Proceedings of IMECE2010
2010 ASME International Mechanical Engineering Congress and Exposition
November 12-18, 2010, Vancouver, British Columbia, Canada

IMECE2010-38940

STAND-UP FORKLIFT ACCELERATION

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ABSTRACT

This paper will examine the accelerations present during the operation of stand-up forklifts. Forklifts, or powered industrial trucks, are typically operated from 1 of 2 postures. Forklifts are either operated from a seated posture or a standing posture. Previous research has focused on the threshold of acceleration at which a standing forklift operator will be unable to maintain postural stability, but did not detail peak and average accelerations generated by forklifts during typical turning maneuvers. This paper will detail the accelerations generated by stand-up forklifts during typical operation from a theoretical examination of vehicle dynamics and present experimental data acquired during stand-up forklift testing. This paper will further examine performance required by consensus and industry standards, industry practice and the safety implications of stand-up forklift acceleration.

The record of serious lower leg injury associated with stand-up forklifts, reports of ejection or loss of balance from the operator and data regarding acceleration present in the operator compartment support the use of a door for stand-up forklifts.

Keywords: Lift truck, forklift, injury, accident, acceleration

INTRODUCTION

Sit-down forklifts are operated from a seated posture, and the driver is typically restrained in the seat by a winged seat and seatbelt. In contrast, narrow aisle, end control, stand-up forklifts are operated in a standing posture that is typically enclosed on 3 sides with an opening to the rear of the forklift. The operator may be facing toward or away from the forks or may be facing perpendicular to the forks in a side stance.

Operators of stand-up forklifts have 3 to 5 points of contact between their bodies and the forklift. The feet of the operator are in contact with a floor board, and the hands of the operator are in contact with a steering tiller and multifunction control or joystick. The hips of the operator may or may not be in contact with a wall of the operator compartment depending on the design of the compartment and the operator's posture. Stand-up forklifts are typically equipped with a "dead man" brake pedal on the floorboard. The brake pedal is referred to as a dead man brake pedal because the removal of weight, or release of the pedal, actually applies the brakes of the forklift. During braking maneuvers, the operator is required to remove pressure from the brake pedal, which reduces the number of contact points the operator has with the forklift. During braking, the operator may only have contact with the forklift through one weight bearing foot and both hands on operational controls, which reduces the operator to 3 points of contact.

The most frequent accident mode for stand-up forklifts is a collision with another object, such as a rack system, warehouse column or another forklift. [1], [2] Since stand-up forklifts are primarily operated in a forks-trailing mode where the operator's compartment is at the leading edge of the forklift, the operator is in close proximity to any collision. Operators of stand-up forklifts will often raise their foot off of the dead man pedal in an attempt to decelerate and avoid a collision. When the operator is braking due to an impending collision, the operator is in a posture with only one weight-bearing leg and the forklift will be decelerating at its maximum performance capability. Stand-up forklift accident reports have contained descriptions of the operator being ejected from the forklift or losing their balance immediately prior to a collision with another object. As a result of collision accidents, one manufacturer of stand-up forklifts has reported over 500 incidences of serious lower leg injury over a thirty year period. [3] Other manufacturers of stand-up forklifts have also experienced serious lower leg injuries.

PREVIOUS RESEARCH

Harris and DeRosia [4], [5] have found that the acceleration levels associated with the threshold of loss of balance or loss of postural stability range from 0.06 to 0.12 g's depending on the direction of acceleration applied to the test subject. Harris and DeRosia have concluded that the levels of acceleration causing loss of balance support the use of doors on stand-up forklift and control corridors on pallet jacks (walkie riders).

Mkandawire et al [6] reported deceleration levels of 0.06 to 0.27 g's during testing of a Baker BRT35 stand-up forklift and found that forklift operators can maintain postural stability during routine braking. Mkandawire obtained the deceleration levels during braking and plugging (braking using the electric drive motors) while the forklift was traveling in a straight line.

STAND-UP FORKLIFT BRAKING

Stand-up forklifts are typically equipped with brake systems that are hydraulically or electromechanically released and spring applied. The use of springs to create a braking force generates a relatively constant braking force as the forklift decelerates. The spring force may be modulated with the dead man pedal depending on the model of forklift. The braking action creates a longitudinal deceleration that causes the forklift to slow down.

Stand-up forklifts are typically designed to carry loads of 3,000 to 4,000 pounds. Braking distances are shorter and deceleration rates are higher when the forklift is unloaded since the maximum braking capacity is typically fixed.

The Industrial Truck Standards Development Foundation (ITSDF) publishes the voluntary consensus standard B56.1 Safety Standard for Low Lift and High Lift Trucks. [5] The standard states that low lift and high lift trucks (except order pickers) with capacities of less than 16,000 kg shall develop a drawbar drag equivalent to 1.86 times greater than the velocity of the truck, but the drawbar drag is not required to exceed 25% of the weight of the truck. Therefore, the maximum deceleration rate required by the standard is
0.25 g's.

