Journal of the National Academy of Forensic Engineers®

http://www.nafe.org
ISSN: 2379-3252

Vol. 35 No. 1 June 2018

Forensic Engineering Analysis of Unintended Movement of Powered Industrial Trucks

By Ben T. Railsback, PE (NAFE 713S), Richard M. Ziernicki, PhD, PE (NAFE 308F), Stephen Knapp, PE (NAFE 819S) and Ricky Nguyen, PE

Abstract

Unintended movement of powered industrial trucks after operators have left the operating position has led to serious — and sometimes fatal — accidents. Even though operators are trained to prevent unintended movement of powered industrial trucks, they can forget to shut off the power source or activate systems to prevent the unintended movement when leaving the truck. Operators are known to make mistakes, especially if they are working in a fast-paced environment and are required to frequently leave the trucks. Engineers have designed electrical interlocks and other systems (e.g., automatically applied parking brakes) to prevent unintended movement; however, not all powered industrial trucks are equipped with them. Furthermore, some of these systems only disconnect the power source from the truck's drivetrain. These trucks can continue traveling due to their initial momentum or by gravity if the truck was left on a slope. The purpose of this paper is to address the design of forklift operator presence detection systems and unintended movement of unoccupied forklifts through a safety and forensic engineering analysis, highlighting a brief case study to examine the concept of use and foreseeable misuse — and to review the legal concept of strict product liability.

Keywords

Forklift, powered industrial truck, parking brake, operator presence detection, interlock, forensic engineering

Introduction

Powered industrial trucks (also referred to as "PITs"), such as lift trucks (forklifts) and tow tractors, are material handling equipment used to move and/or store products and goods in various industries and workplaces, such as manufacturing plants, distribution centers, and airports. These PITs typically have drivetrains that are powered by internal combustion (IC) engines or electric motors — similar to those found in automotive vehicles. Just like automotive vehicles, these PITs can unintentionally move when operators forget to shut off the power source or to follow steps to prevent the unintended movement, such as putting the PIT's transmission in neutral and setting the parking brake. Forklifts are deceptively heavy, weighing three to four times the weight of a small car while having a smaller footprint than the car. For decades, the unintended movement of PITs has led to many serious or fatal injuries to operators and other personnel in the workplace when an unoccupied forklift crushes the operator or a pedestrian against a fixed object. Furthermore, these unintended movements may lead to significant and costly property damage.

Manufacturers provide instructions and procedures in the operator's manual that will prevent unintended movement if they are consistently followed by the operator. Employers also typically train these operators on such instructions and procedures to prevent the unintended movement. However, since these methods require operators to manually activate systems to prevent unintended movement, the methods are prone to operator error, and operators may forget to actuate the systems.

To prevent these deadly accidents, engineers have designed systems (or interlocks) that would automatically prevent unintended movement (i.e., an automatically applied parking brake). These systems have been available for more than a century. However, many manufacturers

Ben Railsback, PE, 9249 S. Broadway #200-808, Highlands Ranch, CO 80129, 720-320-9339; ben.railsback@gmail.com
Richard M. Ziernicki, PhD, PE, 7185 S. Tucson Way, Centennial, CO 80112, 303-925-1900, rziernicki@knottlab.com

still do not equip PITs with these systems as a standard or even optional feature.

The Incident

At approximately 9 a.m. on a winter morning in 2007, a forklift operator was struck by an unoccupied powered industrial truck at a pallet re-manufacturing facility in St. Louis. The operator had reportedly dismounted the forklift inside a semi-trailer, without setting the parking brake, to hand stack some pallets that were located inside the trailer. The forklift had been driven into the rear of the trailer, and the front of the forklift was facing the front of the trailer. The forklift then rolled forward in the semi-trailer, pinning and crushing the operator between the forklift and the pallets. The operator normally used another model forklift, but was operating a new, rented forklift on the day of the accident. As a result of the incident, the operator sustained fatal injuries.

Photographs of the facility showed that the dock area sloped downward away from the building. The loading dock area also showed standing water out in front of the trailer, away from the building. Photographs of the trailer showed that the landing gear of the trailer did not level the floor of the trailer relative to the slope of the ground. Therefore, the ground and floor of the trailer sloped downward away from the building at the time of the accident, indicating that the floor of the semi-trailer sloped in the direction that the forklift rolled.

