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ERGONOMIC SAFETY ANALYSIS OF TILTING A CONCRETE GRINDING MACHINE

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Abstract: Powered concrete grinding machines provide efficiency advantages compared with polishing or grinding concrete manually. These concrete grinders are by necessity heavy and therefore create ergonomic challenges for designers during certain circumstances where human interaction is near the limits of the user's capabilities. A case study is presented to illustrate a design of such a machine that did not adequately incorporate ergonomic machine design principles, resulting in the user being injured. Some commercially available alternative machine designs are presented that would reduce the risk of injury to the operator.

Keywords: Heavy Machine Tilting, Excessive Pull Force, User-Machine Interaction

1. Literature Review

For large manually controlled portable concrete grinding machines, it is important to be cognizant of the ergonomic factors that accompany the greater mass and larger physical dimensions of the machine. Designers should attempt where practicable to design machines and tools that are within the capabilities and limitations of the people who would use them (Marshall, 1994).

A commonly utilized consensus safety practice to mitigate risk is to apply the concept of a "safety hierarchy" (hierarchy of controls). One such safety hierarchy that describes a preferred method of mitigating risk in order of priority is as follows: (1) "Eliminate hazard and/or risk", (2) "Apply safeguarding technology", (3) "Use warning signs", (4) "Train and instruct", (5) "Prescribe personal protection" (Barnett and Brickman, 1986). The relationship between the worker, the equipment and materials, and the environment can be considered to determine the risks that need to be mitigated (National Safety Council, 1992). International safety standards, such as CSA Z432-2004 *Safeguarding Machinery* (Canadian Standards Association. (2004), provide guidance on the human factors and ergonomics hazards for machine designers. CSA Z432-2004 describes various hazards, including "hazards generated by neglecting ergonomic principles," and gives general risk mitigation principles (CSA Z432, 2004).

When designing machines where manual tasks are involved, it is recommended that the user exert the force with a stable and balanced posture with the handle position not too high or too low (CSA Z432, 2004). In general, the design of machines should work with the body's systems and should not cause undue stress on the body. If these are not fulfilled, then "undesirable results – accidents, are likely to occur" (Marshall, 1994). The shape and size of the machines and tools affect the hazard (National Safety Council, 1992). Safety standards and ergonomics literature were reviewed for acceptable human pull forces and posture combinations. Recommended upper force limits are 315 N (70.8 lb.) for vertical pull-down force from the shoulder level (Ferreira et al., 2004) and 230 N (51.7 lb.) for horizontal pull force at approximately shoulder height per ISO 11228-2:2007 (International Standards Organization, 2007).

2. Accident Description

A machine operator was using a concrete grinding machine when he had to tilt the machine in the manner like Figure 1 and replace the worn grinding discs on the bottom of the unit. The machine had a moveable handle that locked into an upright position, which facilitated tilting the machine over. When the user was tilting over the concrete grinder, the machine's handle

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Figure 1. Concrete grinding machine tilting process.

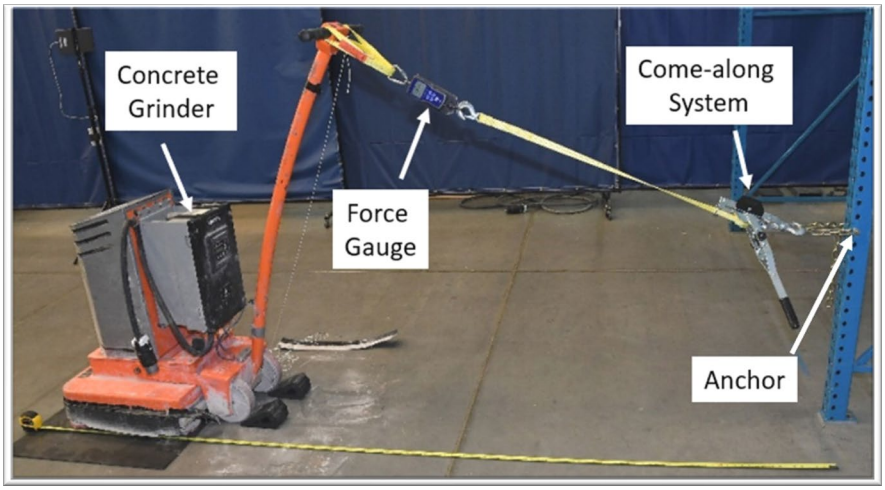

Figure 2. Mechanical test setup.

