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Stump Grinder Accident Reconstruction and Design Testing Methodologies

Dennis B. Brickman[1], Anne C. Mathias[1], and Julius M. Roberts[2]

[1]Engineering Systems Inc., 4215 Campus Drive, Aurora, Illinois 60504

[2]Engineering Systems Inc., 1174 Oak Valley Drive, Ann Arbor, Michigan 48108

Corresponding author's Email: dbbrickman@engsys.com

Abstract: This paper presents human factors accident reconstruction analysis and design testing methodologies to address injury modes associated with worker involvement with a tree stump grinder rotating cutter wheel. A broad-based approach was utilized to evaluate present and proposed machine design features, including human factors audible and tactile feedback measurements, in situ cutter wheel control lever testing, real-world cutting testing in non-intended control lever positions, failure mode testing of a proposed safety device, and accident reconstruction methodologies incorporating all these sources of data. Accident statistics analysis indicates that stump grinder rotating cutter wheel contact injuries generally are not prevented by operator presence control designs when two workers are present. Following the operational safety requirements contained in the manufacturer's warnings and instructions, arboricultural safety standards, and the Tree Care Industry Association best practices will contribute to reducing tree stump grinder worker accidents.

Keywords: Stump Grinder, Accident Reconstruction, Design Testing Methodologies

1. Stump Grinder Safety Literature Review

1.1 Stump Grinder Accident Statistics

Large stump grinders are heavy-duty cutting machines used in varying outdoor conditions to grind tree stumps and require hydraulic controls for cutter wheel operation. They are utilized by dedicated professionals as well as rented by homeowners for residential use. The Tree Care Industry Association (TCIA) reported a 2014 incident where a Michigan homeowner sustained a leg injury while operating a rented stump grinder at his home (TCIA, 2015). The injured man was working with his neighbor when he walked backwards towards the operating stump grinder; his pants leg then became caught by the powered rotating cutter wheel. Figure 1A shows a reenactment of this Michigan stump grinder accident.

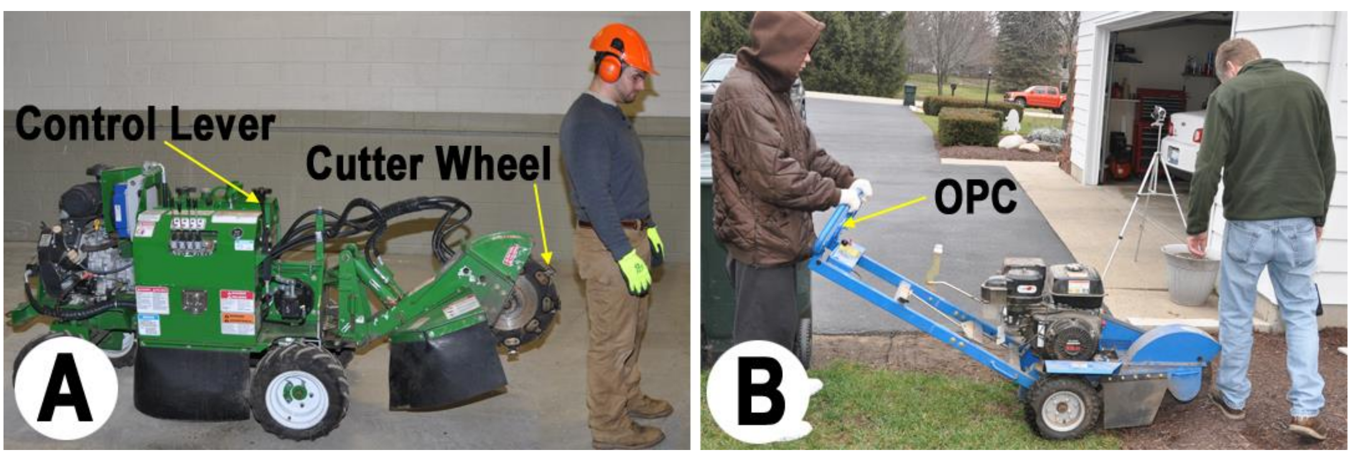

Figure 1. Stump Grinder Accident Reenactments (Large Machine in A and Small Walk-Behind OPC Machine in B)

