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What's Inside…

Abstract
The hazards of dust fires and explosions are poorly understood in the workplace. Often, good prevention and mitigation measures are not undertaken until a facility suffers a devastating loss. This paper provides an introduction to dust fire/explosion phenomena and provides some insight as to how such events occur in industrial facilities.

Abstract
Safety guards and devices are a primary reason that incompatibilities exist between the machinery maintenance community and machine operators. Safety devices are intended to keep machine operators away from the hazardous moving parts of equipment whereas machine maintenance personnel must access both the hazardous parts as well as the safety devices themselves in order to repair and/or maintain them. This article will explore some of the safety philosophies, practices and regulations that apply to machine maintenance personnel who must temporarily bypass safety equipment while performing their trade.

Abstract
When designing a product, it is important to not only have available any recognized safety standards that relate to that product, it is imperative that the designer understand the true "spirit", or safety intent, that the language of the code may not always provide. A case study, which looks at the tipover of a self-propelled elevating work platform, demonstrates what can happen when a designer designs a product strictly to the letter of the code, and not the spirit of the code.

Abstract
When VCR's first came out in the late 1970's, there was a circulating joke about the difficulty in programming them to record broadcasted programs when away from home. Today, VCR's are about to be phased out of production and we have TIVO© to perform that scheduled recording function. For those of us who grew up with VCRs, there is an instinct to want to "rewind" our rental movies after viewing, even when unnecessary because they are in a DVD format. With old VHS players, while difficult to insert the VHS tape in backwards or upside down, if done would cause a jam; the newer DVD players easily allow a disk to be installed upside down, resulting in no function, but causing no damage.

These are examples of some human factors problems and considerations for designers of equipment and processes. They include issues of a user's mental model, consistency of function and performance, and error checking and preventing. The following article is an introduction and survey of some of these and other popular human factors theories and mechanisms.

Dust Explosions and Fires – Part I, How Industrial Dust Explosions Occur

by
Kim R. Mniszewski, P.E.

One poorly understood hazard in the industrial workplace is that of combustible dust. Many large-scale explosion incidents occur each year in facilities that process combustible particulate or generate combustible particulate as a byproduct of their operations. While the technology is available to control or eliminate these hazards, many are left in place due to ignorance, or a misguided low risk perception. When large-scale losses occur, the damage is usually higher than anyone ever imagined at the facility. This results in the impetus for change to increase prevention and mitigation efforts. For example, after many large grain dust explosions in US grain facilities in the '70's, there was a substantial industry effort to improve its hazard awareness, make processes safer and improve housekeeping efforts.

This paper will present some primer information on just how this class of fires and explosions occur in industry.

Dust Explosion Terminology. Many of the concepts involving dust explosions require some definitions to clarify the discussion. National standards and guides provide several useful definitions. Some key concepts are as follows.

Deflagration – Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.

Detonation – Propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium.

Combustible Dust – Any finely divided solid material that is 420 microns or smaller in diameter (material passing a US no. 40 standard sieve) and presents a fire or explosion hazard when dispersed and ignited in air.

Combustible Particulate Solid – Any combustible solid material, composed of distinct particles or pieces, regardless of size, shape, or chemical composition. These can include dusts, fines, fibers, flakes, chips, chunks or mixtures of these.

Flammable limits – The minimum and maximum concentration of a combustible material, in a homogenous state with a gaseous oxidizer that will propagate a flame.

Auto-ignition Temperature – The temperature at which combustion begins simply due to the material temperature, with no igniter

Minimum Explosible Concentration (MEC) – the concentration sufficient to produce an increase in pressure of one atmosphere due to deflagration of the test sample during testing (ASTM E 1515); also considered the lower flammable limit

Minimum Ignition Energy – The minimum energy, discharged into the dust cloud by the test apparatus, sufficient to cause flame propagation

Maximum Deflagration Pressure – The maximum pressure produced by a deflagration of dust particulate when tested in an enclosed test vessel (ASTM E 1226)

Wherever combustible particulate solids are produced, processed, conveyed, or handled, fine particles are always generated during processing. Because of this, it is expected that processes involving combustible particulate solids will usually contain some amount of combustible dust.

