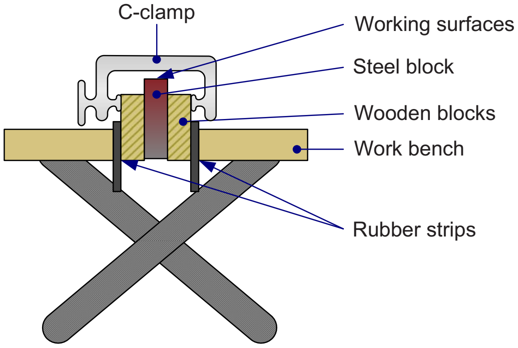


Fig. 16—Test jig for supporting a steel block to steel structure to constrain motion.

In method 2, the data acquisition was automated so that the computer automatically began to acquire data one second after the power tool was switched on. With the automated data acquisition, the tool operator only had to switch on the tool and wait one second then immediately cut through the oak boards. Two rough cut 1×12×48 inch oak boards from a lumber mill were resiliently mounted on a work bench side to side to increase the cutting time. Data was acquired for 2 to 5 seconds depending on how fast the circular saw cut through the oak boards.

A portable work bench was used as the mounting structure for measuring the L_{WA} of circular saws, shown in Fig. 17. Two 1-inch thick oak boards were resiliently mounted to the top of a work bench. Rubber strips were then laid out on the workbench top and oak boards were then placed on the strips and clamped into position using C-clamps having rubber feet. During cutting, nominal pressure was applied to the saw by the tool operator to keep the saw moving through the wood at a continuous rate.

3.2.7 Reciprocating saws (toothed blade contact tools)

A 1×12×36 inch oak board was resiliently mounted to the work bench using rubber straps and the built-in bench clamps as shown in Fig. 18. The reciprocating saw was held horizontally with vertical cuts being made starting at the top of board as indicated by the arrow.

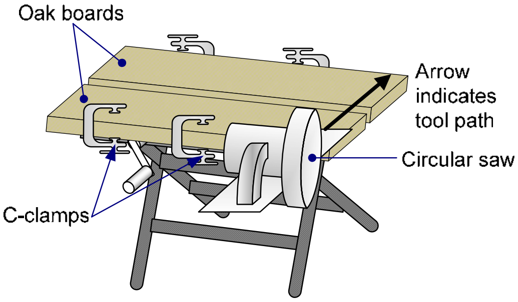


Fig. 17—On the left, the circular saw cuts through two oak boards of nominal dimensions of 1 × 12 × 36 inch. *The boards were placed side by side to increase the duration of the cutting time and subsequently, the data acquisition time. On the right, a reciprocating saw held horizontally, cuts through a single oak board from top to bottom. The dark black arrows indicate the direction of the cuts.*

3.2.8 Jig saws (toothed blade contact tools)

Jig saws were tested with the same test setup as the circular saws, using a human operator to make all cuts. The jig saw cut through the oak boards rather slowly so it was easy for the tool operator to coordinate with the computer operator to cut the oak boards while acquiring data. In method 1, the jig saws cut through the smooth planed 1 × 12 × 36 inch oak boards in 5 to 30 seconds. In method 1, some of the jig saws used orbital action causing the saw blades to sweep through an elliptical motion. In method 2, the only change in the procedure is that orbital action was turned off so that all jig saw blades used a straight reciprocating motion. The blade motion for the orbital and straight blade motions is shown in Fig. 19.

3.2.9 Miter saws (toothed blade contact tools)

Miter saws were placed on a 2 × 1 foot oak board clamped to the top of the test table as shown in Fig. 20. The miter saw was clamped to the test table and the work piece was clamped to the miter saw and test table.