In order to investigate potential patterns in stump grinder incident scenarios, the authors conducted further research in the OSHA database (OSHA Accident Report Detail, 2016), legal documents, and accident investigations performed by the authors. Additionally, in 2007, the American Rental Association (ARA) reported that six people have been injured while using rented stump cutters since 2000 (Powers, 2009). Selected stump grinder injury scenarios are presented as follows:

1. Worker slipped in mulch and his right leg came in contact with cutting wheel while another worker operated the machine. (2001)
2. Worker was injured when the rented stump grinder's blade came in contact with his leg while a day-laborer operated the machine. (2008)
3. Blade caught worker's shirt sleeve, pulling his left forearm into rotating cutter while coworker was operating the machine. (1998)
4. Eighteen year old died when he became entangled in the machine operated by his uncle. (2016)
5. Stump grinder operator struck worker from behind, which pulled decedent into the machine. (NJ)
6. Homeowner injured left leg after contacting cutter wheel of small walk-behind stump grinder (equipped with OPC) operated by landscaper. Accident reenactment is shown in Figure 1B. (2011)
7. Male operator moved stump grinder and cutter wheel injured his wife's leg. (2015)
8. Laborer's leg contacted cutter wheel after deadman control cable linkage broke. (1996)
9. Worker's left hand and forearm contacted rotating blades after worker released OPC handle which did not stall the engine as designed. (1991)
10. Worker intentionally activated OPC handle with branches and coworker's shirt contacted cutter wheel. (2014)

Like the 2014 accident reported by the TCIA, the majority of the stump grinder worker injuries cited above involved two workers. Typically the operator is operating the stump grinder from the control station while another worker makes body contact with the moving cutter wheel. Also, cutter wheel contact injuries were reported even involving stump cutters equipped with an operator presence control (OPC) where the OPC failed to operate as designed, the OPC was being held by the operator, or the OPC was intentionally bypassed by the operator.

1.2 Best Practices for Stump Grinder Operations

Safety information is provided for stump grinder operators in multiple forms and by multiple information sources. Stump grinder manufacturers typically provide safety information through on-product warnings, an operator's manual, and a safety video. Selected best practices for stump grinder operations presented by the TCIA include: read the operator's manual before use; use the machine only as intended by the manufacturer; engage the clutch to ensure proper operation during pre-operation start up; never leave the controls while the machine is in operations; and stay away from the moving cutter wheel. The ARA also provides safety and operational tips for rented stump grinders (ARA, 2016). The ARA gives the following recommendations to stump grinder renters: read all manufacturer warnings and instructions prior to using your rented stump grinder; wear appropriate personal protective equipment (PPE); never wear loose clothing or jewelry that can catch on the rented stump grinder during use; and ensure hands and feet stay clear of the rented stump grinder's cutting parts.

1.3 Stump Grinder Safety Standard Requirements

The American National Standard for Arboricultural Operations contains safety requirements for stump grinder operations (ANSI Z133.1, 2012). OSHA can cite the employer under the General Duty Clause for an unsafe act or condition by making specific reference to the ANSI Z133.1 safety requirements (Gerstenberger, 1990). ANSI Z133.1-2012 contains the following stump grinder safety requirements: arborists and other workers shall follow instructions provided by manufacturers; when units are left unattended, keys shall be removed from the ignition, the wheels chocked, and, if applicable, the parking brake applied; and when a worker is doing mechanical work, precautions must be taken to prevent injury caused by moving or elevated parts, or the release of stored energy. MIOSHA safety standard requirements for powered groundskeeping equipment include: before leaving the operator's position, shift the transmission to neutral, set parking brake and disengage attachment clutch (MIOSHA, 2015).

