

EVALUATION OF HANDLE VIBRATION FOR HAMMER DRILLS USING A NEW TEST BENCH SYSTEM

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Introduction

Drilling holes into concrete is a common task in commercial construction required for placing anchor bolts that support pipes, conduit, ducts or machinery or for setting rebar (e.g., dowel and rod drilling) for structural retrofits, seismic upgrades or extending roads and tarmacs. The typical handle vibration levels for this work are 8-16 m/s^2 for hammer drills and 14-20 m/s^2 for pneumatic rock drills (Griffin 2006).

Test bench methods have been developed for evaluating silica dust from cement cutting tools (Akbar-Khazadeh 2010) but not for handle vibration using concrete drills and there are no international standards for such test bench systems. Instead, international standards call for handle vibration to be measured in controlled settings while workers use the drill (ISO 28927- 6&10). There is a concern that a test bench may constrain the system in ways that will alter handle vibration as compared to vibration experienced by workers. The purpose of this project was to develop and evaluate an automated test bench system in order to evaluate drill handle vibration under different conditions of concrete drilling.

Methods

A test bench system was designed and built with the following features: (1) automatically controls an active drill and advances it into concrete under force control, (2) automatically advances concrete blocks between holes, (3) accommodates a wide variety of drill types, and (4) continuously records handle vibration. The drill is firmly coupled to a saddle that is moved horizontally by a linear actuator under force control (e.g., feed force (F_A) = weight on bit (WOB)) managed by a custom LabView program on a PC (Figure 1). The drill is secured to the saddle with ring clamps at the drill handle; between the clamps and the drill a 1 cm thick rubber/foam is inserted with stiffness properties similar to palmar skin. The activated drill drills into a concrete block to a specified depth (up to 250 mm) at a constant feed force (adjustable range: 50 and 500 N) and is automatically withdrawn. After each hole is drilled the concrete block is advanced so that the next hole can be drilled. The drill saddle is coupled to a single axis load cell with a stiff spring aligned to the drilling axis (Figure 2). The load cell is moved by the linear actuator on a lathe bed. Non-reinforced concrete blocks (3.5 x 12 x 12") are made with quality is consistent with reinforced structural concrete (slump 80 mm; EN 206-1:2000).

A tri-axial accelerometer (Larson Davis HVM100) was attached to the drill handle using hose clamps and the signal was sampled at 1Hz and stored to a computer. The accelerometer and load cell were calibrated prior to use (PCB Piezotronics shaker 394C06). Tool handle vibration acceleration magnitude was measured and interpreted according to ISO standards (ISO 28927-6&10).

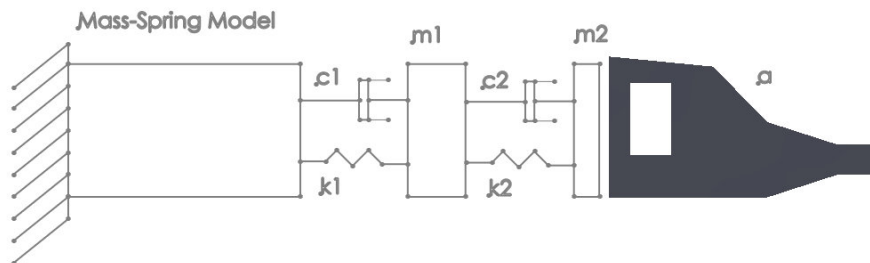


Figure 2. Mechanical model of system with linear actuator (left), stiff spring (k_1 , c_1), load cell and drill saddle (m_1), drill mount (mass), rubber interface (k_2 , m_2 , c_2), and drill (a).

Validation of the test bench system was assessed by comparing test bench results to those from 4 experienced construction workers drilling 5 holes per test condition, following ISO methods. Subjects signed a written consent form and the study was approved by the University Committee on Human Research. Subjects drilled vertically into concrete block to measure thrust force while subjects stood on an electronic force plate (Sampling rate 25Hz; Acculab Digital Scale, Bradford, MA). The workers were instructed to apply thrust force similar to their usual drilling. Handle vibration measurements were similar to measurement on the test bench system.

Four test conditions were evaluated on the test bench: two electric hammer drills (TE40 and TE7, Hilti), each with a 3/8 and 3/4" concrete bit. For each condition, 5 holes were drilled to 125 mm (ISO 28927-10) with a target linear force of 90N. Two test conditions were evaluated by the human studies: the same two electric hammer drills with the 3/8" bit. Human testing was not done with the 3/4" bit. Productivity was measured as drilling time to complete drilling depth.

Results and Discussion

Summary measures of findings (mean (SD)) are presented in the Table below.

Drill	Bit	Holes	Linear Force (N)	Drilling Time (s)	Mean Peak Vibration (m/s ²)	Mean Mean Vibration (m/s ²)
TEST BENCH						
TE40	3/4"	21	90.2 (3.8)	32.7 (1.4)	17.0 (2.0)	7.2 (0.5)
TE7	3/4"	16	89.7 (1.8)	78.8 (4.0)	29.1 (1.6)	9.0 (0.3)
TE40	3/8"	11	73.3 (4.3)	13.5 (0.6)	16.2 (2.1)	7.1 (1.1)
TE7	3/8"	22	88.5 (9.5)	15.2 (1.1)	31.1 (0.6)	9.5 (0.2)
HUMAN TESTING (N=4)						
TE40	3/8"	5	74.6 (4.1)		24.4 (1.6)	7.9 (1.0)
TE7	3/8"	5	81.6 (23.0)		31.5 (5.3)	10.1 (1.0)

Linear force for the test bench was close to target values of 90N with low variance for the 3/4" bit. The 3/8" bit was undersized for the TE40 leading to difficulty maintaining constant feed force. The self-selected linear force by workers was somewhat less than the force used for the test bench. As expected, the coefficient of variance (CV) for linear force for the workers was higher (0.05 to 0.28) than the test bench (0.02 and 0.11).

Mean mean vibration levels were similar between the test bench and the human testing. Mean peak vibration levels were similar for the small drill but not the large drill.

The test bench system included foam rubber damping at the coupling to the drill handle designed to be similar to the palm coupling. In addition, a stiff spring isolated the drill from the linear actuator, mimicking the role of the forearm and upper arm. It appears that the masses of the saddle and load cell provided a response that was similar to the human system (Dong 2010). Future validation studies should involve larger bits (e.g., 5/8" and 3/4") that are more appropriate for the drills tested.

The test bench methods differ from the ISO standard in several ways. The ISO standard calls for drilling downward, but when drilling downward with an electric hammer drill, the bit will bind in a 250 mm depth hole because there is no air flushing of the dust. So drilling on the test bench was done horizontally to prevent bit binding. In addition, the ISO standard calls for subjects do the drilling. This may lead to handle grip force and force on tip that are similar to work. However, this approach is also associated with increased variance in measures while the robotic system minimizes variance. The problem of robotic system not matching real world grip and feed force can be addressed by having the robotic system perform testing under different feed force and grip force levels. This approach may provide greater insights into drill design and vibration and may influence instructions to end-users. A test bench system for concrete drilling can provide information that compliments data from human compliance testing. [Acknowledgements: This study was supported in part by a grant from The Center for Construction Research and Training and NIOSH].

References

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