Stand-up forklift braking systems can require stopping distance testing and adjustment. Such forklifts typically provide a table of acceptable stopping distances within the service manual. Based on the top speed of the forklift and the specified stopping distance, such forklifts can decelerate at average rates as high as 0.4 g's or as low as 0.15 g's and still be within the performance specification. Following an accident, forklift braking performance should be tested at the truck's top speed, with the maximum load permitted by the manufacturer, and the distance required to stop should be recorded. Testing should be performed in both the forks leading and forks trailing direction.

LATERAL ACCELERATION

Stand-up forklifts are typically equipped with a steering tiller operated by a single hand. The action of the tiller causes the rear wheel(s) of the forklift to turn which causes the forklift to turn. Since the rear wheel(s) turn the forklift, the forklift is said to "tail swing," where the rear of the forklift swings out during a turn. Because of tail swing, the operator's compartment at the rear of the forklift experiences the greatest lateral acceleration.

There are two primary types of stand-up narrow aisle forklifts. Counter balance stand-up forklifts carry a load outside of the area created by contact between the wheels and ground. Narrow aisle stand-ups carry the load inside the area created by contact between the wheels and ground. Counter balance forklifts are typically equipped with load wheels directly behind the mast of the forklift and have a steer wheel near the rear of the forklift. Narrow aisle forklifts are equipped with outriggers that place load wheels in front of the mast. Steer wheels on narrow aisle forklifts are also located at the rear of the forklift. Counter balance stand-up forklifts have shorter wheelbases and can turn 360 degrees within their own footprint. Narrow aisle stand-up forklifts can turn 360 degrees in a circle with a radius that is the length of the wheelbase of the forklift.

Lateral acceleration experienced on a stand-up forklift is dependant on the rate and magnitude of steering input from the operator, the speed of the forklift at the initiation of the steering input and the effective radius of the turn. In an impending collision scenario, operators will likely initiate the fastest and greatest magnitude steering input possible to avoid a collision.

LATERAL ACCELERATION TESTING

The lateral acceleration generated by a rapid steering input during emergency braking was tested using a Dockstocker DSS300TT forklift. The Dockstocker DSS300TT is a counterbalance stand-up forklift equipped with 3 wheels. There are two load wheels directly behind the mast of the forklift and the third wheel is approximately centered in the rear of the forklift. The wheel base of the forklift is approximately 4 feet. The forklift is operated in a side-stance position, with the operator's right side closest to the forks and left side near the opening to the rear of the forklift.

Acceleration data was captured using a 3-axis SENSR GP1 Programmable Accelerometer. Acceleration data was sampled at 100 Hz at a programmable range of 2.5 g's. Raw data from the sensor is unfiltered. Moving averages with periods of 10 and 50 data points were utilized to remove noise from the data. Raw data and data from the moving average with a 50 point period are presented in this paper. Acceleration data reported in this paper is also taken from the data sets associated with the 50 point moving average. Therefore, peak values reported likely underreport the true peak, since the reported values are actually the average value of 50 points leading up to a peak.