2. Stump Grinder Accident Reconstruction and Design Testing

2.1 Stump Grinder Human Factors Testing

Utilizing the classic systems approach that recognizes the interaction between the human user, the equipment, and the environment (National Safety Council, 1992), human factors testing was conducted on the stump grinder associated with the TCIA reported 2014 leg injury incident. When the stump grinder cutter wheel is rotating under power ("engaged"), the operating status of the cutter wheel can be determined by visual, audible, and tactile feedback. By presenting these cues to multiple senses, the likelihood that this information will be received is increased (McCormick, 1976). This evaluation noted that when the cutter wheel is at rest, the individual cutting teeth are visible, but when the cutter wheel is rotating under

Figure 2. Pants Test Fixture (Cutter Wheel Disengaged in A and Engaged in B)

Figure 3. Cutter Wheel Control Lever Testing (Cutter Wheel Disengaged in A and Engaged in B)

power, the individual cutting teeth cannot be seen (See Figure 2). This is similar to the behavior of a powered rotating table saw. Additionally, sound level measurements were taken at the operator control position of the stump grinder, and a noted change in pitch during cutter wheel disengagement provided an audible indicator of the change in operating status of the cutter wheel. Air flow testing measured 1,057 feet per minute (cutter wheel engaged) and 0 feet per minute (cutter wheel disengaged) at approximately five feet from the cutter wheel. A test fixture that simulated pants being worn by a surrogate was positioned approximately five feet from the cutter wheel. With the cutter wheel engaged, the air flow caused the loose pants material to flutter (see Figure 2B). Therefore, the injured worker would have had advanced warning that the cutter wheel was engaged through the tactile feedback in his pants even with his back facing the cutter wheel.

2.2 Stump Grinder Cutter Wheel Control Lever Testing

Previous studies investigated commercial walk-behind lawn mower control lever failure modes under various conditions (Brickman, 1999). Similarly, cutter wheel control lever testing was performed to analyze the design and operating characteristics of the stump grinder associated with the above 2014 incident. Dozens of cutter wheel control lever tests were performed involving a variety of engine throttle settings by moving the lever from the engaged to the disengaged position. Both lever positions possess a detent which captures the cutter wheel control lever. Changing the cutter wheel engagement condition requires two deliberate control inputs: the top button of the lever must be depressed in order to move the lever out of the cutter wheel engaged and disengaged detent positions. During all test trials, the cutter wheel stopped rotation in a few seconds after the control lever was placed in the disengaged detent position (see Figure 3A). Under all test conditions, the stopped cutter wheel did not reengage spontaneously after the control lever was placed in the detent disengaged position. Even if the control lever was pulled without depressing the top button or even if the button was pressed without pulling the lever, the cutter wheel remained stopped as expected.

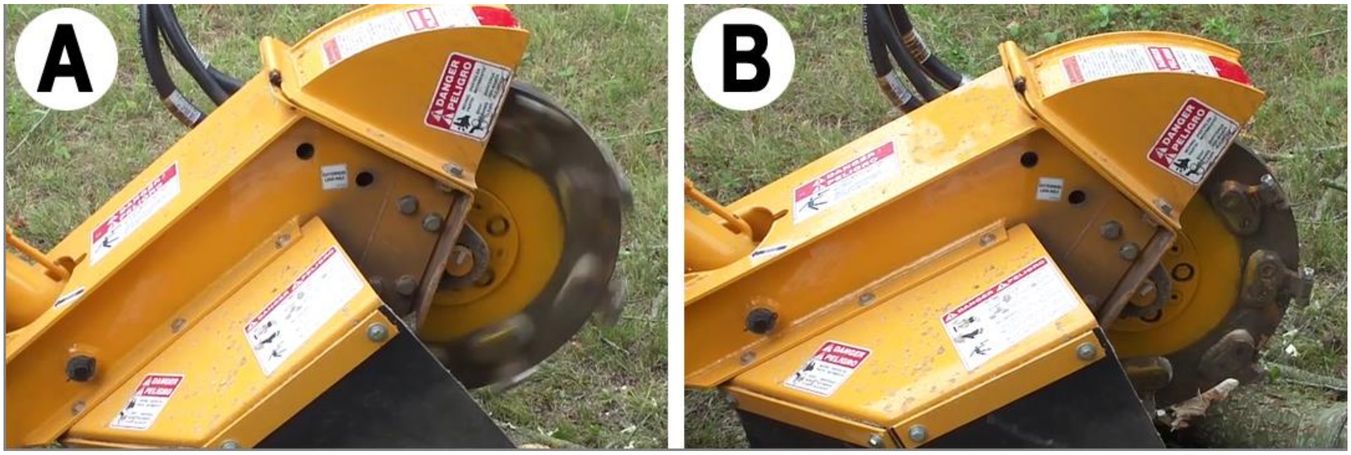

Figure 4. Cutter Wheel Tree Branch Contact Testing (Cutter Wheel Rotating in A and Stopped in B)

