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Empirical Study for Noise Reduction of an Impact Power Wrench and Jig Saw

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1. INTRODUCTION

This paper summarizes a student term project conducted as a part of two quarters sequence Acoustics course, which is one of the projects sponsored by the National Institute for Occupational Safety and Health (NIOSH). The construction tools selected are, an electric impact wrench and a jig saw, specifically DeWalt DW290 and DW321.

Various studies have shown that almost 60% of workers suffer significant noise induced hearing loss (NIHL) as a result of work related noise [1]. Power tools have been shown to be a major contributor to construction noise. Studies have also shown general noise exposure from portable power tools to range from 85dBA to 110 dB [1]. Unlike the EC nations or Japan, the United States does not have specific legislation that mandates manufacturers to minimize NIHL risk and to declare noise level information, thus the noise level of a tool is not given the high priority which it deserves.

2. MEASUREMENT PROCEDURE

The ANSI S 12.15-1992 standard [2] is used as a guide to measure the Sound Pressure Level (SPL) and estimate the sound power of the tools. Measurement is conducted in a semi-anechoic chamber at the University of Cincinnati. This standard covers the test procedure to measure airborne sound from portable electric power tools like the tools of interest in this study. The experimental set-up consists of 5 microphones arranged 1 meter from the center of the tool, four at the front, back, left and right at the same height as the tool, 1 meter from the floor, and one at the top, 2 meters from the floor. Larson-Davis 2900B real time analyzer and Computerized Acoustic Power System (CAPS) software are utilized to obtain the SPL in 1/3 octave bands. Each test is conducted a few times to ensure that the testing results are repeatable. The operating noise levels are measured in the no-load and the loaded conditions for the impact wrench and only in the no-load condition for the jig saw. A fixture is designed and fabricated to provide a fixed magnitude of torque to the impact wrench in the loaded condition.

3. MEASUREMENT RESULTS

A. Impact Wrench

The measured SPL of the impact wrench in dB A-weighted (dBA) is shown in Figure 1. The SPL has strong high frequency components between 3,000 to 12,500 Hz. The total SPL measured is 102 dBA. This frequency range overlaps with the frequency range in which hearing losses are most typically observed, the range of 3,000 – 5,000 Hz [3]. These high frequency components are generated as a result of metal to metal impacts when the impact wrench is operating in the loaded condition.

An impact wrench is used to generate high torques in a very short time. This cycle of energy storage and release occurs almost 45 times per second. Figure 2 shows the interior components of the impact wrench. The components in Figure 2 from left to right are: the anvil housing with the anvil inside, the rotary hammer, the gear reducer, the motor rotor, and the rear wrench housing with the motor stator built into the interior. The impacts of the hammer on the wrench and the wrench surfaces impacting the bolt head surfaces transmit a great amount of energy in a very small period of time. This impact between the hammer and anvil, and the ensuing reflections of the impact wave in the wave propagation path generates very sharp impulses. A close-up view of the wrench hammer and anvil is shown in Figure 3. While the direct impact between the hammer and anvil cannot be altered, other surfaces may be modified to provide smooth impedance change to reduce wave reflections.

B. Jig Saw

The one-third octave SPL spectrum of the jig saw running free of load is shown in Figure 4 along with the SPLs measured after some noise reduction attempts are made. The original free of load spectrum shows that the sound power distribution is more concentrated than that of the impact wrench. The highest peaks are observed around 2,500 Hz band and total SPL is 89 dBA.

Unlike the impact wrench, jig saw has a mechanism that extends and retracts a thin saw blade of negligible mass in a smooth sinusoidal motion. After observing the measurement results, most of the jig saw sound energy is believed to come from the motor and cooling fan. The motor has several components that generate noise. The motor commutator is possibly an important noise source. A solution to the brush noise would be a brushless motor. The brushless motor is often more quiet and efficient because it does not have brush friction, however it generally is more expensive. The noise produced by the cooling fan further contributes to the radiation of noise energy. The mechanism for transferring the rotary motion to reciprocating motion includes a cam follower with needle bearings and a bronze bushing on the slider. This arrangement is well designed and lubricated, and does not appear to be a primary contributor to the overall sound emissions as was observed in the measurement results.