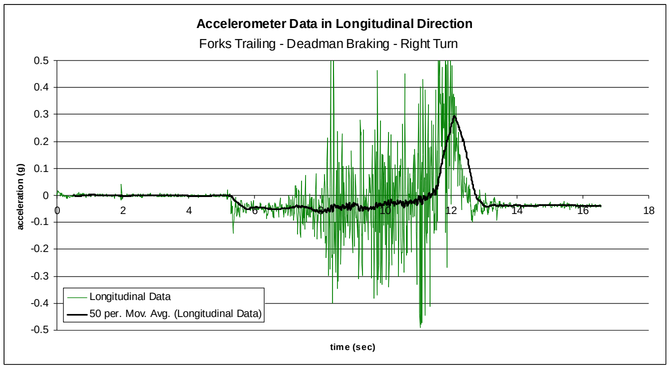

Figure 1. Longitudinal Acceleration

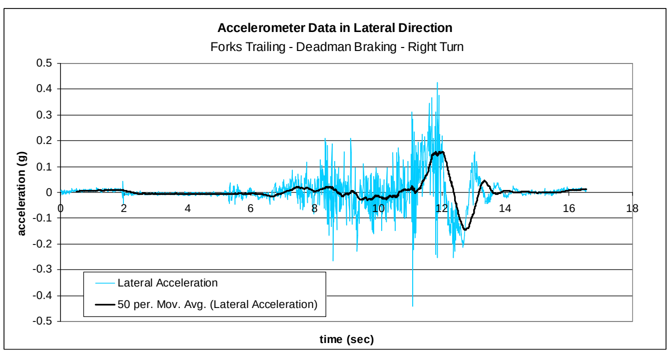

Figure 2. Lateral Acceleration

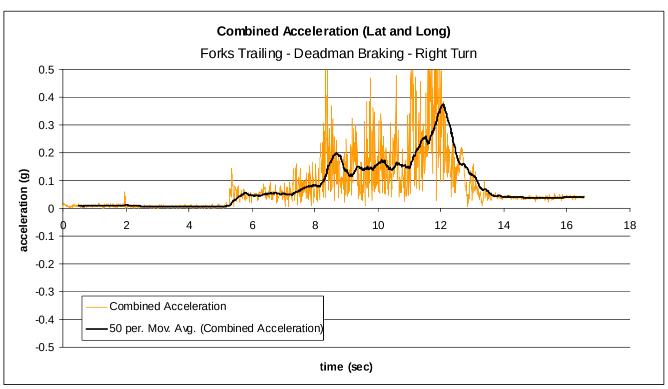

Figure 3. Combined Acceleration

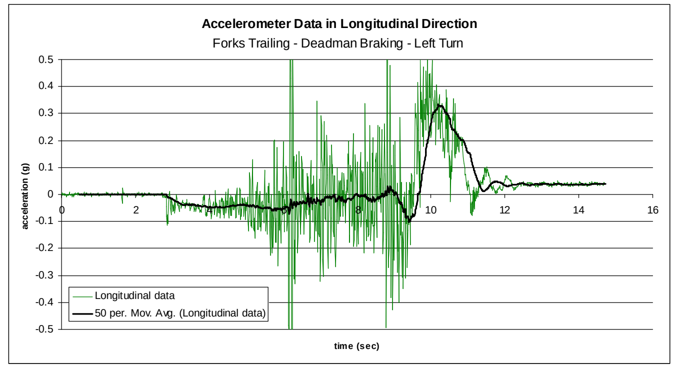

Figure 4. Longitudinal Acceleration

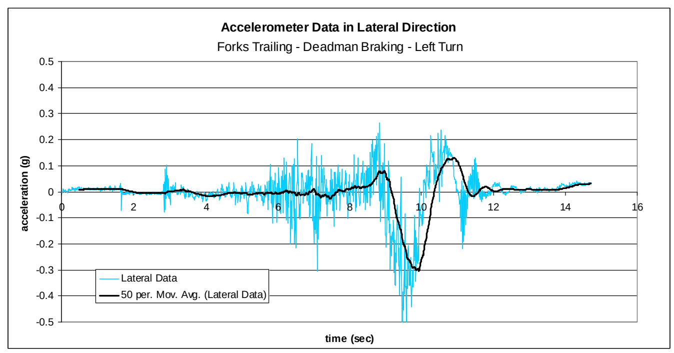

Figure 5. Lateral Acceleration

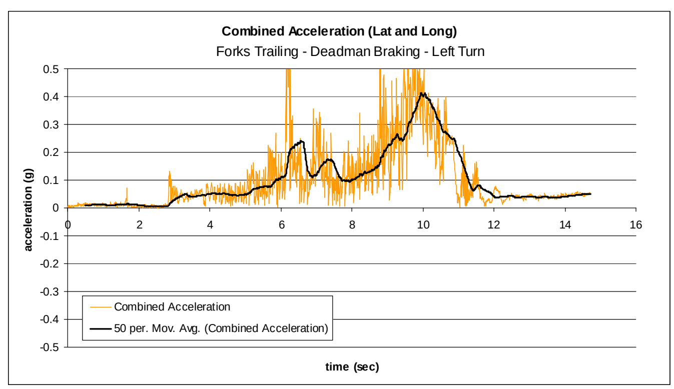

Figure 6. Combined Acceleration

The forklift was accelerated for approximately 30 feet and then dead man braking was initiated at the same time that a rapid steering input was performed. Left and right turns were tested in the forks trailing direction of travel. Average deceleration rates during dead man pedal braking for the forklift was approximately 0.25 g's. As a result of the rapid steering input the forklift would initially turn with a peak lateral acceleration of 0.15 to 0.3 g's. As the forklift decelerated due to the braking input, the angular velocity also began to decrease and the lateral acceleration reversed sign, peaking at approximately 0.1 to 0.15 g's. The combined lateral and longitudinal acceleration was summed and found to reach approximately 0.4 g's for both the left turn and right turn. Experimental data for the right turn is presented in Figures 1 to 3, and data for the left turn is presented in Figures 4 to 6.

SUMMARY/CONCLUSION

Lateral acceleration experienced during testing on the Dockstocker DSS300TT exceeds the threshold of acceleration identified by Harris and DeRosia as causing loss of balance. Further, the deceleration caused by braking also exceeds the threshold. The combination of lateral and longitudinal acceleration caused by a steering input during an emergency braking event produced approximately 0.4 g's of acceleration. Therefore, an unprepared operator could lose postural stability and be ejected or step out of the forklift due to such acceleration.

The record of serious lower leg injury associated with stand-up forklifts, reports of ejection or loss of balance from the operator and data regarding acceleration present in the operator compartment support the use of a door for stand-up forklifts.

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