Dust Explosion Phenomena. In reality most dust explosions are deflagrations unless highly confined in long vessels. In those rare cases, more devastating detonations are possible. For a deflagration to occur, four basic conditions must be met, (1) the combustible particulate solid must be of a sufficiently small size to be deflagrable, (2) the particulate must be suspended in air (or other oxidizing medium), (3) the particulate must be suspended in a sufficiently high concentration, and (4) a competent igniter must be applied to the suspension where the concentration is sufficient for flame propagation.

To meet the first condition, the particulate solid must generally be less than 420 microns in diameter. This is about the size of table salt granules. In some unusual cases, larger and longer particulate may be deflagrable, e.g. plastic fibers greater than this size were responsible for explosions in the famous Maldin Mills fire (Lawrence, MA, 12/95).

To meet the second condition, the particulate need be lofted or suspended in air. Some processes, e.g. grinding, milling, high speed conveying, tend to produce dust clouds as part of their normal operation. In other cases, a process upset condition or abnormal condition, resulting in the release of a large dust pocket that may suspend in air and fill a large area. After an initial dust explosion, other dust clouds may quickly form due to lofting from building vibrations and the pressure front of the deflagration. Such secondary dust suspensions are typically responsible for the escalation of an initial fire/ explosion to a large loss incident.

To meet the third condition, enough particulate must be suspended in air. It depends on the material, but a typical minimum explosible concentration (MEC) may be on the order of 100 grams per cubic meter. The MEC is usually determined in accordance with ASTM E 1515.

To meet the fourth condition, a sufficiently potent ignition source must be present in the suspension of particulate, or in a dust layer prior to lofting. The minimum ignition energy of a dust cloud is a somewhat different phenomenon from that involving a dust layer, and is determined by standard test ASTM E 1491. Dust layer ignition is usually expressed in terms of hot surface ignition temperature, and is determined by standard test ASTM 2021.

During an explosion event, typically lasting a fraction of a second, the main effects are that of overpressure and high temperatures. Momentary high temperatures can singe or start lightweight combustibles on fire. Overpressures may rupture any containment and send shrapnel flying. Overpressure levels may range from barely imperceptible to that of highly damaging, with extreme cases on the order of 150 psi. Maximum overpressure is basically a function of the dust material type, particle size, concentration and the strength of confinement.

The severity of the explosion hazard is usually determined by the peak pressure and rate of pressure increase. The current accepted method for classifying the severity of a dust hazard is to use a normalized rate of pressure increase as a deflagration index, K_{st},, derived from flame speed relations, where $K_{st} = (dP/dt_{max})(V)^{1/3}$. As K_{st} is relatively constant for a given material over a wide range of containment volumes, it is quite useful for classification and quantitative assessment. It is has been found that there are three convenient regimes (ST class) to define dust hazards using this classification method.

> Where K_{st} is less than 200, (ST1), deflagration flame fronts can be produced that can knock down walls, lift roofs, and blow out windows and doors. Secondary fires are ignited. If K_{st} is less than 100, a weak increase in pressure is experienced, flame fronts that roll through compartments are produced, and many secondary fires are produced. Some example dusts include corn, coal, charcoal, vinyl chloride and sugar.
>
> Where K_{st} is between 200 and 300, (ST2), deflagrations with higher rates of pressure increase are experienced and initial structural damage can be substantial. Secondary fires are ignited. Some example dusts include corn starch, wood flour and methyl acrylate.
>
> Where K_{st} is above 300, (ST3), deflagrations with extremely high rates of pressure increase can occur. The building or containment structure can be shattered during the event. These events often do not result in secondary fires. Some example dusts include aluminum and magnesium.

These classifications are used in the prevention and mitigation of dust explosion hazards such as, in minimizing accumulations, explosion vent design requirements, explosion suppression design requirements, resistive containment design, etc.

How Dust Explosions Develop in Real Facilities. In general a dust explosion hazard exists anywhere the four aforementioned conditions can potentially exist. For example, where all the conditions exist except for that of suspension, there is the potential for an explosion if some abnormal force can loft the dust in the air. NFPA 654 states that any area where dust accumulation on horizontal surfaces exceeds 1/32” constitutes an explosion hazard. Likewise, NFPA 664 states that any area where dust (wood fines) accumulation exceeds 1/8” constitutes an explosion hazard.

