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A new test bench system for hammer drills: Validation for handle vibration

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A R T I C L E I N F O

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A B S T R A C T

Workers' can be exposed to high levels of hand vibration when drilling into concrete or rock using hammer drills; exposures that can cause hand arm vibration syndrome. Exposure levels may be reduced by different drill and bit designs and drilling methods, but these interventions have not been systematically evaluated. The purpose of this project was to develop a robotic test bench system for measuring handle vibration on drills in order to compare differences in drill designs, power sources, bit designs and drilling methods. The test bench is a departure from the ISO method for measuring drill handle vibration (ISO 28927-10), which requires drilling by humans. The test bench system was designed to repeatedly drill into concrete blocks under force control while productivity and handle vibration were measured. Handle vibration levels with different drills and bit sizes were similar to those collected following ISO methods. A new robotic test bench system for measuring handle vibration is presented and validated against ISO methods and demonstrates dynamic properties similar to human drilling.

1. Introduction

Drilling into concrete with hammer and rock drills is a physically demanding task associated with exposure to hand vibration, noise, silica dust and high hand and arm forces. Typical hand vibration levels are 8–16 m/s^2 for hammer drills and 14–20 m/s^2 for pneumatic rock drills (frequency-weighted acceleration levels per ISO 5349-1) (Griffin et al., 2006). These exposure levels can cause hand arm vibration disorders after months of exposure to many hours of exposure per week (Palmer et al., 2000; Edwards and Holt, 2006).

Drilling holes into concrete is a common task in commercial construction required for placing anchor bolts to support pipe, conduit, ducts or machinery and for setting rebar (e.g., dowel and rod drilling) for structural retrofits, seismic upgrades or extending roads and tarmacs (Fig. 1). Recent examples of large jobs in Northern California were (1) a highway sound wall upgrade in Northern California required 25,000 1″ diameter, 12″ deep holes drilled with 30 lb rock drills; (2) seismic upgrades to all Bay Area Rapid Transit (BART) train towers, each tower required 800 1″ diameter holes 18″ deep, (3) a 6″ conduit hung from the ceiling of a 5 mile tunnel required 13,000 5/8″ diameter holes, and (4) a commercial building remodel in San Francisco required 40,000 3/4″ diameter holes. In the US, concrete drilling is done by laborers (697,980), brick and block masons (56,590), cement masons (143,250), carpenters (516,340), electricians (424,810), and plumbers (304,480) and drilling into rock is done by miners (51,810) [BLS and National Industry-Specific Occupational Employment Estimates 2014].

Handle vibration levels when drilling into concrete can be reduced with a drilling rig (Rempel and Barr, 2015). Other interventions may also reduce handle vibration. For example, new high torque electric hammer drills may have lower handle vibration levels compared to the equivalent weight pneumatic rock drills. Dampening systems that are integrated into the drill handle may reduce handle vibration. Drilling with different feed force may change the handle vibration profile. Drill bit design or bit wear may alter handle vibration. However, the effects of these designs and drilling methods on handle vibration have not been systematically evaluated.

Automated test bench methods have been developed for evaluating silica dust exposure from cement cutting tools (Heitbrink and Bennett, 2006; Akbar-Khanzadeh et al., 2010; Meeker et al., 2009). However, automated bench methods have not been developed for measuring handle vibration with hammer drills and there are no international standards for such test bench systems. Instead,

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Fig. 1. Manual drilling with pneumatic rock drill for structural work.

international standards for measuring handle vibration require workers to drill into concrete under controlled conditions (ISO 28927-5; ISO 28927-10). Variance between subjects may be high with this approach due to differences in drilling technique. On the other hand, a test bench system may constrain the drill in ways that alters handle vibration as compared to drilling by workers.

The purpose of this project was to develop and evaluate a new automated test bench system for concrete drilling in order to compare handle vibration under different drilling conditions. Handle vibration measures from the new automated system were compared to handle vibration with workers drilling following ISO methods. The null hypothesis was that there were no differences in handle vibration levels between holes drilled using the test bench method compared to the ISO method.

