Overhead Drilling

Development and evaluation of a new device

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IN THE CONSTRUCTION INDUSTRY, innovations are created in the field to address a specific, temporary challenge for which there is no available tool or process. Often, these innovations spring from the grassroots efforts of tradespeople who know the work and understand the need for the intervention. The interventions usually are crude devices—fabricated from scrap material—that provide a temporary working solution. Unfortunately, many of these interventions are short-lived and abandoned at the end of a project. This article describes the effort of a research team to capture alternative ideas for overhead drilling, fabricate functional devices based on those ideas and improve the designs based on two rounds of field testing.

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Scope of the Problem

Overhead work is associated with shoulder pain and disorders of the shoulder muscles and tendons (Olson, 1987; Welch, Hunting & Kellogg, 1995; Hunting, Welch, Cuccherini et al., 1994; Holmstrom, Lindell & Moritz, 1992). Rotary hammer drills can weigh up to 20 lb and an upward force of 90 lb can be applied for 1 to 2 minutes while drilling into concrete. The task is further complicated by dust and debris falling on the worker's face as well a risk of falling from ladders or scissor lifts.

Electricians, pipe fitters, sheet metal workers and carpenters drill holes into metal or concrete ceilings in order to attach anchors for hanging pipes, duct work, cable tray and similar items (Photos 1 and 2). Overhead drilling into metal or concrete ceilings has been identified as one of the most physically demanding tasks in the construction setting (NIOSH, 2006).

No commercial devices are available for overhead drilling from the ground. However, on several construction projects, rudimentary drill stands have been built to help with this task. The fact that these devices are being developed in the field suggests a need that is not being fulfilled. The goal of this project was to develop a device for overhead drilling and to improve the usability and safety of the device through several rounds of field testing. Two first-generation devices were developed and fabricated based on rudimentary designs observed at construction sites. Based on feedback from field testing, a set of three second-generation devices was designed and fabricated and, again, field tested. Ultimately, a final design will be evaluated by a large group of workers.

Generation 1 Prototype Design

The research team identified two crude device designs for overhead drilling. The first was a cantilever design where the operator depresses a foot or hand lever that pivots and raises a vertical column with a drill on top. The second used a hand crank, like an inverted drill press, to control gears or cables that cause a nested vertical column to rise with a drill on top. The research team refined these designs and fabricated the first generation of devices. Photos 3 and 4 (p. 32) show the two first-generation devices (termed the foot-lever drill press and the inverted drill press, respectively).

Each device consisted of a drill saddle, a telescoping column, a trigger switch and outlet, a method for raising the column and a base. The drill saddle was custom made to hold one of three of the most commonly used drills in the field. These drills were provided by the research team. The universal drill saddle developed was adjustable so that it could hold any drill or roto-hammer in case the provided drills did not meet task specifications (Photo 5, p. 32). The telescoping columns came in two forms—one that can be raised by a gear and track system controlled by a crank handle (as with the inverted drill press) or one whose height could be adjusted by hand and locked with a pin (as with the foot-lever drill press) (Photo 6, p. 33).

The base was a flat metal plate welded to the bottom of the column with two wheels that engaged when the device was tilted for transportation at the construction site (Photo 7, p. 33). Each column had an outlet whose power could be controlled by a switch that was attached to the column near the column handle. The drill trigger was depressed continuously with a hook-and-loop strap. When the drill was plugged into the outlet on the column, the operator could activate the drill by engaging the momentary on/off switch on the column.

Field Testing Generation 1 Devices

The two Generation 1 prototypes were tested by 14 construction workers on various commercial construction projects in Portland, OR. Two participants were women, 3 were apprentices, 2 were preapprentices and 9 were journeymen. Seven of the 14 participants were sheet metal workers, 3 were from the piping trades, 3 were carpenters and 1 was an electrician.

Each test included both the worker's usual method of drilling and drilling with the two intervention devices; the order of testing was randomized. An equivalent number of holes were drilled for each method. The tests were integrated into the usual activities involving drilling into concrete or metal ceilings.

After each method was tested, the participant completed a questionnaire that scored the ease of use, fatigue levels and functionality (e.g., accuracy, stability). Open-ended questions also asked for suggestions for improving the device/method.