The performance of the subject truck was tested by a mechanic from a local service company. The mechanic concluded that there were no performance problems with the truck. Video of the mechanic's testing and photographs apparently taken at the forklift dealership/rental agency demonstrated that the parking brake held the subject truck against a 12.5% grade, and in a separate test, against the engine power at idle while in gear. Dissimilar to the forklifts that the decedent normally operated, the subject forklift was equipped with a presence detection system. One of the features of the presence detection system is a seat switch that is used to detect the presence of the operator in the seat. When the switch is open for more than 2 seconds, mast controls are disabled, the transmission controls are disabled, and the truck shifts into neutral (although the transmission stalk does not physically move). The parking brake does not automatically engage.

An eyewitness to the scene of the accident testified that the forklift was found with the transmission selector in the reverse position, and the parking brake was not set.

Strict Products Liability

The estate of the plaintiff filed a complaint against the manufacturer of the forklift, alleging that the forklift was defective under a strict products liability claim. *Black's Law Dictionary*[1] defines "strict products liability" as a "products liability arising when the buyer proves that the goods were unreasonably dangerous and that: (1) the seller was in the business of selling goods; (2) the goods were defective in the seller's hands; (3) the defect caused the plaintiff's injury; and (4) the product reached the consumer without substantial change in condition."

A strict products liability action is one of three legal theories that a products liability action can be based on. Products liability actions can also be based on negligence or breach of warranty. *Black's Law Dictionary* defines "negligence" as "the failure to exercise the standard of care that a reasonably prudent person would have exercised in a similar situation." A fundamental difference between a strict products liability action and a negligence action is the focus of the analysis that a forensic engineer performs. In a strict product liability analysis, the focus of the analysis is on the design of the product and whether the product was unreasonably dangerous. In contrast, in a negligence action, the focus will be on the conduct of the manufacturer in the design or production of the product and the conduct of the injured party.

Safety Engineering

The Codes of Ethics of ASME and the National Society of Professional Engineers state that "Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their duties." Methodologies for proper product design and safety engineering principles have been published in many texts on safe product design[2,3,4,5] and have also been recognized in engineering standards[6,7]. In essence, when hazards are identified, a hierarchy of steps should be followed, including:

a. Eliminate hazards associated with products by design processes.

b. Guard against residual hazards. If the hazard cannot be eliminated by design, and effective guarding cannot be provided, then:

c. Warn about the hazards.

d. Instruct the operator.

Further, if it is technologically and economically feasible, designers should not use lower-tier hazard mitigation methods as a substitute for methods in a higher tier. For example, if the hazard could feasibly be designed out or guarded against, a designer cannot use warnings to forego the elimination or guarding of the hazard. Residual risks that cannot be addressed through design and guarding efforts should be mitigated with proper warnings and instructions. In performing the forensic engineering analysis of the case study, the authors of this paper first performed a safety engineering analysis of the forklift based on the engineering hierarchy.

The Hazard of Unintended Movement of PITs

PITs are used in the movement and/or storage of products and goods in various industries, such as manufacturing plants, distribution centers, and airports. Title 29 (29CFR1910.178) of the United States Code of Federal Regulations (OSHA General Industry Regulations) defines PITs as "fork trucks, tractors, platform trucks, motorized hand trucks, and other specialized industrial trucks powered by electric motors or internal combustion engines."

PITs can weigh significantly more than automotive vehicles and are constructed with thicker steel panels and sometimes have solid metal counterweights that can weigh thousands of pounds. A lift truck operating in a warehouse typically weighs 9,000 pounds — more than two and a half times as much as a typical 3,500-pound sedan. Therefore, if traveling at the same speed, these trucks have more than two and half times as much kinetic energy and momentum as typical automotive sedans. The equations for kinetic energy and momentum are given in Eq. 1 and Eq. 2 below.

$$KE=½mV^2 \quad (1)$$

$$P=mV \quad (2)$$

PITs do not need to travel at a high speed to cause serious harm. A recent fatal accident investigation was conducted where a man's chest was crushed in between a warehouse rack and a lift truck. Analysis of the accident indicated that 870 foot-pounds[8] of work energy was required to compress the man's chest 6.7 inches. Based on Work-Energy Theorem (see Eq. 3 and Eq. 4), a 9,000-pound lift truck would only need to travel 1.7 mph to have enough energy to fatally crush the man's chest.

$$W=\Delta E \quad (3)$$

$$W_{chest\ compression}=½mV^2 \quad (4)$$

Besides bodily injury, unintended movement of PITs can also lead to costly property damage, such as PITs running into and damaging structures like storage racks or building columns, and PITs driving off loading docks. Therefore, the authors of this paper have concluded that there is a significant hazard associated with the unintended movement of a powered industrial truck.