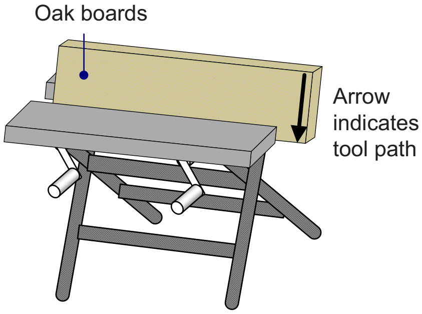


Fig. 18—Test jig for supporting an oak board to test reciprocating saws.

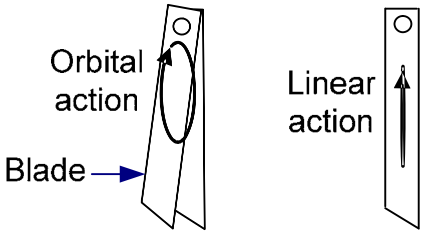


Fig. 19—Jig saw blade motion for test methods 1 and 2.

The miter saws were tested in the loaded condition using three methods. In method 1, miter saws cut through smooth planed 1 × 12 × 36 inch oak boards. The miter saws cut through the oak boards in approximately 1 second or less and the saw blades. The tool operator communicated to the computer operator when to start acquiring the data, unfortunately the cutting time was so short that it was very difficult to synchronize cutting the wood with acquiring data

In method 2, automated data acquisition was used, allowing the miter saws to speed up for one second. However, the miter saw still cut through the oak boards in approximately one second or less; even though, thicker and wider oak boards, rough cut 1 × 12 × 48 inch oak boards from a lumber mill, were used.

In method 3, thicker wood was selected to increase the cutting time. The miter saw was loaded by cutting 1/2-inch slices from the end of 4 × 6 × 48 inch ash blocks were cut by the miter saws. The automated data acquisition was used to coordinate cutting the wood with acquiring data. The miter saws had one second to come to full speed before cutting the ash block. It took the miter saw from 2 to 8 seconds to cut through the ash blocks. Data was acquired for 1 to 6 seconds depending on how fast the miter saw cut the ash block.

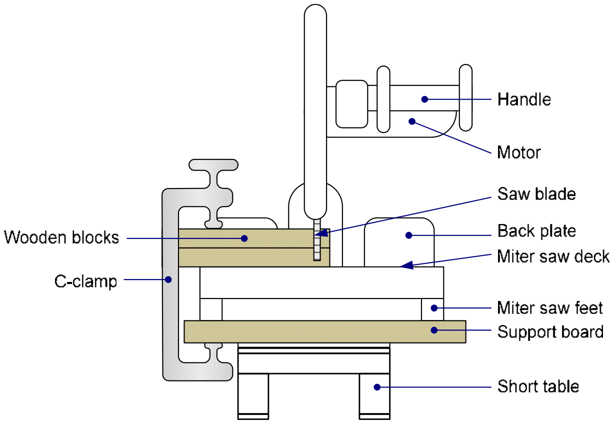


Fig. 20—Impact wrench test setup design.

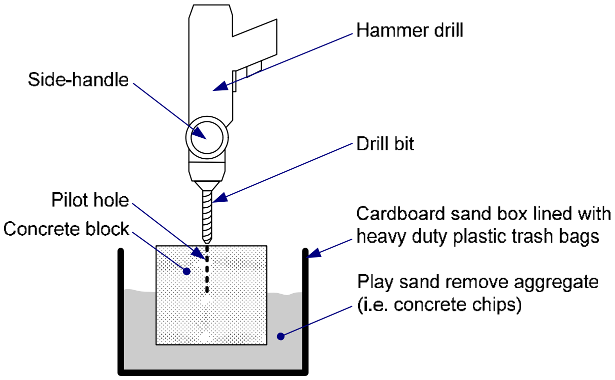


Fig. 21—Hammer drill test setup design.

3.2.10 Hammer drills (impulsive contact tools)

ANSI S12.15 had sufficient detail for sound power measurements of hammer drills. The hammer drills drilled vertically into a concrete block. The concrete block weighted about 150 lb and required the use of an engine crane for setup and transport. The hammer drill test exposed the tool operator to considerable vibrations. The risk of over torque and kick back due to bit binding was reduced for some hammer drills having built in safety devices. Figure 21 shows the test jig for the hammer drills.