2.3 Stump Grinder Cutter Wheel Tree Branch Contact Testing

The previous testing showed that the cutter wheel stopped rotating only after the control lever was placed in the disengaged detent; it remained rotating while the lever was in between the "engaged" and "disengaged" detents. In order to study the real-world design performance of the stump grinder with the control lever in varying middle positions, various tests were conducted by lowering the rotating cutter wheel onto a six-inch diameter tree branch. A variety of engine speeds and cutter wheel control lever positions were attempted. The cutter wheel control lever was progressively positioned at the $^7/_8$, $^3/_4$, $^1/_2$, and $^1/_4$ disengagement settings. Under all test conditions, the rotating cutter wheel immediately stopped after making contact with the tree branch (see Figure 4B).

2.4 Stump Grinder Cutter Accident Reconstruction Analysis

The witness descriptions of the 2014 Michigan incident were considered. The injured worker reportedly stopped the cutter wheel by moving the control lever as far as it would go into the disengaged position. That worker confirmed by sight that the cutter wheel control lever was fully disengaged and the cutter wheel was stopped. Then he left the stump grinder for approximately 15-25 seconds to rake some wood chips. He walked backwards toward the stump grinder and the powered rotating cutter wheel contacted his leg. After the accident occurred, the cutter wheel control lever was not found to be in the disengaged position. The injured worker's neighbor had to utilize the two-step process of depressing the cutter wheel control lever top button and simultaneously moving the lever to the disengaged position.

The scientific method process was utilized as a framework for testing compatibility or consistency of different aspects of data or information that had been gathered about the accident (Knox, 2015). The accident reconstruction utilized the available data (consistent with the laws of physics and the physical interaction between the man, machine, and environment) to bound the potential scenarios, provide limits to rule out alternatives, and ultimately draw conclusions regarding what actually occurred. According to statements made by the 2014 injured worker after the accident, the cutter wheel was stopped and the associated control lever was in the disengaged position within half a minute before the accident occurred. Extensive testing performed on the same stump cutter after the accident demonstrated that the stopped cutter wheel did not reengage spontaneously after its control lever was placed in the disengaged detent position. Further testing reveals that the cutter wheel control lever did not migrate from the disengaged detent position due to engine vibration or physical contact. It is unlikely to be mistaken as disengaged after only partially moving the control lever because the cutter wheel rotation could be detected by audible, visual, and tactile feedback cues. In this mid-position control lever condition, any cutter wheel contact with an object such as a tree branch would stop cutter wheel rotation.

Applying the aforementioned accident reconstruction methodology, it can be ruled out that the disengaged stump grinder spontaneously restarted without human input. Therefore, because the cutter wheel was rotating at the time of the incident, and given the worker's reports that he had disengaged it, the cutter wheel control lever had to have been moved to the engaged detent position before he walked backwards into it. The root cause of the accident thus involves a second person (such as the neighbor) moving the cutter wheel control lever from the disengaged position to the engaged position shortly before the injury sequence. This finding is consistent with the witness accounts, physical evidence, and stump grinder test results. It is further consistent with known stump grinder accident scenario patterns.

Figure 5. Capacitivity-Sensing OPC Testing (Wet Glove Detection Error in A and Water Detection Error in B)