2. Methods

2.1. Design of test bench system

A test bench system was designed and built with the following features: (1) automatically controls an active hammer drill and advances it into concrete under force control, (2) automatically advances concrete blocks after each hole is drilled, (3) accommodates a wide variety of drill types, (4) has similar dynamics to human dynamics, and (5) continuously records handle vibration during drilling. The drill is firmly coupled to a saddle that is moved horizontally by a linear actuator under feed force control (i.e., linear force or weight on bit). The drill saddle is coupled to a single axis load cell (Bertec, Columbus, Ohio) with a stiff spring aligned to the drilling axis (Figs. 2 and 3). The load cell, drill saddle and drill are moved on a lathe bed by a linear actuator. Non-reinforced concrete blocks (3.5 × 12 × 12?) are made consistent with reinforced structural concrete (slump 80 mm; EN 206-1:2000) and ISO standards (ISO 679; ISO 28927-10). Concrete blocks cure for at least 28 days before being used.

The drill is secured to the saddle with ring clamps at the drill handle. Closed cell foam-rubber (1 cm thick) is inserted between the clamps and the drill handle. The stiffness properties are similar to palmar skin; the foam compresses 25% of original thickness at 12 psi. The chuck rests on a support padded with the same rubber/foam.

A tri-axial accelerometer (Larson Davis SEN040F) is attached to the drill handle using hose clamps and the acceleration measurements are averaged with a vibration meter (Larson Davis HVM100)

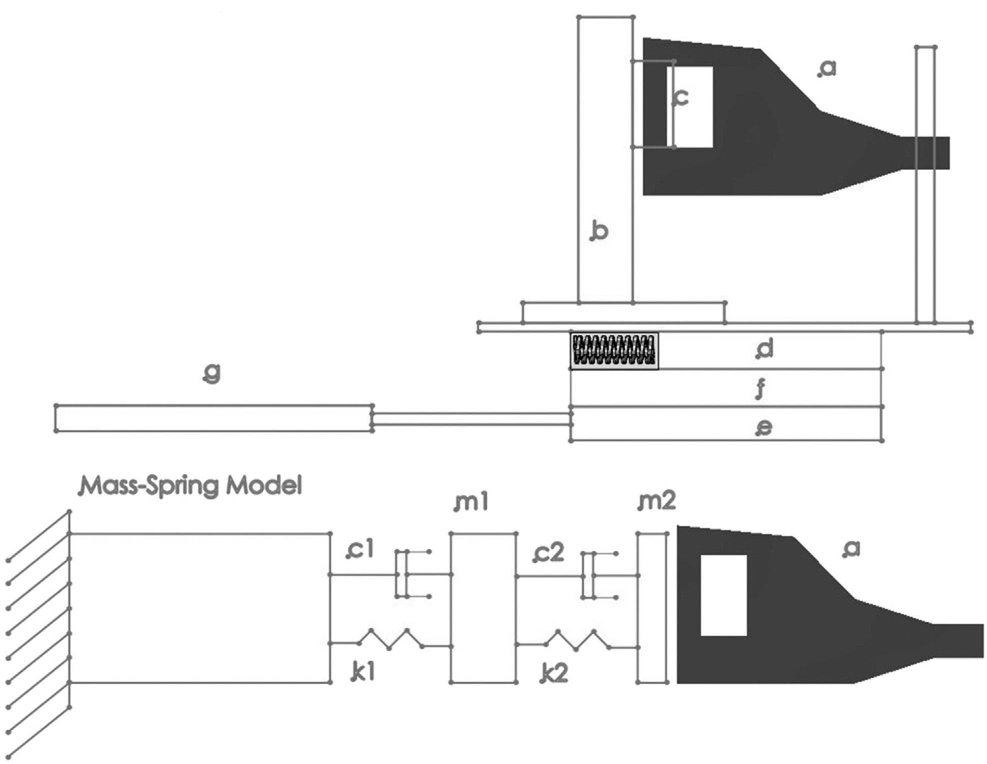

Fig. 2. Drawing of test bench system and corresponding mechanical mass-spring model with a hammer drill (a). The drill handle is clamped to a fixture (c) with rubber-foam between the clamp and the handle. The chuck rests on a rubber-foam support. In the model, m1 includes plate d, vertical bar b, and fixture c; k2, m2 and c2 are the rubber-foam interface. The stiff spring is k1; dampener c1 is the friction between d and f. The linear actuator (g) drives the whole assembly toward the concrete block.