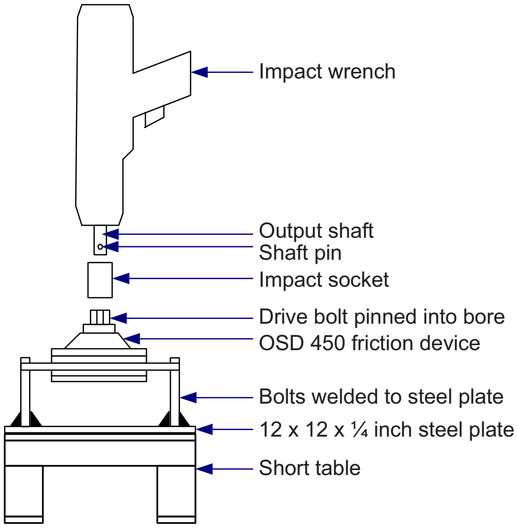


Fig. 22—Impact wrench test setup design.

3.2.11 Impact wrenches (impulsive contact tools)

As shown in Fig. 22, the socket of the impact wrench engaged a drive bolt connected to the model OSD450 overload safety device (Dalton Gear Company, Minneapolis, MN) that ensures constant torque applied to the wrench. The device uses friction discs to provide the torque load on the impact wrench. The overload safety device was bolted to a steel plate that was clamped to the test table. The testing jig may fail due to fatigue during testing. This test jig can be constructed with a replaceable drive bolt; that may be changed out as necessary in a timely fashion, thus reducing test down time for repair.

4 RESULTS

For each tool type, the L_{WA} was compared in the loaded and unloaded conditions to determine the condition emitting the greater L_{WA}. Table 1 shows the mean and standard deviation (STD) for L_{WA}, calculated inclusive of all models of the particular tool type tested. For instance, 28 circular saws were tested in the loaded condition. Within all of the 28 loaded circular saws tested, the overall mean was 108.5 with a STD of 2.8 A-weighted dB. The process of calculating the standard deviation of the sound power level of a tool type (e.g.

Table 1—Comparison of tool types with loaded and unloaded mean L_{WA} for the particular family of tool types and Standard Deviations (STD) (A-weighted dB) between the tool types.

	Loaded	Unloaded
Tool Type (# of tools tested)	Mean L_{WA} (STD) (A-weighted dB)	Mean L_{WA} (STD) (A-weighted dB)
Circular Saw (28)	108.5 (2.8)	100.9 (3.6)
Drill (14)	91.9 (1.8)	91.9 (2.4)
Grinder (18)	99.8 (2.6)	97.5 (3.1)
Hammer Drill (12)	105.0 (3.9)	92.9 (2.7)
Jig Saw (5)	99.2 (1.9)	96.0 (2.5)
Miter Saw (6)	107.2 (4.5)	100.8 (1.0)
Orbital Sander (17)	84.7 (5.6)	88.8 (6.1)
Reciprocating Saw (14)	106.7 (2.9)	99.4 (2.6)
Screw Driver (4)	88.1 (2.6)	91.7 (1.3)

circular saw) consists of collecting the single number overall sound power level of each model of circular saw, then calculating the standard deviation of those sound power levels.

Table 1 also provides the number of tools tested within a particular tool type family. Note that circular saws, hammer drills, jig saws, miter saws, and reciprocating saws showed an increase in L_{WA} in the loaded condition over tests done in the unloaded condition.

Detailed test data and test reports for individual tests can be found in Ref. 1. The STD within each model for the unloaded and loaded cases along with the STD of the measurement system is discussed in Ref. 27.