A rotary cam and the counterweight are used to reduce vibrations. Figure 5 shows the internal components, which from top to bottom are, the motor housing with the rotor inside, driven gear for speed reduction, gear spacer, rotary cam, counter weight, front cover with the reciprocating slider inside. Inside the jig saw, the motor rotates the gear mechanism; the gear mechanism in turn rotates a cam that provides reciprocating motion to the blade. The cam also moves a counterweight, which balances the blade motion.

The linear reciprocating mechanism for the translation of the blade (Figure 6) seems to contribute less to the total SPL as compared to the carbon brush and cooling fan noise. This is observed when the SPL plot of the jig saw without the reciprocating mechanism is compared to the original measurement as shown in Figure 4. It is observed that most of the noise comes from the fan and commutator segments of the motor. These two peaks are seen in the plot of no-load run and also in the run without reciprocating mechanism. When the noise level is measured without the reciprocating mechanisms, the noise level changes mostly over a frequency range of 80 Hz to 3KHz. However, there are two distinct peaks at 1.2 kHz and 2 kHz. The 1.2 kHz peak corresponds to the friction between the commutator segments and brushes. There are 24 commutator segments, which produce a frequency component approximately equal to 1.2 kHz when the motor turns at the rated speed of 3100 rpm. The cooling fan blade pass frequency is found to be 2040 Hz and appears as a peak 2 kHz on the plot. The cooling fan blade pass frequency can be changed by reducing the number of blades so that the noise level would reduce at lower frequencies in the A-weighted plot. Likewise, attenuation could also be achieved by changing the number of commutator segments or by changing the design to a brushless motor design.

4. NOISE REDUCTION ATTEMPTS

A. Impact Wrench

As a first effort to reduce the sound level, pressure sensitive adhesive aluminum tape is applied to the barrel of the impact wrench hoping it reduces the sound emitted by the impact mechanism from the metal enclosure. This is applied and tested in several layers. Additionally, an intermediate layer of thin foam is sandwiched between layers of aluminum tape. This provides direct damping of the hammer to anvil impact through attenuation as well as by providing additional mass to the housing. The aluminum damping tape is shown on the barrel in Figure 7.

A muffler is designed from hard plastic styrene and glass fiber batting to provide a crude low pass filter to the sound radiating from the internal mechanism. When the muffler is installed, it covers all three of the exhaust ports of the cooling fan. The small exhaust ports from the muffler perform as a low pass filter. Openings are provided at the end of the muffler to provide for cooling air flow, however for reliability purposes, the airflow and cooling characteristics of the tool would need to be examined for this muffler. In an effort to address the acoustic noise emitted from the armature brush exhaust port, a second device is fabricated from a poly-styrene cup and hard plastic styrene labyrinth baffles covered on the interior with glass fiber batting.

Measurements are conducted step by step after carrying out each of these noise control measures. The results of the above three modifications are seen in Figure 1 along with the measured SPL of the original impact wrench. After the first modification, reductions of the SPL by 3 to 8 dBA in the range of 100 Hz to 630 Hz and by 1.2 dBA to 4 dBA in the range of 630 Hz to 1600 Hz are observed. However, no significant reduction is observed in the frequency range of dominant peaks around 5000 Hz. An additional layer of foam is sandwiched between the damping tape and another layer of aluminum tape to reduce the noise further. The sound level is further reduced by 2 to 8 dB in the 100 to 5000 Hz frequency range; however only about 2 dB at the primary peak at 5,000 Hz. Since the noise can escape from both the cooling fan and the brush cap openings, mufflers are installed. The noise is attenuated by 5 to 10 dB in the 100 Hz to 4000 Hz frequency range. This reduction is better than the earlier case; however the peak SPL did not decrease by any more than 2 dB.

The overall linear and A-weighted SPLs for the noise reduction experiments are tabulated below in Table I. The overall SPL reduction is observed to be around 2 dB.

B. Jig Saw

A similar approach is used to develop and fabricate a muffler device for the jig saw. In the case of the jig saw, examination indicated that the primary source of acoustic sound emissions would be the cooling fan and the armature brush contacts. Initial efforts to reduce the sound level are focused on the armature brush contact noise. Pressure sensitive adhesive foam tape is applied around the armature brush contact area.

A simple muffler is fabricated to address the cooling fan exhaust. This muffler is designed from hard plastic styrene and glass fiber batting. The interior labyrinth construction and the glass fiber batting on the interior surfaces are similar to the impact wrench muffler in design execution.