After all three methods were tested, a final questionnaire was completed. Participants were asked to rank order each method based on various characteristics such as setup time, moving to next hole, productivity or overall rank. The tests were videotaped, photographed and observed by the team's field technician; this feedback helped the team determine how the devices should be modified.

Based on the comparison ranking for ease of setup and moving, 53% of the subjects preferred their usual method, 27% preferred the inverted drill press and 18% preferred the foot-lever drill press. The subjects found the intervention devices top-heavy, awkward and cumbersome to move. The bases of these devices were flat metal plates that required the device to be rocked or kicked into position (Photo 7, p. 33).

Analysis of the videos revealed that although it

Photo 1 (top): A contorted neck posture is common during the usual method for overhead drilling. This construction worker is wearing eye and hearing protection but not respiratory protection for possible dust/silica exposure.

Photo 2 (bottom): An example of an extended reach while drilling overhead into concrete with the usual method.

Abstract: *Drilling overhead into concrete is a strenuous task that is associated with shoulder, arm, neck and back musculoskeletal disorders because of the forceful and awkward aspects of the task. This task is performed to hang pipes, ducts and trays, and is performed by construction workers in the electrical, pipe fitting, sheet metal, ironwork and carpentry trades. In this project, alternative devices for overhead drilling were developed in order to reduce the high shoulder loads. These devices were evaluated for usability, productivity and fatigue in two rounds of testing. After each round of testing the designs were modified based on feedback. The feedback, design suggestions and field testing by experienced construction workers were vital to the successful development of these devices.*

Photo 3 (left): Foot-lever drill press.

Photo 4 (right): Inverted drill press.

Photo 5 (bottom): Three drills and four drill saddles. The saddles attach to the top of the drilling columns.

took longer to move the intervention devices into position and to align the drill bit with the hole-mark, actual drilling time was shorter with the devices than with the usual method. The devices allowed the operator to apply more force to the drill without fatigue.

Results from the comparison survey were mixed. The usual method ranked first for setup time, but the inverted drill press ranked first for work speed (drilling). Participants found the intervention devices easier on the body. However, because of slow setup time and difficulty moving from hole to hole, the usual method received the top rating overall. Several suggestions were made to speed setup time and the time required to move between holes.

Generation 2 Design

The design was modified based on suggestions from the participants and the review of the videos. First, the inverted drill press design was selected over the foot-lever design. Second, wheels were added to the base to make it easier to move around the construction site and move between holes. Third, an adjustable positive stop was added to the drill saddle because it was difficult to see the depth of the drill bit during drilling (Photo 8, p. 34). Fourth, a method was added for leveling the column so that the device could be lined up on a mark on the floor rather than on the ceiling. Finally, the device was made modular, with removable components (e.g., drill saddle, telescoping column, base), to make it easier to transport and assemble on site.

The inverted drill press design was selected because the foot-lever drill press design was cumbersome. For example, the height of the column on the foot-lever drill press had to be set manually; this required the device to be tipped to the ground for adjustment, an awkward and strenuous movement that often caused the drill to hit overhead obstacles when it was righted. Another problem involved the force required to depress the foot lever and the resting height of the foot lever. Two subjects reported pain in their lower backs upon depressing the foot lever. Finally, some operators found it awkward and unstable to depress the foot lever in a controlled manner for a prolonged period of time.

The column-leveling innovation can eliminate the need to climb a ladder to mark the drill hole on the ceiling, thereby improving productivity and decreasing risk of falls. Two subjects demonstrated this improved efficiency during the Generation 1 field tests by aligning the center point of the device base with their marks on the floor, leveling the column using a torpedo level and drilling holes in the ceiling without having to climb a ladder to mark the ceiling. This field innovation was incorporated into the second-generation design; a plumb chain was added to the center of the base for aligning the device to a floor mark and small bubble levels were attached to the column.

Another major design innovation involved developing three interchangeable bases for supporting the column. Each base had four double-locking casters so that the devices could be easily transported from one hole to the next (Photo 9, p. 34). Enabling the devices to roll also eliminated the awkwardness of moving the device and reduced the top-heavy factor since the Generation 2 devices were not being tipped as much as the first-generation devices.