Some example scenarios judged to be typical by the author, which have resulted in large explosions are listed below.

A. A smoldering nest (smoldering dust bed) develops in a particulate layer within a cyclone bin, initiated by an ember originating from a milling operation. An explosion occurs as the smoldering material is released into a rotary feed into a pneumatic transfer system, where the MEC is exceeded. The pneumatic duct ruptures, resulting in the shaking up and lofting particulate suspended on structural members. A larger secondary explosion results.

B. While the automatic shaker in a baghouse filter momentarily suspends dust within and the MEC is exceeded, a spark enters the filter from a sanding operation it serves enters resulting in an initial explosion. The baghouse containment then ruptures, and secondary explosions result from lofted dust fines originating on horizontal structural members.

C. A pocket of accumulated methane gas in a coal mine explodes, dislodging and lofting coal dust fines in the area and beyond to exceed the MEC. As fines are ignited by methane flames, a series of major secondary dust explosions occur.

Figure 1 shows the destruction from a dust explosion in a paper shredding operation. The ignition source found by the investigators was a smoldering nest within a mill (see figure 2), resulting from an unwanted metal piece entering the process stream. The smoldering particulate were lofted into pneumatic conveying air streams and ignited dust above the MEC in a dust collector. An initial explosion in the dust collector resulted in its rupture. Secondary effects from that explosion throughout the facility included fires and secondary explosions. This is somewhat similar to that described in scenario A.

A second article is forthcoming as, Dust Explosions and Fires – Part II, Prevention and Mitigation of Dust Explosions.

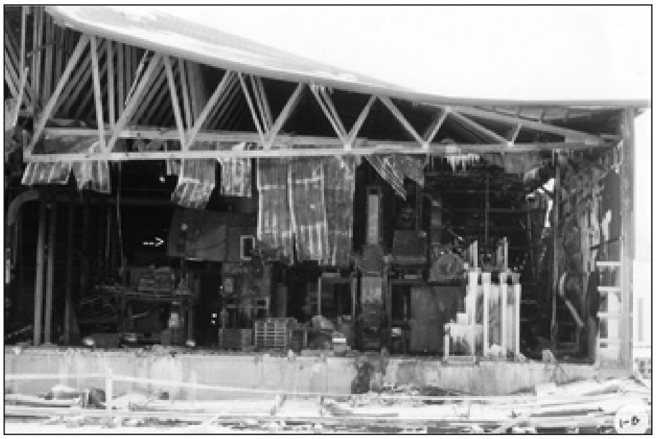

Figure 1 - Destruction from a Dust Explosion in a Paper Shredding Operation. An arrow points to the ruptured dust collector.

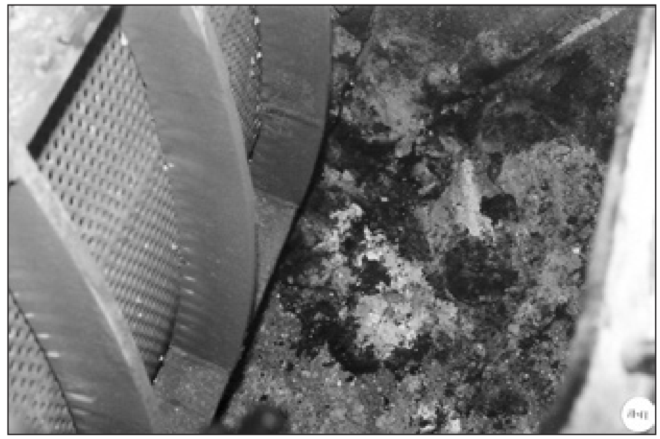

Figure 2 - Ignition Source Found to be a Smoldering Nest Within a Mill

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NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids, National Fire Protection Association

NFPA 68, Guide for Venting of Deflagrations, National Fire Protection Association

NFPA 69, Standard on Explosion Prevention Systems, National Fire Protection Association

ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dust

ASTM E 1491, Standard Test Method for Autoignition Temperature of Dust Clouds

ASTM E 1515, Standard Test Method for Minimum Explosible Concentrations of Combustible Dusts

ASTM E 2019, Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air

ASTM E 2021, Standard Test Method for Hot Surface Ignition Temperature of Dust Layers

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Machinery Maintenance and Temporary Bypassing of Safety Devices

by

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Until the advent of OSHA (Occupational Safety and Health Administration) in the early 1970’s, the field of safety was primarily focused on the safety of machine operators. Safety of the personnel who maintain and repair the hazardous moving machinery enclosed behind the safety guards was virtually unaddressed.