In a further effort to reduce the sound level, the damping adhesive aluminum tape is applied to the barrel of the jig saw. This is applied and tested in several layers. This design is used to provide direct damping of the motor noise through attenuation as well as providing additional mass to the housing.

To reduce the noise from brushes, adhesive foam tape is inserted in the end cover of the jig saw. Damping tape is mounted on the front to damp the noise from the gear and reciprocating mechanism. The jig saw with the above noise reduction mechanisms is seen in Figure 8.

Measurements are then carried out after applying the first noise reduction modification. There is no significant attenuation of noise. More damping tape is added with a layer of foam sandwiched between layers of aluminum tape, mufflers are installed on the fan openings and a muffler is mounted on the brush cap. SPL measurements are taken again. The overall linear and A-weighted SPLs for the noise reduction experiments are tabulated in Table II. As can be seen in Table II, this modification did very little to attenuate the overall noise of the tool. The SPL of these cases are compared with that of the original jig saw in Figure 4. It can be seen that some attenuation from 1 to 4 dB is achieved at a high frequency range between 2.5 kHz to 16 kHz. It can therefore be concluded that the major part of the noise seemed to be coming from the mechanical components like the gears, counter weight and the reciprocating mechanism of the blade which are not affected by the installation of the muffler. Further study is needed to evaluate the particular component sources and come up with other design alternatives.

5. SUMMARY AND CONCLUSIONS

This project involves case studies of two commonly used power tools to study their noise characteristics and develop methods to reduce the noise levels. When comparing the load and no load measurements in case of the impact wrench, it is observed that the impact of the socket hitting the bolt also had a dominant effect. The impact wrench has dominant peaks in the SPL at about 5 kHz and 12 kHz, which are caused either by the hammer anvil impacts or the impacts of socket hitting the bolt. Propagation and reflection of the impact stress wave may have to be studied to better understand the noise generation mechanism. Short Time Fourier Transform of the impact wrench noise as shown in Figure 9 indicates strong presence of impulsive noise. It is believed that more study is necessary to evaluate the health risk of such highly transient sound.

Predominant noise is observed at frequencies corresponding to the internal motor, especially the brush contacts, and gear mechanisms in the case of jig saw. Attenuation could be obtained by changing the number of commutator segments or using a brushless motor. The cooling fan blade pass frequency could be changed by reducing the number of blades in order to attenuate the noise level at lower frequencies in the A-weighted plot. In both these cases the actual results of the noise reductions are confirmed by comparing the SPLs measured before and after the noise reduction measures were applied.

6. ACKNOWLEDGMENTS

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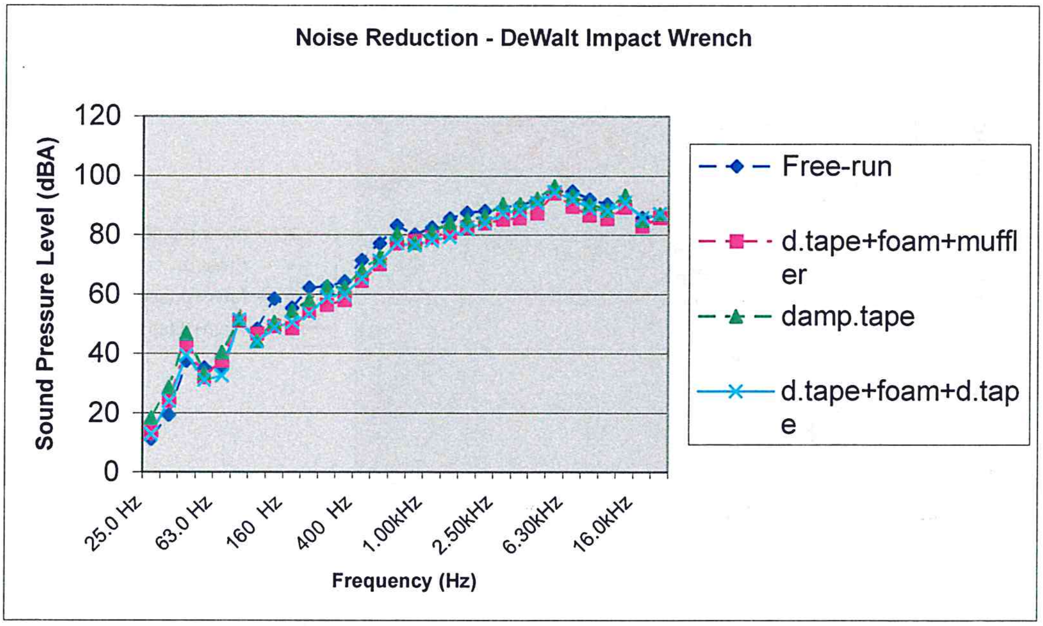