Each of the three interchangeable bases used a different method for leveling the column. The spring base was brought into plumb by pressing down on the base; each wheel was secured to the base with a spring. The adjustable caster base was leveled by adjusting the height of each of the four castors with a knob and bolt. For the collar base, the column could be tilted and locked into place with a collar about 2 ft above the ground (Photo 10, p. 34).

Photo 6 (top): Gravity pin for telescoping column of foot-lever drill press is visible at the top of the lower red column.

Photo 7 (bottom): T-shaped base of foot-lever drill press.

The feedback, design suggestions and field testing by experienced construction workers were vital to the successful development of these devices.

Field Testing of Generation 2

Testing of the Generation 2 devices involved field testing with 16 subjects using the same methods as used for the first-generation devices. The feedback on the Generation 2 devices was much better. All subjects rated them as more comfortable. For overall rating, almost all of the subjects (93%) preferred one of the intervention devices over his/her usual method. Setup time was still longer with the intervention device, but drilling time was much shorter. In several tests with the Generation 2 devices, productivity was increased four-fold as compared to the usual method.

The type of work and setting of the work affected the ease of use and the setup time for the intervention devices. For example, drilling that occurred in "tenant improvement" projects (remodel projects with construction occurring in existing buildings where overhead obstacles such as conduit, plumbing and duct work were pervasive) had mixed results. In some cases, operators were able to direct the drill with the intervention device between narrow openings in the overhead obstacles to access the ceiling, which they would have been unable to do when drilling by hand because they could not squeeze their bodies through and around the overhead utilities (Photos 11 and 12, p. 35).

However, in those cases, maneuvering the scissor lift with the device in the basket often was difficult and time consuming because the operator had to maneuver the lift around obstacles on the ground while being limited by the clearance of the device among the overhead obstacles. Unlike the human body, the devices could not be leaned beyond the rails of the lift; therefore, an operator using a lift had to position the lift directly below the area where the hole needed to be drilled.

In another example that occurred on a hospital project, using the device in a scissor lift was impractical because the locations where the drilling occurred required access to small hospital rooms with low clearances through doors; the operators had to dismantle and reassemble the device in the lift after every two to four holes (Photo 13, p. 35). The devices could reach the ceiling height of 15.5 ft from the ground only with the use of a fixed 4 ft extension for the column (normal working height of the devices without the extension was 12 ft). However, since the overhead obstacles ranged in height from 8 ft to 10 ft above the ground, lateral movement of the devices was blocked or hindered by the fixed column extension's inference with the lower hanging obstacles.

The variation in field setting application yielded surprising results in other ways. The more difficult (strenuous, prolonged and awkward) the drilling was by hand, the better the devices were received. Sometimes, the factors that made drilling difficult were counterintuitive. For example, one might think that drilling a large diameter hole would be more difficult than drilling a small diameter one.

However, field testing showed that ceiling material and access to the ceiling were more critical factors than hole diameter. In one such case, drilling a small diameter hole (11/64 in.) into a specialized aluminum ceiling with restricted access required several minutes (between 2 and 5 minutes) of awkward drilling by hand whereas drilling time with the devices ranged from 40 to 90 seconds with little perceived levels of fatigue.