Often, an incompatibility exists between the safety guards and devices intended to protect equipment operators and the job responsibilities of machine maintenance personnel. After all, the job responsibility of maintenance personnel includes not only the repair and upkeep of the basic machine but also the safety devices.

Defeating Safety Devices – An Unsafe Practice or Necessary Procedure?

The removal of a safety device by a machine operator is usually considered an unsafe practice, especially if the motivation for removal is, for example, increasing the production rate to earn an incentive bonus based upon exceeding production quotas. The removal of the safety device by the maintenance mechanic, on the other hand, is a necessary step toward accessing the moving parts that require adjustment, replacement or lubrication.

The effectiveness of a first order safety device, such as a barrier guard, is often enhanced by the use of second order features such as a *Hinge* (which allows the guard to be opened without removing it from the machine) or an *Interlock Switch* (which interrupts power to the control system if the guard is moved from its protective position). The interlock will be used as an example for the purposes of this article since it is of special interest during maintenance procedures.

To the maintenance mechanic, the interlock represents another machine component that can fail and eventually will need replacement. It also represents an additional level of impediment with respect to accessing the mechanical parts where maintenance needs to be performed. When troubleshooting, it is often necessary for a barrier guard to be removed in order to observe equipment in operation. If the barrier guard is equipped with an interlock, the interlock must also be disabled so that the machine will operate during the diagnostic process. If the interlock switch itself is suspected of being the source of trouble, the interlock must be bypassed as part of checking its function. If the machine operates properly with the interlock bypassed, but fails when the interlock is enabled, then the interlock has been successfully isolated as the source of the trouble. The maintenance mechanic then proceeds with equipment shutdown and repair or replacement, as required, of the interlock.

Permission is Given to Maintenance Personnel to Defeat Safety Devices

OSHA recognizes that troubleshooting malfunctioning equipment sometimes means that maintenance personnel must bypass an interlock in the performance of their trade:

> Interlocks. Only a qualified person following the requirements of paragraph (c) of this section may defeat an electrical safety interlock, and then only temporarily while he or she is working on the equipment. The interlock system shall be returned to its operable condition when this work is completed.[1]

Machine operators are likely unaware of the hundreds or thousands of times a safety component, such as the interlock, has prevented an injury when the interlocked barrier guard is routinely opened to feed and remove stock from the point-of-operation of a production machine tool. However, when maintenance is performed, service personnel are not allowed to rely upon the interlock to prevent machine movement. OSHA explicitly prohibits this practice:

> The circuits and equipment to be worked on shall be disconnected from all electric energy sources. Control circuit devices, such as push buttons, selector switches and interlocks, may not be used as the sole means for deenergizing circuits or equipment. Interlocks for electric equipment may not be used as a substitute for locking and tagging procedures.[2]

In the course of performing maintenance, all safety guards and devices are subject to bypassing when it is necessary to troubleshoot and isolate the cause of a malfunction. In 1984, the *Safety Standard for Mechanical Power Transmission Apparatus*, ANSI/ASME B15.1, recognized the need for maintenance personnel to perform this activity otherwise considered an unsafe practice for machine operators:

> Exceptions – Servicing/Maintenance. When safeguards must be bypassed during startup, setup, repair, adjustment or maintenance, only personnel who are trained and aware of the hazards shall be allowed access to an unprotected area.[3]

Similarly, the National Safety Council recognized the special needs of machine maintenance personnel:

> General Machine Safety Instructions – Adjustments and Trouble-shooting
> 2. During debugging, adjustment, check-out and certain troubleshooting, it may be necessary to remove guards to observe machine functions…[4]
>
> Troubleshooting with power on. – When necessary to locate and define problems with power on, the employee has authority to work on machines or equipment with guards removed, or to work in areas protected by barriers, if such action will not place any part of his body in the path of any movable machine or equipment element. A machine or piece of equipment may have to be stopped, locked out, or put in ZMS before removing a guard or barrier so that the machine or equipment may subsequently be observed with power on.
>
> -and-
>
> Defeating protective devices. – The employee shall not remove, bypass, or alter any device that was provided to reduce hazardous conditions, other than temporarily, when necessary for maintenance purposes.[5]

What Constitutes Maintenance?