Figure 1: Comparison of A-weighted SPL of Original and Modified Impact Wrench

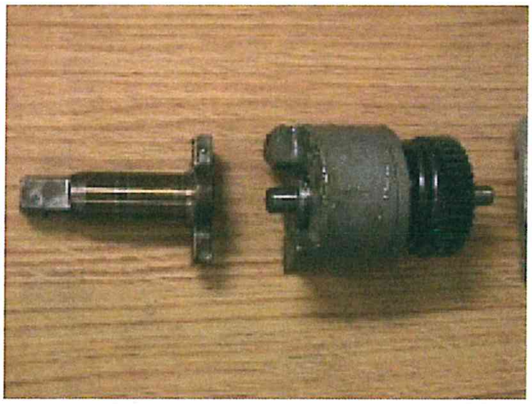

Figure 2: Impact Wrench Components

Figure 3: Impact Wrench, Hammer and Anvil

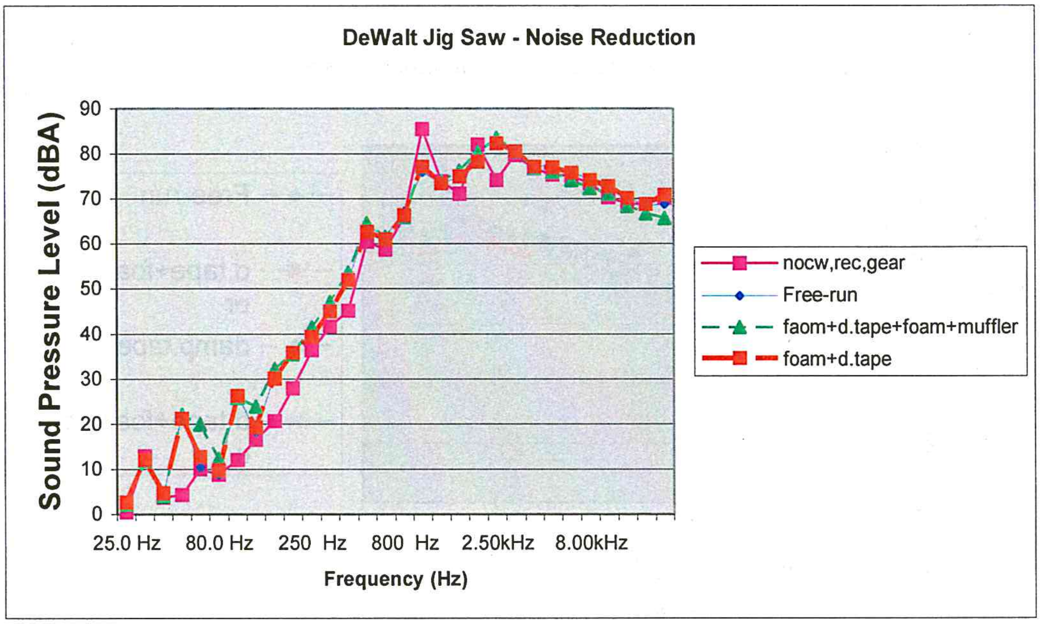

Figure 4: Comparison of A-weighted SPL of Original and Modified Jig Saw

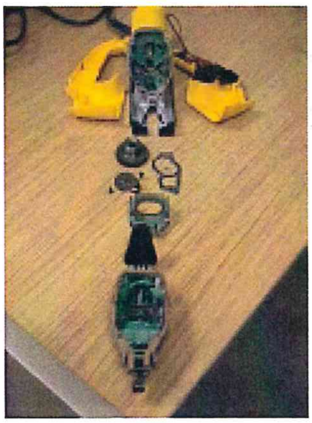

Figure 5: Jig Saw Internal Components

Figure 6: Rotary to Reciprocating Mechanism

Figure 7: Impact Wrench modifications

Figure 8: Jig Saw Noise Reduction Measures

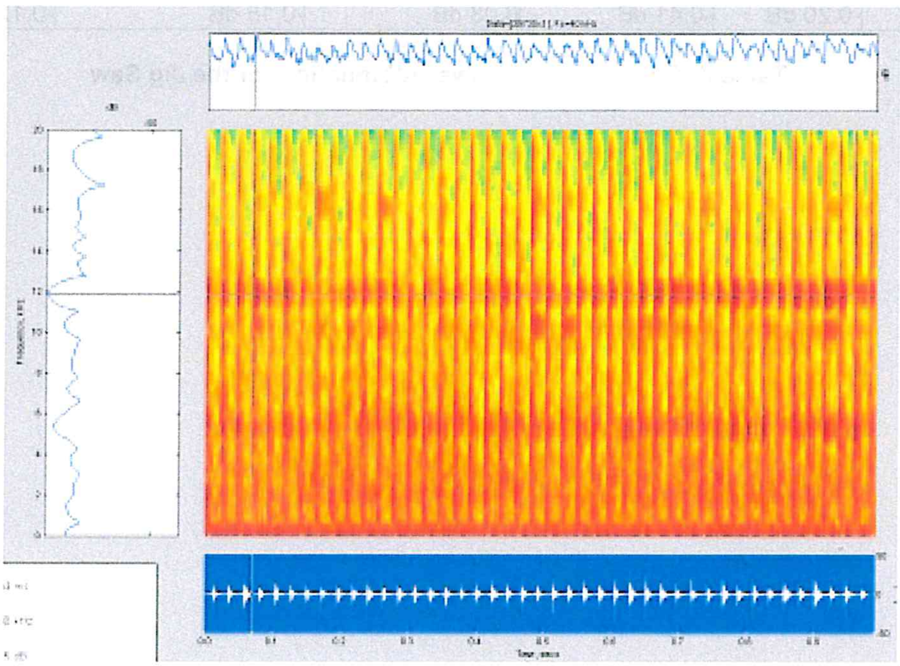

Figure 9. Short Time Fourier Transform of the Impact

Overall Sound Power Attenuation				
	Foam	Al Tape	Al Tape, Foam, Al Tape	Al Tape, Foam, Al Tape, Muffler