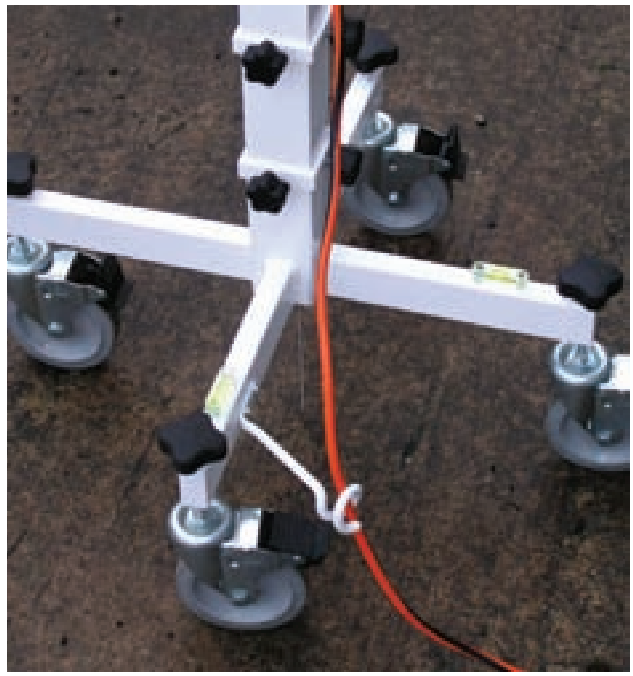

Photo 8 (above, left): A makeshift positive stop was added to prevent the drill bit from going too deep. The newer saddles have a built-in adjustable stop.

Photo 9 (above, right): Generation 2 device with four adjustable-height and locking castors. The base is leveled by adjusting the height of each castor. Note the levels on the base.

Photo 10 (right): The collar base version of the Generation 2 inverted drill press.

Generation 3 Design

Based on feedback from field testing of the Generation 2 devices, a final, third-generation device is being designed. This device will incorporate a version of the collar base because this base required the least amount of bending to adjust the plumb of the column. The column of this device is leveled by tilting and locking the column within the collar of the base at chest level.

Having four wheels on a base caused it to rock when the floor surface was uneven. The Generation 3 device will have only three wheels, but with a larger overall stance than the Generation 2 version so that the tipping risk is not increased.

In response to the challenges of clearing piping and ducts overhead, participants recommended modifications be made to increase the working height of the device while decreasing the resting height. A low resting height would give the operator more opportunity to get the devices below overhead obstacles from both the ground and a lift, while a higher working height would allow the operators to use the device from the ground (which is often faster than using the device in a lift). The Generation 3 design may include a triple-nested column rather than the double-nested version of Generation 2. Triple nesting the columns should give the device a resting height at or near 6 ft and a working height up to 15.5 ft. Another modification is to add a hinge to the saddle so that the drill could be tilted down, thereby lowering the resting height of the column and making it easier to change bits.

Not all of the challenges identified by participants will be addressed by the Generation 3 design. It was observed in the field that more neck extension occurs with use of the device. Another issue not addressed was the difficulty of spotting the prospective hole when the device is used from the ground. Dust and debris falling from the ceiling onto the operator was another limitation identified by participants. This was alleviated to some degree through the addition of a dust control system on one of the drills. This system worked well, but it filled quickly and required frequent emptying and is only available on one drill model from only one manufacturer.

The Generation 3 device is currently being designed and fabricated and will be tested over the next year in field studies. The testing methods will be similar to those used in the earlier field tests, and will also include measurement of shoulder and head postures using inclinometers.

Photo 11 (left): An inverted drill press column with a 4 ft extension threaded between conduits. The device is being operated from the ground.

Photo 12 (right): The worker is unable to maneuver the lift any higher because of overhead obstacles so he must reach beyond the rails of the lift in an awkward posture in order to drill by hand.

Lessons Learned

The feedback, design suggestions and field testing by experienced construction workers were vital to the successful development of these devices. It is difficult to anticipate how intervention devices will perform and be received without testing in varied field settings. Experienced workers play a key role in the process because they are the most affected by the intervention, they are experts in the work and they can identify both the nuanced and the obvious advantages and disadvantages of its application (Schneider, 2006).

Despite the identified limitations of the Generation 1 devices, incorporating suggested modifications led to Generation 2 devices which received overall ratings that were better than the usual method. Based on these preliminary results, the development of an intervention device for overhead drilling has potential. It must first undergo several rounds of field testing and modifications before it can be successfully implemented in the construction community. Field testing should be performed with real tasks, in diverse field settings, with subjects familiar with the task. As the development of these devices has shown, it is important that designers include an adequate number of rounds of testing and modification before settling on a final design. ■

Photo 13 (above): The inverted drill press operated from a scissors lift. The clearance of the lift below the door header would require that the device be dismantled and removed in order to move the lift between rooms. Since the subjects had only two to four holes to drill per room, using the device for this application was inefficient and time consuming.

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