Maintenance activities include much more that troubleshooting, repair and replacement of machine components. OSHA defines maintenance and servicing activities to include:

> "…constructing, installing, setting up, adjusting, inspecting, modifying and maintaining and/or servicing machines or equipment. These activities include lubrication, cleaning or unjamming of machines or equipment and making adjustments or tool changes where the employee may be exposed to the unexpected energization or startup of the equipment or release of hazardous energy."[6]

When is an Individual Authorized to Perform Maintenance?

Machine operators who are not responsible for or not qualified to carry out maintenance should be instructed to summon qualified maintenance personnel when it becomes necessary to perform any of the activities that constitute maintenance. OSHA does not recognize machine operators whose job duties do not involve performing maintenance activities as "Authorized" to perform maintenance.

Machine operators who are expected to perform maintenance tasks must undergo training provided and documented by their employer before they are allowed to conduct maintenance activities. Only then will OSHA recognize these individuals as "Authorized" to perform maintenance. Basic training and employer documentation requirements are outlined in OSHA's Lockout/Tagout regulations, 1910.147. Even if machine operator's maintenance responsibilities are limited to lubrication and unjamming, for example, employer training is required. This training should include recognition of the limitations of the employees' responsibilities. Maintenance activities that go beyond the tasks for which the employee has been trained need to be forwarded to the maintenance department or other more appropriately trained and qualified personnel.

Removable Safety Devices is Usually a Design Necessity

Machine designers must provide safety guards and safety devices which can be removed and/or bypassed. Although this may sound like an undesirable feature for safety equipment, it is necessary so that safety equipment can be maintained and machines can undergo troubleshooting by qualified personnel. It is not possible for the machinery behind the guard to be repaired if the maintenance person cannot access it behind the guard. Similarly, in an effort to troubleshoot a machine, the safety device(s) may need to be bypassed so the repair technician can observe the moving parts of the machine in action without being obstructed by the guards. Hence, an "un-bypassable" safety guard or device can be considered defective if it makes the machine or equipment un-maintainable.

It is also recognized that some industrial equipment contains safety devices that are enabled solely during maintenance procedures. The mechanical power press with dual inching buttons used during die set-up is such an example. Of course, the machinery maintenance worker is expected to be diligent enough to not disable devices provided specifically for his own protection.

Too Easily Bypassed or Defeated is Undesirable

On the other hand, the ease at which a safety guard or device can be removed or bypassed is an important design consideration. For example, machine operators should not be able to defeat a safety feature without the use of a tool. The tool required should not be an item that is part of the machine operator's ordinary job activity. The use of a tool to remove or bypass a safety feature often demonstrates intent on the part of the individual performing the task.

Not all guards, on the other hand, require fasteners to secure them in their protective position and may be removable without the use of a tool. Ease of guard removal and re-installation can be a very desirable feature when primarily maintenance personnel are expected to interact with a machine. An example is the hood covering an automobile engine.

Automatic Equipment

Not all machinery and equipment requires a human operator to perform its intended function. Automatic equipment, for example, is a class of machinery for which no operator is required. Even though maintenance personnel must be able to access the moving parts, adequate guarding remains necessary. Inter-airport transportation systems serve as an example. There is often no operator or conductor running the train or bus, but the equipment is utilized by the general public. The importance of adequate guarding and safety devices is obvious.

Restoring Safety Devices is Part of the Maintenance Procedure

Maintenance personnel are required to replace and re-enable safety guards and devices before releasing equipment back to the machine operator or returning it to service. It is unsafe and unacceptable for safety equipment to remain in a disabled state at the completion of a maintenance task:

> **Maintenance practices.**
> If guards must be removed for convenience in making repairs, the job cannot be considered complete until the guards, plates, and other safety devices have been replaced.[7]

Machine operators and equipment users often become accustomed to the protection afforded by a safety device. When this dependency is violated by an incomplete maintenance procedure, a ripe condition for an accident has been created.