5 DISCUSSION

As described in this paper, human operators were used to provide realistic and relevant testing of the tools. To the extent that different operators may not vary force and feed rates appreciably during a powered hand tools use, noise level measurement variance would not be expected to vary significantly. The effects of varied feed rates and forces were not examined as part of this work. Given the large population of power tools tested, measurement repeatability was not examined for each tool. However, the measurement system repeatability was examined using the RSS, and negligible variation (STD <0.138 A-weighted dB, range of ±0.6 A-weighted dB) was found over the two year period the powered hand tool data was acquired.

Also note that as shown in Table 1, the STD for loaded tool tests was lower than for unloaded tests. This is the result of introducing the work-piece into the sound level measurement system. The commonality of the work-piece effects tended to drive the STD lower. In general, the high STD can be considered to demonstrate the high variability between different brands of the same type of powered hand tool.

Given a reasonable estimator of sound pressure level exposure such as L_{WA}, it becomes feasible to provide the most comprehensive and economical noise exposure data set for powered hand tool operators. Of course, an accurate estimate is only viable where the L_{WA} is obtained appropriately and then made available to the tool user or safety professional through tool labeling and/or the convenience of an internet accessible product noise declaration database.

There are models for estimating sound pressure at the operator's position from a noise source located at some distance from the operator's ear[17]. Other models are shown to be applicable to larger equipment located one meter or more from the tool operator; consequently, other models are less applicable to portable power tools use. Reference 17 showed the value of the L_{WA} is within 5 dB of the value of the A-weighted sound pressure level exposure over a wide range of source directivities, distances from tool to operator's ears, number of nearby reflecting planes, and amount of sound absorption (room constant). Note that the direct field dominates the reverberant field for hand held tools, with minimal effect on sound pressure level exposure increases due to surrounding reflecting planes and sound absorbing surfaces.

Given there are thousands of power tools on the market, being used by millions of workers on tens of thousands of worksites, it would not be feasible to collect exact sound pressure level exposure data for each permutation and combination of tool use or workplace environment. However, knowing and reporting the L_{WA} of the tool provides the necessary information to make reasonable assumptions as to a worker's noise exposure. The L_{WA} can therefore be used as an effective metric in making purchasing decisions to minimize worker exposure, as well as a guide in selecting adequate hearing protection, if necessary. These types of purchasing decisions are at the heart of buy-quiet programs. However, buy-quiet programs necessitate noise level procurement specifications, the ability to buy the "quietest tool available," and the necessary noise level information. A purchasing decision considering noise level as one of many factors can obviously only be made if the noise level information is provided to the tool purchaser. Given the variation in customer needs and tool uses, this paper makes no recommendation on procurement criteria, noise or otherwise. However, providing noise level information on power tools, equipment, and machinery should be the responsibility of the manufacturer of the tool or machinery. Particularly so when the tool or machinery produces greater than 80 A-weighted dB L_{WA}.

6 RECOMMENDATIONS

Measuring the L_{WA} in both the loaded and unloaded conditions and reporting the greater value is appropriate for the intended use of providing appropriate L_{WA} data to make relevant purchasing decisions and to choose correct hearing protection. As a matter of protecting tool operators from hazardous noise, always report the greater L_{WA} whether it is in the loaded or unloaded condition. To protect tool operator's from hazardous noise, ANSI S12.15 must be revised so that powered hand tools are tested in the condition (loaded or unloaded as the case may be) radiating the greater L_{WA}.

Manufacturers should develop and make available the quietest powered hand tools and machinery in an effort to reduce noise induced hearing loss in the industries that use their products. While the NIOSH power tools database lists the L_{WA} of 122 power tools, tested in both the loaded and unloaded conditions, much of the testing in the loaded condition required development of test jigs, methods, and procedures not detailed in the test standards. Ideally, recommended test codes for measuring sound power would use loading conditions and work pieces similar to use in the construction industry. It is recommended that efforts be initiated to develop standardized test jigs and methods so noise emission levels of power tools can be determined in a relevant and uniform manner from lab to lab.

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