unexpectedly released, resulting in the operator falling down and backwards and sustaining an injury. The operator placed his right foot on the back of the machine near the base of the moveable handle to keep it in place while simultaneously pulling back and down on the machine handle, as represented in Figure 1. The concrete grinder weighed 2,940 N (660 lb.), had a handle length of 155 cm (61.0 inches), and the handle grip was 151 cm (59.3 inches) vertically from the floor. The machine manufacturer's instruction manual specified that the concrete grinder was a one-person machine but did not prescribe specific methods or instructions on how to tilt the machine over for performing maintenance.

3. Mechanical Testing and Analysis

Mechanical pull tests were conducted on the concrete grinder at the handle to determine the force to start to tilt the machine and the maximum force required during the process of tilting the machine. Multiple pull force measurements at the handle grip were measured with a force gauge (e.g., Shimpo FGE-200HX) anchored to a large metal structure, as displayed in Figure 2. A condition was observed in which the handle release pedal was lower on one side and the handle unexpectedly released during two of the mechanical pull tests.

The force to start to tip the machine and the maximum pull force during the tipping process were determined via testing and ranged from 703 N (158 lb.) to 783 N (176 lb.). These forces applied at the handle grip are unreasonably high for a typical person. When the unexpected handle release was observed during testing (Figure 3), the pull force at the handle grip was 641 N (144 lb.). The industry safety standards and literature researched recommend or require pull forces between 230 N

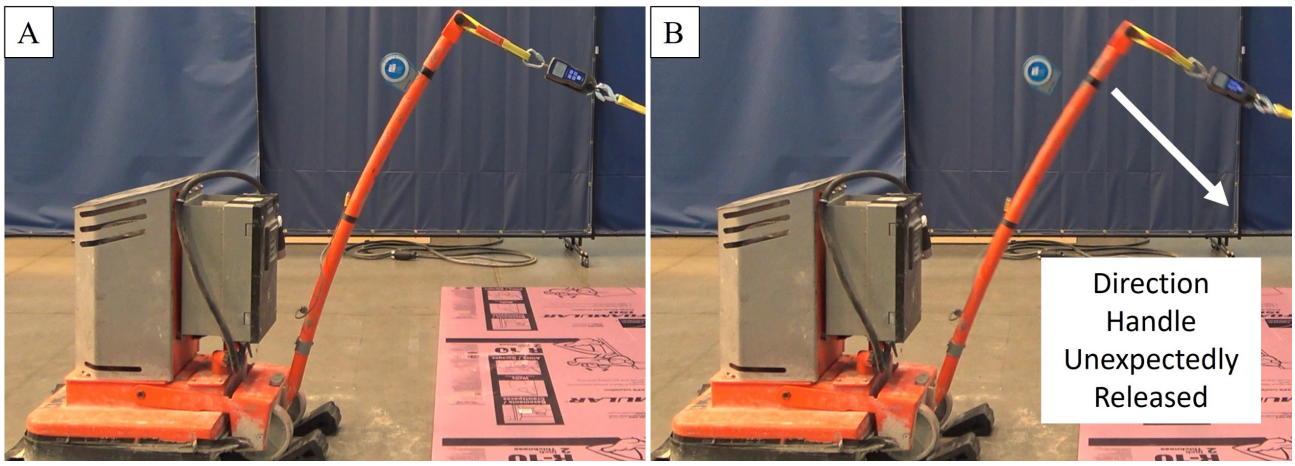

Figure 3. Handle unexpectedly releasing before (A) and after (B) testing.

Figure 4. Location of concrete grinder's handle release mechanism.

(51.7 lb.) (ISO 11228-2: 2007) and 315 N (70.8 lb.) (Ferreira et al., 2004). These pull forces are much lower than the pull forces required to tilt the concrete grinder in the two handle release button conditions analyzed in this case study.