Linear	-0.70 dB	0.66 dB	-0.56 dB	-2.23 dB
A-Weighted	-0.63 dB	1.19 dB	-0.48 dB	-2.11 dB

Table I: Overall Sound Attenuation for the Impact Wrench

Overall Sound Power Attenuation					
	Cap Foam	Cap Foam, Al Barrel Tape	Cap Foam, Al Tape on Whole Saw	Cap Foam, Al Tape on Whole Saw, Mufflers	Cap Foam, Al Tape on Whole Saw, Mufflers, Extra Foam & Tape on Barrel
Linear	-0.02 dB	-0.07 dB	0.05 dB	-0.48 dB	-0.45 dB
A-Weighted	-0.20 dB	-0.41 dB	0.03 dB	-0.15 dB	-0.12 dB

Table II: Overall Sound Power Attenuation for the Jig Saw

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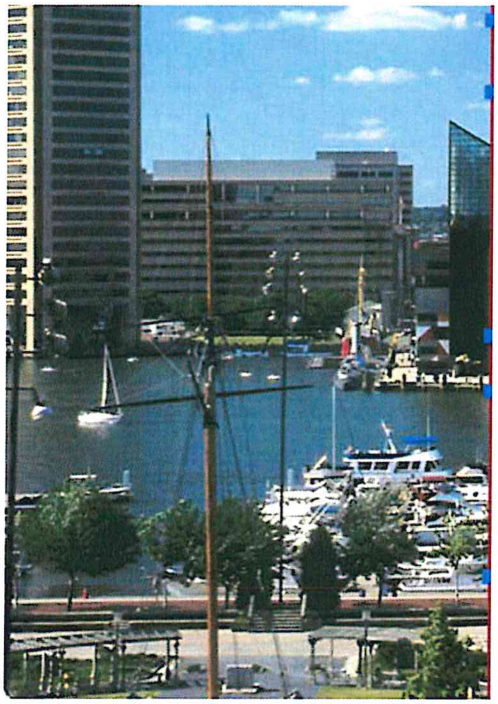

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