Exploring the Likelihood of Entanglements and Interactions with a PTO Knuckle

Charles V. Schwab  
*Iowa State University, cvschwab@iastate.edu*

Isaac J. Rempe  
*Iowa State University, ijrempe@iastate.edu*

Follow this and additional works at: [http://lib.dr.iastate.edu/abe_eng_conf](http://lib.dr.iastate.edu/abe_eng_conf)

Part of the [Agriculture Commons](http://lib.dr.iastate.edu/abe_eng_conf) and the [Bioresource and Agricultural Engineering Commons](http://lib.dr.iastate.edu/abe_eng_conf)

The complete bibliographic information for this item can be found at [http://lib.dr.iastate.edu/abe_eng_conf/519](http://lib.dr.iastate.edu/abe_eng_conf/519). For information on how to cite this item, please visit [http://lib.dr.iastate.edu/howtocite.html](http://lib.dr.iastate.edu/howtocite.html).
Exploring the Likelihood of Entanglements and Interactions with a PTO Knuckle

Charles V. Schwab
Isaac J. Rempe
Iowa State University, 3335 Elings Hall, 605 Bissell Rd, Ames IA 50011-3270

Written for presentation at the
2017 ASABE Annual International Meeting
Sponsored by ASABE
Spokane, Washington
July 16-19, 2017

ABSTRACT. Power take-off (PTO) is a common method of transferring power from a tractor to a towed piece of machinery. The PTO is also a well-documented cause of severe and often permanent disabling injuries to farm operators. The physical conditions that cause entanglements are not well established. Several studies have explored the parameters of PTO entanglements as materials have been drawn across a rotating PTO knuckle to test for entanglement probability. The objective of this study was to determine probability of entanglement when materials are dropped vertically onto a PTO knuckle spinning at 540 RPM. A total of 360 randomized trials were conducted with 10 replications for each of the six positions (center of yoke, edge of yoke rotating downward, edge of yoke rotating upward, center of cross, edge of cross rotating downward, and edge of cross rotating upward), and six different types of materials (woven cotton athletic shoe lace, cotton work boot lace, leather boot lace, cotton twine, denim strip, and Tyvek® strip). Not a single entanglement was recorded. Dramatic high speed video imagery authenticates the material’s motion and path as it interacts with the rotating PTO knuckle.

Keywords. Accident prevention, Farm safety, Probability, PTO, Safety.
Introduction

Beer, Deboy, & Field (2007) conducted a review and provided a summary of prior research on PTO and driveline-related injuries. A total of 911 events were reported and 400 fatalities were connected to PTO or drivelines entanglements using published works by Knapp & Piercy (1966), McKnight (1984), Wilkinson (1991), and Beer & Field (2005). These events and fatalities totals illustrate the common occurrence of PTO and driveline entanglements.

Freeman, Schwab, & Judge (2006) investigated the physical parameters of types of materials, lengths of materials, and angles of introduction that affected PTO entanglement probability. They reported that lighter materials were more readily entangled, the introduction angle perpendicular to the shaft was more likely to result in entanglement, and as the length of material extended below the midline of the shaft the likelihood of entanglement increased. Another PTO entanglement study by Xu, Kroeker, & Mann (2009) examined a PTO shaft rotating at high speed and different joint angles. They concluded that the joint angles of the yokes greatly influence probability of entanglement and the slower the speed for material introduction increased the probability of entanglement. Xu et al. (2009) confirmed the findings of Freeman et al. (2006) that as the length of materials increases so does the likelihood of entanglement.

A common feature between the two studies on PTO entanglement is how the material is introduced to the rotating PTO knuckle. The material is dragged across the rotating PTO knuckle at a set speed. This procedure can account for how materials are introduced to a rotating PTO knuckle in everyday events but it does not cover all possible ways. Another unique introduction procedure could be a vertical drop into a rotating PTO knuckle. This study examines the likelihood of entanglement of materials that are dropped into a rotating PTO knuckle.

Methods

Samples

A total of six different materials were selected as samples for this study. These samples are representative of materials that could be associated with activities near a PTO knuckle. Samples are: #1 a common athletic woven cotton shoe lace; #2 a compact woven work-boot lace; #3 a square leather work-boot lace; #4 a braided cotton cord; #5 a strip of denim jean fabric; and #6 a strip of Tyvek®. All experimental samples were 43 cm (17 in.) in length. The physical surface characteristics and relative size of these samples are shown in Figure 1.