4. Biomechanical Analysis

A biomechanical analysis of the concrete grinding machine tilting process was conducted to study the interaction between the human user, the equipment, and the environment (National Safety Council, 1992). The biomechanical analysis utilized the scientific method as the framework for drawing conclusions related to user interaction and injury potential (Knox et al., 2015). Biomechanical analysis of multiple users showed how an operator would commonly tilt the machine back (see Figure 1).

When the user attempted to tilt the concrete grinder backwards, he employed a body posture that was awkward and hazardous. The user applied a dynamic pulling force on the handle in a backward and downward direction and simultaneously restrained the machine with his right foot to prevent it from moving backwards due to the backwards pulling force. At 2,940 N

Figure 5. Alternative machine designs employing step to tilt (A & B), and removable counterweights (C).

Figure 6. Alternative machine design employing an electro-mechanical mechanism.

(660 lb.), the machine weight was significantly heavier than a typical user. Because of the weight of the machine, the user dynamically loaded the handle with his body mass moving in a downward and backward direction, which caused him to become effectively hanging off the handle. The long handle (moment arm) required the user to stretch to reach the rear of the machine to place his foot to prevent the machine from moving backwards. This awkward and compromised posture resulted from the need to impart a large dynamic tipping moment to tilt the unit over. The resulting awkward posture was hazardous because: 1) the user was exerting an excessive amount of force to move the machine, which could result in overload injuries (e.g. strains/sprains), and 2) the unexpected sudden release of the handle while in the compromised awkward posture (see Figure 1B) results in a backward and downward fall that can result in dynamic impact loads to the opposite lower limb, spine, and/or head.

A handle release button was located at the base of the machine (Figure 4) to release the handle so the grip can be adjusted to a comfortable position for the operator when grinding concrete. The handle release button was positioned close to the area where the user put his foot. Locating the handle release button near where operators could place their foot to restrain the machine is additionally not safe as they could inadvertently contact the handle release button and the handle could unexpectedly release as the user is leaning back.

5. Alternative Designs

Alternative commercially available concrete grinder designs include a step to tilt to tilt the machine backwards. The step to tilt alternative designs provide a suitable location for the user to stand on the machine to tilt it backwards, as seen in Figure 5A and Figure 5B. In addition, some alternative concrete grinder designs utilize removable counterweights that are placed near the handle, such as depicted in Figure 5C, to assist tilting the machine backwards. Furthermore, another alternative commercially available concrete grinder design incorporates an electro-mechanical mechanism. This automated mechanism employs a motor and two arms that lift the front of the machine to allow the user access to the bottom of the machine to replace the grinding discs, as shown in Figure 6. In general, these alternative concrete grinder designs reduce the pull force required by the operator to tilt the machine back, do not result in the operator being in an awkward position, and provide a dedicated place for the operator to safely put their foot without contacting the handle release mechanism.

6. Conclusions

When designing large manually controlled portable concrete grinding machines, it is important for the designer to understand how the human user, the machine, and the environment interface with each other and determine whether risks are at an acceptable level. Safety hierarchy (hierarchy of controls) priorities can be implemented to address these concrete grinder design ergonomic hazards. This case study demonstrates that some manufacturers do not employ effective human factors safety principles in their design. Appropriate user postures and human force inputs regarding machine-user interaction are relevant safety considerations in concrete grinding machine design.

In this case study, the design of the concrete grinder did not adequately facilitate the routine task of the operator tilting over the heavy concrete grinder to replace the grinding discs. The manufacturer's design resulted in a heavy machine that required a long handle to create the necessary tilting moment, which resulted in the operator employing a dynamic loading posture that was awkward and hazardous. In addition, the foot activated handle release button was located near where the operator would place their foot to brace the machine when tilting it, creating a potential for the user to inadvertently release the handle while tilting back the machine. The force required to tilt back the concrete grinder in this study exceeded the maximum recommended ergonomic threshold values for safe human pulling forces. There are commercially available alternative concrete grinder designs that include a dedicated location where the operator could use their body weight to tilt the machine, a dedicated location to place separate counterweights to assist in tilting back the concrete grinder or employ motor-powered tilt arms to tilt the concrete grinder back without the need for any use of force by the operator.

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