Applied Ergonomics 74 (2019) 31–36

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Pneumatic rock drill vs. electric rotary hammer drill: Productivity, vibration, dust, and noise when drilling into concrete

David Rempel[a,*], Andrea Antonucci[a], Alan Barr[a], Michael R. Cooper[a], Bernard Martin[a], Richard L. Neitzel[b]

[a] Department of Bioengineering, University of California, Berkeley, CA, USA
[b] Department of Environmental Health Sciences, University of Michigan, Ann Arbor, MI, USA

ARTICLE INFO

Keywords:
Masonry
Concrete
Hand-arm-vibration
Silicosis
Silica

ABSTRACT

Objectives: Both pneumatic rock drills and electric rotary hammer drills are used for drilling large holes (e.g., 10–20 mm diameter) into concrete for structural upgrades to buildings, highways, bridges, and airport tarmacs. However, little is known about the differences in productivity, and exposures to noise, handle vibration, and dust between the two types of drills. The aim of this study was to compare these outcomes with similar mass electric rotary and pneumatic rock drills drilling into concrete block on a test bench system.

Method: Three experiments were conducted on a test bench system to compare an electric (8.3 kg) and pneumatic drill (8.6 kg) on (1) noise and handle vibration, (2) respirable silica dust, and (3) drilling productivity. The test bench system repeatedly drilled 19 mm diameter x 100 mm depth holes into cured concrete block while the respective exposure levels were measured following ISO standards.

Results: Productivity levels were similar between the electric and the pneumatic drill (9.09 mm/s vs. 8.69 mm/s ROP; $p = 0.15$). However, peak noise (L_{Peak}: 117.7 vs. 139.4 dBC; $p = 0.001$), weighted total handle vibration (a_{hw}: 7.15 vs. 39.14 m/s^2; $p = 0.002$), and respirable silica dust levels (0.55 vs. 22.23 mg/m^3; $p = 0.003$) were significantly lower for the electric than the pneumatic drill.

Discussion: While there were no differences in drilling productivity between an electric and pneumatic drill of similar mass, there were substantial differences in exposure levels of noise, handle vibration, and respirable silica dust. Structural contractors should switch from pneumatic rock drills to electric rotary hammer drills for structural drilling into concrete in order to reduce worker exposures to the hazards of noise, hand vibration, and silica dust.

1. Introduction

Drilling large holes into concrete is performed in commercial construction for structural upgrades (e.g., dowel and rod) and for inserting anchor bolts. The work is physically demanding with high levels of exposure to hand vibration, noise and respirable silica dust. Therefore, such jobs may cause acute injuries, musculoskeletal disorders such as hand-arm-vibration syndrome, hearing loss, and silicosis or lung cancer (Atzeri et al., 1987; Flanagan et al., 2006; Forouharmajd and Nassiri, 2011).

These large holes, typically 1″ in diameter to a depth of 6–24”, are drilled with pneumatically powered rock drills, or, more recently, with electrically powered rotary hammer drills. The diameter and depth of the hole determines the size of the drill required. Typically, structural construction and mining operations used pneumatic drills while electrical and plumbing contractors used electric rotary drills. Reasons for selecting one drill over the other include tradition, power source, tool mass, bit designs, durability and cost. Recent advances in electric motor technology have led to the production of large electric rotary drills with mass and power that can compete with light and mid-weight pneumatic rock drills.

Pneumatic rock drills have historically been considered as the most robust and productive tool for cutting large holes by structural contractors, stone workers, and rock miners. However, pneumatic rock drills are the number one cause of acute injuries among minors due to their heavy weight and are associated with very high levels of noise and vibration levels (Marras et al., 1988). Electric rotary hammer drills are lighter and have been considered as less productive and less suitable for heavy use (Phillips et al., 2007; Camargo et al., 2010; Vergara et al., 2008; Zuchelli, 2011; Lopez-Alonso et al., 2013; Nataletti et al., 2014).

* Corresponding author. Department of Bioengineering, University of California, Berkeley, 1301 S. 46th Street, Building 163, Richmond, CA, USA.
E-mail address: david.rempel@ucsf.edu (D. Rempel).

https://doi.org/10.1016/j.apergo.2018.08.005
Received 17 February 2018; Received in revised form 15 April 2018; Accepted 9 August 2018

However, the newer, heavier and more powerful electric rotary hammer drills may be competitive with pneumatic rock drills. To date, no studies have compared electric and pneumatic drills, of similar mass, on noise, vibration, dust and productivity under the same drilling conditions.

The purpose of this study was to use a new test bench system to measure productivity, respirable silica dust, noise, and handle vibration for a pneumatic rock drill and an electric rotary hammer drill, of similar mass, drilling into concrete block. The test bench system allows for the precise control of drilling force and depth.

2. Methods

The study involved 3 laboratory experiments, one measured handle vibration and noise, one measured respirable silica dust, and one measured productivity. These experiments could not be performed simultaneously because they had to be optimized for each outcome. The studies were conducted using a test bench system previously described and validated with some modifications to accommodate the high levels of vibration from the large drills tested (Rempel et al., 2017). The primary modification was the use of a mass and pulley system to advance the drill under constant load (88N force on bit - adjusted for system friction) rather than the computer controlled, closed-loop load cell and actuator system used in previous studies. This modification was made to prevent damage to the load cell. In addition, larger concrete block were used (610 mm length; 305 mm width; 610 mm high) compared to prior experiments.