Foreseeable Use and Misuse

Even though PIT operators are trained on how to park these vehicles, operators are sometimes required to follow numerous steps to properly park the vehicle before leaving the operator position. For example, these are the following steps that operators follow to properly park a standard IC, hydrodynamic transmission lift truck:

1. Select a safe area to park. Do not block aisles or exits.
2. Apply the service brake and come to a stop.
3. Shift the transmission into neutral.
4. Set the parking brake.
5. Lower the forks.
6. Turn the ignition off.
7. If on an incline, block the wheels.

Further complicating the process is an exemption to the requirement for turning the ignition off if the operator intends to remain within 25 feet of the forklift (29CFR1910.178(m)(5)(iii)). Requiring operators to follow numerous steps to properly park a truck increases the chance for human error because operators tend to follow procedures that involve minimal physical and mental effort, discomfort, or time.

Foreseeability can be defined as the quality of being reasonably anticipatable[6]. The 1992 International Organization for Standardization (ISO 12100-1) standard entitled *Safety of Machinery – Basic Concepts, General Principles* states that "Intended Use" of the machine "also involves the compliance with the technical instructions laid down notably in the instruction handbook, taking into account reasonably foreseeable misuse[6]." The standard outlines that the following behavior should be taken into account for foreseeable misuse in the risk assessment:

- *the foreseeable incorrect behaviors resulting from normal carelessness, but not resulting from deliberate misuse of the machine,*

- *the reflex behavior of a person in case of malfunction, incident, failure, etc., during use of the machine,*

- *the behavior resulting from taking the "line of least resistance" in carrying out a task,*

- *for some machines (especially machines for non-professional use), the foreseeable behavior of certain persons, such as children or disabled.*

In the analysis of the subject incident , the question of foreseeability was not difficult to establish, given knowledge of similar incidents within the PIT industry. For example, an expert for the manufacturer was quoted in a forklift publication article regarding the mistakes operators make:[9]

"Before, lots of things were missed, such as how to go up and down a ramp, applying the parking brake, what to do when getting off the truck," [The Expert] told Modern. "Now we have a training program that helps them make better decisions."

The quote indicates awareness of the issue of not setting the parking brake and getting off of the truck — and a reliance on training rather than engineering design to solve the problem. Since the manufacturer's representative (and expert for the manufacturer) had already demonstrated awareness of the issue, foreseeability of the incident had been proven. Further, the forklift had been designed and equipped with an operator presence detection system. The system was designed to shift the forklift out of forward or reverse gear when the operator left the seat. The presence detection system prevents unintentional *powered* movement of the forklift, but does not prevent unintentional *unpowered* movement due to either the initial speed of the forklift, gravity or sloped surfaces, or other conditions. Therefore, the designer of the forklift was clearly aware of the hazard of unintended movement of the forklift.

Technical Feasibility of Preventing Unintended Movement of the PITs

The prevention of unintended movement of PITs is technically feasible. The manner in which the manufacturer chooses to prevent unintended movement depends on the power source of the truck and the control system of the truck.

Electric sit-down forklifts generally have electrically released brake systems that are applied by springs when power is removed from a solenoid. Operator presence or absence is generally detected by a seat switch. The accelerator pedal will return to neutral or zero when released. Electric stand-up forklifts have hydraulically released or electrically released brakes that are spring applied. Operator presence is detected using a "dead man pedal" that the operator must depress with a foot to release the brake. By lifting this foot, which the operator must do to exit the forklift, the brakes are applied. The accelerator, generally a joystick, returns to neutral after release. Therefore, electric PITs generally have designs that prevent unintended movement.

The largest group of PITs that do not prevent unintended movement are equipped with IC engines and hydrodynamic transmissions (torque converters). IC engine PITs, or IC forklifts, rely on the combustion of diesel, liquefied petroleum (LP), or gasoline. The IC engine power is transmitted to the wheels through a torque converter and transmission. When the operator leaves the forklift, if it is left in gear without a parking brake, the forklift will move under the engine power at idle. If the transmission is in neutral without the parking brake set, the forklift may move (or not), depending on the slope of the driving surface.

IC PITs that are equipped with hydrostatic transmissions prevent unintended movement of the forklift. Some manufacturers of lift trucks — Linde, for example — equips its truck with a hydrostatic drive system that uses a hydrostatic pump with a swashplate that controls the rate and direction of oil delivery to the hydraulic motors that power the wheels. When the swashplate is in the neutral position, there is no oil delivery to the wheel motors, and the wheels do not turn. When the forward direction is selected, the swashplate tilts, oil is delivered to the wheel motors, and the wheels drive forward. When the reverse direction is selected, the swashplate tilts in the opposite direction and delivers oil in the opposite direction to the wheels, and the wheels rotate in reverse.