Locations

This study selected a total of six positions along the PTO knuckle as the intended initial impact locations. Those six positions and the direction of rotation for the PTO knuckle are shown in Figure 2 and 3. Locations A and B are on the center line of the rotating shaft and do not require the trailing and leading edge descriptors (Figure 2). Locations C, D, E, and F require trailing and leading edge descriptors (Figure 3). The difference between locations C and E is how the edge of yoke arm is coming towards the sample (leading) or going away from the sample (trailing). The leading edge of the yoke arm is rising up to meet the dropping sample whereas the trailing edge of the yoke arm is falling away from the approaching sample. Locations D and F have a similar relationship as C and E with the trailing and leading edges of the yoke arms.
Experimental Design

This study examined six samples being introduced at six locations along the PTO knuckle (6 samples by 6 locations) for a total of 36 experimental conditions. Each condition was replicated 10 times for a total of 360 tests for entanglement. A complete randomization of sample and locations variables was achieved using a spreadsheet and random number generator. The sequence of testing was governed by randomized variable combinations.

Experimental Apparatus

The experimental apparatus used was the same as the apparatus described by (Freeman et al. 2006) with some modifications to the components that suspended and introduced the samples to the rotating PTO knuckle. The motor, electronic control, frame, and PTO knuckle were not altered for this experiment.

The lead screw assembly and indexing plate were removed and replaced with a vertical drop mechanism. The vertical drop mechanism was centered over the top of the PTO shaft and secured. The vertical drop mechanism travels a distance of 56 cm (22 in) and is 25 cm (10 in) above the PTO knuckle. The sample and the vertical drop mechanism travels the 56 cm extension in 0.48 s for an average speed of 117 cm/s. The experimental apparatus used in this study is shown in Figure 4.

Recording Cameras

The cameras used to record the video of each test run were Go-Pro Hero 4’s. One camera was mounted above and in-line with axis of the PTO shaft. The second camera was perpendicular with the axis of the PTO shaft and positioned facing the leading edge side of the apparatus. The Go-Pro Hero 4’s camera features a wide angle lens that allowed for a complete

Figure 2. Top view of the center line intended impact locations on the PTO knuckle and the direction of rotation

Figure 3. Top view of the trailing and leading intended impact locations on the PTO knuckle and the direction of rotation
picture of each test. All videos were captured using the WVGA resolution at 240 frames per second. From this high frame rate, it was possible to analyze the sample’s reaction to the PTO in more depth and clarity than possible by the human eye observation or even standard video camera recording at 15 frames per second.

Experimental Procedure

The vertical drop mechanism was raised to the full drop height and secured in position with a release pin. Using the prescribed sample and impact location from the test randomization, the sample was placed in the appropriate clip on the vertical drop mechanism. Cameras in both positions were activated to record the test. A video marker board was used to tag the test sample, location, replication, and date. The power to the experimental apparatus was activated causing the PTO knuckle to start rotating. A few seconds passed before the PTO knuckle speed was tested with a tachometer. The preset speed of 540 rpm was desired and if the speed was outside the accepted range, the dial on the motor was adjusted accordingly. A second measure of speed was obtained by the tachometer. This process was repeated until the measured preset speed was within 7% of 540 rpm.

The release pin holding the vertical drop mechanism and sample was pulled. The vertical drop mechanism completed its downward path, engaging the sample with the rotating PTO knuckle. The outcome of the sample entangling with the PTO knuckle was recorded and so were any other observations that were made as the sample engaged the rotating PTO knuckle. Power to the experimental apparatus was disconnected. The sample was removed and the vertical drop mechanism was reset for the next test after rotation had ceased.

Results

Impact Locations

The intended impact locations on the PTO knuckle: A. Gap between yoke arms; B. Center of yoke arm; C. Trailing edge of yoke arm at position #1; D. Trailing edge of yoke arm at position #2; E. Leading edge of yoke arm at position #1; and F. Leading edge of yoke arm at position #2 were not always achieved. There was a chance that the dropping sample may hit another part of the PTO knuckle because the impact locations are spinning at 540 rpm. There was no synchronization between the vertical drop speed, time when the release pin was pulled, and PTO knuckle rotational speed.
A video review was used to determine if the impact location was achieved because the real time speed of this event created observational errors. The video review allowed accurate assessment of the intended impact location at the exact moment when the impact occurred. The likelihood of the sample landing on the intended impact location was close to 50%. Figure 5 shows the outcome of all 360 tests contacting the intended impact location.

Acknowledging that the leading edge of yoke arm location E is similar to location F and is just a different point (#1 vs #2) on the leading edge of yoke arm, these results were combined for reporting the impact location observation. The same would be true for the trailing edge of yoke arm location C and D. If all intended impact locations were achieved the expected distribution would be 60 – for gap between yoke arms (location A), 60 – center of yoke arm (location B), 120 – for trailing edge of yoke arm (location C&D), and 120 – leading edge of yoke arm (locations E & F). Any tests where the sample did not initially contact the PTO knuckle on one of the six locations were eliminated from the data set. There were 96 tests where the sample did not contact the PTO knuckle or initially contacted another part of the PTO knuckle not previously described. Due to sample 6’s wide surface area and lightweight nature, it did not fall uniformly and experienced more tests where it never contacted the PTO knuckle than any other sample. The actual distribution of the impact locations is given in Figure 6. Three of the four intended impact locations recorded lower values than expected while one location – Center of yoke arm (location B) exceeded expected values.