The test bench system was programmed to drill a hole approximately every minute. After each hole was drilled the concrete block was automatically moved to a new location in preparation for the next hole. A “sampling” mannequin was fixed behind the drill in a location similar to where a worker would be in order to properly place noise and dust sampling equipment. Non-reinforced concrete blocks were prepared on site, as previously described, and cured for at least 28 days (Carty et al., 2017).

The electric rotary hammer drill used (Hilti TE-70 AVR; 8.3 kg; 46 Hz percussion frequency) is toward the high end of the weight range of electric drills. The pneumatic rock drill (American Pneumatic Tool, Model APT-115; 8.6 kg; 48 Hz percussion frequency) is toward the low end of the weight range of rock drills. For each study, the drills were fitted with new 19 mm diameter 2-carbide tipped bits of similar mass (Hilti TE-Y for the electric drill and Crowder WB77-750-14 for the pneumatic tool). The drills were held at the handle with a 4 fingered rubber lined mechanical gripper and supported at the chuck by a rubber lined Y fixture (Fig. 1).

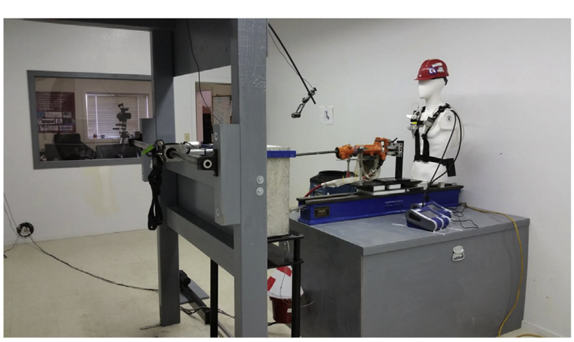

Fig. 1. The pneumatic drill mounted in the test bench system with rubber grips securing the handle and a Y mount supporting the drill near the bit. The drill mounting system slides on a lathe bed. After each hole is drilled actuators move the concrete block to a new location.

2.1. Vibration and noise experiment

Tool handle vibration acceleration magnitude was measured and interpreted following the ISO 28927-10 (2011) standard with some differences. ISO 28927-10 calls for downward drilling, but when drilling downward with an electric hammer drill, the bit may bind due to the lack of air flushing. Therefore, the test bench drilling was done horizontally. The ISO standard also calls for measuring handle vibration while the holes are drilled by test subjects. With the test bench, no humans handle the drill during testing, thereby increasing the precision of force and depth control.

Tool vibration was measured with a triaxial accelerometer (Svantek SV105AF; sensitivity of 0.6 mv/g) attached to the drill handle at the location of the hand grip using zip ties and oriented according to ISO 5349-1 and ISO 28927-10, i.e., the z-axis is aligned with the axis of the bit; the y-axis is vertical; and the x-axis is to the side. The accelerometer was connected to a 6-channel human vibration meter and analyzer (Svantek SV-106 A). All three axes were sampled simultaneously at 6000 Hz and analyzed (Svantec SVAN PC++) to generate the 1/3 octave spectra and the unweighted and weighted (a_{hw}) rms hand acceleration levels according to ISO 5349-1. The accelerometer was calibrated at the beginning and at the end of each test with a calibration shaker (PCB Piezotronics 394C06). Acceleration magnitudes (rms a) were interpreted according to ISO 28927-10.

Tool noise was measured for the entire duration of each hole drilled according to the ISO 9612:2009. The microphone was positioned within 0.1 m of the mannequin ear. Noise samples were collected using a Type 2 personal noise dosimeter (Model 706RC; Larson Davis, Depew, NY) configured to measure noise according to the Threshold Limit Value (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH, 2018) and analyzed using Blaze software (Larson Davis v 6.0.1). Data were collected in terms of L_{eq} in A-weighted decibels (dBA) and L_{Peak} in C-weighted decibels (dBC) for each hole drilled. Noise measurements made inside the test room required the microphone to be located approximately 1 m from the room walls, consistent with real-world use of the tool in rooms and other enclosed environments (e.g., tunnels, vaults, etc). The compressor power source for the pneumatic drill was outside the test room and did not contribute to the measured noise level. The dosimeter was calibrated at sound pressure levels of 94 dB and 114 dB before and after each sampling session (Model CAL150; Larson Davis).

Three test holes were drilled for each drill to a depth of 100 mm. Differences in acceleration, noise and productivity were evaluated statistically using two sample *t*-test.

2.2. Respirable silica dust experiment

The study consisted of two trials for each drill. For each trial, the test bench drilled 60 holes over approximately 70 min. Each hole was drilled to a depth of 100 mm. After each trial, the test room was cleaned with a vacuum and wiped down. The air cleaner was operated until the respirable dust concentration returned to the levels before the start of the trial.

During each trial, three respirable dust samples (4 μm median cut point) were simultaneously collected in the mannequin's breathing zone, e.g., within 30 cm of the nose or mouth. Two of the respirable samplers followed the German methods and were FSP-10 cyclones with 37 mm filters (previously described in Carty et al., 2017); one positioned on the left shoulder and one on the right (Fig. 2). The third respirable sampler followed the US/NIOSH method and was a GK 4.162 cyclone (BGI by Mesa Labs, Inc., Butler, NJ) holding a pre-weighed 47 mm polyvinyl chloride (PVC) filter positioned on the right shoulder. The purpose for using 3 cyclones was to compare, side-by-side the German to the US method with the apriori decision to primarily rely on the US method. In addition, two direct-reading aerosol monitors (DustTrak II and DustTrak DRX, TSI Inc., Shoreview, MN) were located