3. Stump Grinder Operator Presence Control (OPC) Analysis

3.1 Stump Grinder OPC Literature Review

One potential safety feature considered for this large stump grinder application is an operator presence control (OPC) system, also known as a "deadman control." Previous research has studied the safety implications associated with incorporating deadman controls on consumer lawn mowers and snowblowers (Barnett, 1989). Small walk-behind stump cutters equipped with handlebars have unique safety and operation characteristics and typically utilize traditional OPCs (interlocks) to automatically disengage power to the cutter wheel when the operator releases the separate handle. On these small walk-behind machines, the cutter wheel typically contacts the ground when the operator releases the handle, potentially creating a hazard of a runaway machine. However, on the larger machines the cutter wheel does not fall and contact the ground upon operator release of the control handle. Larger stump cutters instead require hydraulic controls for the cutter wheel travel. These larger stump cutters have historically not been equipped with OPC systems due, in part, to human factors concerns, such as hand/arm fatigue. Traditional operator presence strategies are not practical on these larger machines (Powers, 2009). Currently ANSI Z133.1 does not require stump grinders to be equipped with OPCs (ANSI Z133.1, 2012). TCIA recognizes the failure potential for the stump grinder OPC, and their best practices include checking and then not operating the stump grinder if the OPC fails to stop the engine upon release (TCIA, 2015).

A patent for a large stump grinder capacitivity-sensing OPC states that one drawback of the system is that water (such as from rain or snow) touching the handle may provide a change in the capacitance ("false positive"), even if the operator's hand is not on the handle. Because stump cutters are used in outdoor environments, the handles are exposed to the elements and so detection errors may occur. Water flowing on the handle creates a conductive path to ground, imitating hand capacitance (Khapochkin, 2011). To address these OPC detection errors, this stump grinder manufacturer provides instructions to check the OPC system to ensure the cutter wheel stops within five seconds after the operator's hand is no longer touching the OPC levers and to contact the dealer if this system does not work as intended. In addition, the stump grinder manufacturer provides instructions to ensure no vegetation, tree limbs or other objects are in contact with the OPC levers as they might inadvertently simulate operator presence. Operators of this large stump grinder capacitivity-sensing OPC have reported functional problems with the system and have described their own methods to bypass the OPC (ArborSite, 2016 and TreeBuzz, 2016). Such bypassing would violate OSHA requirements to not defeat electrical safety interlocks during normal operation (OSHA 1910.333, 2017).

3.2 Stump Grinder OPC Testing

A testing program was performed using a stump grinder equipped with capacitivity-sensing OPCs to analyze potential failure modes and effects. Functional problems were experienced during the testing, including the cutter wheel not operating when one of the OPC levers was held with a bare hand and a gloved hand ("false negative"). Also, another OPC lever exhibited intermittent functionality with the OPC lever being less sensitive at the bottom of the lever than the top. Consistent with the Khapochkin 2011 patent, testing of the stump grinder capacitivity-sensing OPC indicated that cutter wheel powered operation occurred when the OPC lever was wet even without an operator's hand contacting the OPC lever as depicted in Figure 5B ("false positive"). In addition, a wet glove placed on the OPC lever without the presence of an operator's hand enabled the cutter wheel to rotate under power as shown in Figure 5A ("false positive"). Finally, a demonstration was made showing how the OPC lever circuit wiring can be bypassed to allow cutter wheel powered rotation without an operator's hand contacting the OPC lever as described in the arboriculture online literature.

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4. Conclusions

Results of this stump grinder accident reconstruction investigation indicate that the only plausible way for the cutter wheel to begin rotating and for the worker's injury to occur is if physical force was applied to the cutter wheel control lever by a second person such as the neighbor, moving the lever to the engaged position seconds before the worker walked backwards into the rotating cutter wheel. Testing of the stump grinder did not result in reengagement of the cutter wheel after it was disengaged and stopped. Research of available stump grinder accident statistics and investigations reveals a common pattern involving the presence of two workers where one worker is operating the stump grinder controls and the other worker's body contacts the powered rotating cutter wheel. Injuries associated with stump grinders equipped with operator presence controls commonly involved bypassing the OPC, failure of the OPC, or a second worker activating the OPC. According to stump grinder safety standards and recommended industry best practices, operators should deenergize the machine, remove the key, and ensure the cutter wheel is at rest before leaving the operator position as primary protection. This is consistent with OSHA control of hazardous energy regulations that require workers to perform lockout/tagout whenever they place any part of their body into a machine danger zone (OSHA 1910.147, 2017). Following the operational safety requirements contained in the manufacturer's warnings and instructions, arboricultural safety standards, and Tree Care Industry Association best practices will contribute to reducing tree stump grinder worker accidents.

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