![Figure 5. Results of the likelihood of sample landing on the intended impact location for all tests](image)

![Figure 6. Distribution of actual impact location for four unique locations excluding the 96 tests](image)
Initial Bend and Wrap Angles

The vertically positioned sample travels downward until it intersects with the PTO knuckle. After the initial point of contact, the sample is typically deflected or bounced to a side. The sample would form an angle from the initial vertical travel direction and this was identified as the initial bend angle. Figure 7 A shows the deflected shape of a sample and the angle measurement that was superimposed on the video frame on a test. Again a video frame review was used to determine the initial bend angle because the real time speed of this event made it impossible to determine this angle.

The sample continued on its path downward, outward, and typically would wrap around the PTO knuckle or the sample would swing out and then back, causing it to bend around the PTO knuckle. As the sample passed through to the other side of the vertical axis from the side where the initial bend angle was measured, it formed another angle with the vertical axis of initial travel. This angle was identified as the wrap angle. Figure 7 B shows the deflected shape of a sample and how the wrap angle was measured.

The initial bend and wrap angles for each sample were recorded and the average value of these angles are shown in Figure 8. Data from 5 tests were not included because the video record of those test was damaged and not able to be reviewed. Sample 4 was observed to have both the largest average initial bend angle and average wrap angle of all the samples. Sample 6 had the lowest average initial bend angle of all the samples at 9 degrees. Sample 6’s wide surface area and lightweight material was often moved by air currents or air resistance when dropped. That is partly why it had the lowest average initial bend angle. Sample 6 was observed never to wrap around the PTO knuckle so it does not have an average wrap angle.

Entanglement Outcome

No sample in all 360 tests was observed to entangle in the PTO knuckle. There were several tests where entanglement was considered to be almost achieved but the sample came back to a resting position against the PTO knuckle. The resting position for nearly all tests was on the trailing side (downward rotational side) of the PTO knuckle accounting for 91 percent. Three percent of the tests had the sample remain on the leading side (upward rotational side) of the PTO knuckle and the remaining 7 percent were composed of sample 6 missing contact with the PTO knuckle during the test.

Visual Observations of Samples

Every one of the 355 high speed video records was reviewed one or more times. Video recording from 5 tests were not available because the video record was damaged during transfer. The video recording of the two locations (1. in-line with axis of the PTO shaft and 2. perpendicular with the axis of the PTO shaft) were synchronized and viewed as a split screen so the observer was able to simultaneously see both views. This permitted the observer to see how the sample interacted in two planes at the same moment of time. While it is impractical to share all the imagery captured in this paper, the highlights of different tests are shared in Figures 9 to 14.
Summary

The hypothesis that a vertically dropped sample might entangle more frequently than a sample introduced into a revolving PTO knuckle by being laterally pulled over the center line of rotation has been rejected. Not one entanglement was observed in 360 tests where six samples were vertically dropped into a rotating PTO knuckle. Reconciling the numerous reports of PTO injuries caused by entanglements and the inability to measure or observe a staged laboratory entanglement with a PTO knuckle is extremely perplexing.

The findings of this experiment are NOT intended to pronounce PTOs as safe because no entanglements were recorded. The intent of this experiment was to develop a better understanding of the characteristics of the circumstance that create PTO entanglements. The high speed videos of the 360 tests generated additional understanding as each sample hit and interacted with the rotating PTO knuckle. Those high speed videos allowed each test to be examined and re-examined a number of times.

Sample 4, a braided cotton cord, was determined to be the liveliest of all samples having the most interaction and contact with the PTO knuckle. Sample 4 also recorded the highest average initial bend angle and average wrap angle for any sample in this experiment. This sample also experienced the only near entanglements of any sample.

Clearly the entanglement phenomena remains obscured and the ability to characterize the potential for PTO entanglement is beyond the current understanding gained by this experiment and the two earlier experiments. As each new experiment examines potential parameters, a better understanding is being developed. It appears the primary PTO entanglement phenomena still eludes observation in a staged laboratory condition.

References


Figure 9. Selected still frames of entanglement tests that highlight the various behaviors experienced by sample 1.
Figure 10. Selected still frames of entanglement tests that highlight the various behaviors experienced by sample 2.
Figure 11. Selected still frames of entanglement tests that highlight the various behaviors experienced by sample 3.
Figure 12. Selected still frames of entanglement tests that highlight the various behaviors experienced by sample 4.
Figure 13. Selected still frames of entanglement tests that highlight the various behaviors experienced by sample 5.
Figure 14. Selected still frames of entanglement tests that highlight the various behaviors experienced by sample 6.