During forward or reverse motion when the operator wants to decelerate, the operator releases the directional pedal. When the operator releases the pedal, the swashplate returns to neutral, oil delivery from the hydraulic pump is stopped. The hydraulic motors continue to rotate as the inertia of the lift truck is dissipated, converting kinetic energy to hydraulic pressure and heat. Since the swashplate on the hydraulic pump is in neutral, the hydraulic fluid cannot flow through the pump, and the truck automatically comes to a stop. After stopping, the neutral position of the swashplate balances pressure on the wheel motors, and prevents further motion. Unlike other lift trucks, an advantage of this system is that it does not require service brakes that will mechanically wear down[10,11].

With the hydrostatic transmission, the operator must select a direction of travel and acceleration input. When the operator releases the control, the control and the swashplate return to neutral, and the vehicle decelerates automatically. When the operator leaves a stopped forklift, the acceleration input will be zero, and the forklift will remain motionless. Therefore, unintended movement of the IC hydrostatic transmission forklift is well controlled.

The subject forklift was equipped with an IC engine, torque converter, and powershift transmission (an electronically controlled automatic transmission). The presence detection system on the forklift did detect when the operator left the forklift, detected that the forklift was left in reverse, and shifted the forklift into neutral. However, the forklift did not apply a parking brake or immobilize the forklift in any way. The subject manufacturer also offers an enhanced presence detection system for some forklifts in the European market. The enhanced presence detection system performs the same functions as the standard presence detection system, but also has the added feature of applying a parking brake when the operator leaves the seat[12].

A rough terrain forklift manufacturer has implemented a parking pawl design combined with an interlocked seatbelt. The parking feature on this lift truck uses a spring-loaded pawl that locks into a spline on the truck's axle. When the operator has the seatbelt latched, hydraulic pressure releases the spring-loaded pin and allows the axle to freely rotate. When the parking pawl is disengaged from the axle, powered travel is possible. However, when the operator unbuckles the seatbelt, the parking pawl in the transmission is applied, locking the axle and preventing motion of the truck from a stopped position. A limitation of the seatbelt interlock system is that the operator can latch the seatbelt and operate the forklift while unrestrained, defeating the interlock.

Since several manufacturers have developed and provide systems that prevent unintended movement of the forklift after the operator leaves the operating position, the authors concluded during analysis of the subject incident that at the time of the subject PIT's design, it was technically and economically feasible to manufacture a forklift that prevents unintended movement of the forklift after the operator leaves the operator compartment.

The subject case study incident occurred in 2007 with a new forklift. The legal case was litigated in 2010. The research and analysis of the incident was presented to the National Academy of Forensic Engineers in 2017. In 2018, Clark Material Handling introduced a new counterbalance lift truck with force-cooled, wet disc brakes. The new braking system features an automatically applied parking brake that would have also prevented the subject incident, on a truck equipped with a hydrodynamic transmission.

Design Standards and Regulations

Currently, federal regulation 29CFR1910.178 requires manufacturers to design and equip PITs to meet the 1969 revision of the American National Standards Institute ("ANSI") B56.1 *Safety Standard for Low Lift and High Lift Trucks*[13]. Although the B56.1 standard has been revised several times, federal regulations have not incorporated by reference more recent versions.

The B56.1 standard does require manufacturers to design and equip some electric lift trucks with systems that will only allow powered travel if the operator is in the normal operating position and to automatically apply the brakes when the operators leave the truck. Since the 1960s, the B56.1 standard has required electrically powered stand-up and sit-down trucks to be equipped with systems that would automatically disconnect the truck's drivetrain from the power source and automatically apply the brakes if the operator leaves the truck.

In the 2004 version of the B56.1 standard, changes were made to require IC trucks to be equipped with systems that would not allow powered travel until the operator is in the normal operating position. Manufacturers have responded to this change in the standard and equipped their trucks with presence detection systems, to prevent powered travel when operators are not in the operating position. However, there was no requirement for the automatic application of parking brakes for IC-powered sit-down and stand-up lift trucks. Since the standard does not require the lift truck's brakes to automatically apply when operators leave the operating position or require that motion due to gravity or initial speed be arrested, the truck can roll after the operator leaves the seat. Since there is no requirement to prevent motion due to gravity, or slope, the subject forklift was compliant with the B56.1 standard.

Although not required by the B56.1 standard, some manufacturers do equip their PITs with deadman switches/controls that would automatically apply the brake, like the enhanced presence detection system offered by the subject manufacturer. Further, since IC PITs with a hydrostatic transmission will prevent movement on slopes (by balancing hydraulic pressure across the wheel motors with a neutral swashplate) when the operator is out of the operating position, there are safer designs that are technically and economically feasible. Therefore, the subject forklift was not compliant with standards of good machine design that require hazards to be designed out or guarded against when feasible.

Conclusion

Accidents caused by the hazard of unintended PIT movement have been known for decades. The unintended movement of the PITs could be guarded (or interlocked) against with deadman switches/controls that would automatically prevent the hazard of the PITs unintended movement from occurring when operators leave the operating position.

Even though deadman switches/controls have been available for more than a century, there are manufacturers that still rely on operators following warnings on the PITs and instructions or procedures in the operator manuals to prevent the unintended movement of the vehicle. Had these manufacturers followed recognized and effective design methodologies to produce safe products, these PITs would have been equipped with deadman/controls switches that would automatically prevent the PIT from unintentional movement. Instead, these manufacturers did not follow methods to design out or guard against the hazard of the PITs unintended movement and relied on warnings and/or instructions to prevent accidents caused by the hazard.

A criticism of deadman switches/controls has been that they can be an inconvenience to operators — and that operators will attempt to remove them or make them inoperative. However, for the design of safety systems/designs to be effective, the manufacturers must design the deadman switches/controls in such a way that they are durable and not easily defeated. Furthermore, federal regulations do not allow user modification that affects the safe operation of the PITs without manufacturer approval, and users can be cited for removing or defeating manufacturer installed deadman switches/controls.

Based on recognized and effective safety methodologies for proper product design and safety engineering principles, manufacturers should not rely on operators following warnings and instructions or procedures to prevent unintended movement. Warnings and instructions are only intended to address residual risks and are not intended to address design defects. Instead, manufacturers should design out the hazard by equipping these PITs with systems (or interlocks) that would automatically prevent movement when the operator is not in the truck. These systems would not only prevent powered travel, but they would also slow down and stop moving PITs or prevent them from traveling down a slope when the operators leave the operating position. Therefore, equipping PITs with systems that would prevent unintentional movement would increase the safety of the PITs, and would bring the designs up to the engineering design standard of care for safety.

Appendix Notation

KE = kinetic energy
m = mass
V = velocity
P = momentum
W = work
ΔE = change in energy

References

1. Black's law dictionary. St. Paul (MN): West Group; 2000.
2. Hammer W. Handbook of system and product safety. Englewood Cliffs (NJ): Prentice Hall; 1972.
3. Hammer W. Occupational safety management and engineering. Englewood Cliffs (NJ): Prentice Hall; 1981.
4. Roland H, Moriarty B. System safety engineering management. Hoboken (NJ): John Wiley & Sons, Inc.; 1990.
5. Brauer R. Safety and health for engineers. Hoboken (NJ): John Wiley & Sons, Inc.; 1994.

6. ISO/TR 12100-1:1992. Safety of machinery – basic concepts, general principles for design. Geneva, Switzerland; International Organization for Standardization.

7. ANSI Z244.1-2003. Control of hazardous energy, lockout/tagout and alternative methods. Washington, DC; American National Standards Institute.

8. Kent R, Sherwood C, Lessley D, Overby B. Age-related changes in the effective stiffness of the human thorax using four loading conditions. Paper presented at IRCOBI 2003. Proceedings of the International Research Council on Biomechanics of Injury Conference; 2003 Sep 11-13; Gothenburg, Sweden: pp 249-263.

9. Forkliftnet.com: lift truck OEMs and OSHA: allies in industrial safety. Guangzhou (China): Forkliftnet.com; 2007 [accessed 2011 Oct 24]. https://bit.ly/2Bruxj4.

10. Spotlight on Linde Hydrostatic Drive. Linde Material Handling GmbH; 2016 [accessed 2018 Nov 5]. https://bit.ly/2QIgP5J.

11. “PMT Linde Hydrostatic Drive Forklift No Brakes Transmission low cost of fuel.” PMT Forklift Corp. 2014. [accessed 2018 Nov 5]. https://bit.ly/2S7JQ7G

12. Escutia M. Productivity taken to a maximum with our new DP/GP40-55N range. Guangzhou (China): Forkliftaction.com; 2010 [accessed 2017 Aug 21]. https://bit.ly/2rHUp5A.

13. ANSI/ASME B56.1-1969. Safety standard for powered industrial trucks. New York (NY); American Society of Mechanical Engineers.