Summary

1. The community of users that includes machine operators and the community of users that includes maintenance personnel often have opposing needs when it comes to safety equipment. These needs become more complex when the same individual is a member of both communities.
2. It is the combined responsibility of machine operators, maintenance personnel and supervisory personnel to confirm the function and usage of safety equipment.
3. Temporary discretionary bypassing of safety guards and/or devices is acceptable among qualified members of the machine maintenance community.
4. Safety guards and devices on mechanical equipment generally need to be bypassed for maintenance purposes. If the safety equipment were "un-bypassable," a maintainability defect may exist. On the other hand, the ease at which safety devices can be bypassed is a design consideration often based upon the community of intended users.
5. As part of employee training, employers are encouraged to distinguish employees who are not "Authorized" to perform maintenance activities from those who are "Authorized" in accordance with OSHA guidelines. Non-authorized employees must be trained to summon

qualified maintenance personnel not only for repairs, but also for lubrication, unjamming, setting-up, etc. All "Authorized" employees must be qualified or trained in Lockout/Tagout procedures.

6. Maintenance procedures are not complete until the safety guards and devices have been restored. Only then is it acceptable to return equipment to active service or to the control of the machine operator.

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2. 29 CFR 1910.333(b)(ii)(B)
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4. *Accident Prevention Manual for Industrial Operations*; Engineering and Technology; National Safety Council, ninth edition, 1988; pg. 199
5. *Accident Prevention Manual for Industrial Operations*; Engineering and Technology; National Safety Council, eighth edition, 1980; pg. 289
6. 29 CFR 1910.147(b) *Servicing and/or maintenance*
7. *Accident Prevention Manual for Industrial Operations*; Administration and Programs; National Safety Council, ninth edition, 1988; pg. 453

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Case Study: Tipover of a Self-Propelled Elevating Work Platform

by

R. Kevin Smith, P.E.

The stability and design for safety is examined for a self-propelled elevating work platform, scissor type. Many times a strict reading of a safety standard applying to a product is not enough to fully understand the intended spirit and safety goals that went into its development. In fact, language that appears in some safety standards is misunderstood and misused by engineers and product designers in the development of a product, sometimes resulting in serious safety deficiencies. Some safety standards attempt to prevent misunderstanding by providing explicit or implicit rationale into the standard. Often, current members of safety standards committees must deal with frequent requests for interpretation, and are at a loss when asked to give rationale for language that was developed decades earlier. It is important to understand the true spirit of the safety concepts that a safety standard is intending to address in order to avoid design pitfalls that can result in hidden safety defects.

In the subject case, a self-propelled elevating work platform tipped over after it was set up on a smooth, level concrete surface. The unit was a scissor type, and was rated for use on rough terrain. Rough terrain use is facilitated by employing a center-sprung axle, which allows the axle to rotate when the unit is driven over rough terrain. With the platform fully lowered, the axle is free to rotate. When the platform is raised above a certain level, the axle locks to provide greater stability. The unit contained four outriggers, one at each corner of the base, which need to be lowered and pressurized before lifting above a certain height is allowed. In addition, the unit needs to be leveled within a certain range before lifting above a certain height is allowed. Check valves were incorporated into each of the four outrigger cylinders to prevent cylinder/outrigger collapse in the event a hydraulic line failed. All of these features were designed into the unit in order to meet the general goal of maintaining stability during use. However, in spite of all of these features, the unit tipped over when elevated on a perfectly smooth surface, and being used according to all of the manufacturers instructions.

The nationally recognized safety standard for self-propelled elevating work platforms at the time of the unit's manufacture was ANSI A92.6 – 1990, and two different sections applicable to stability read as follows:

> ***4.8.2 Stabilizing Devices.*** *Aerial platforms requiring the use of outriggers, stabilizers or extendable axles to meet the stability requirements of this standard shall be provided with interlocks to ensure that the outriggers, stabilizers, or extendable axles are properly positioned. Interlocks shall also prevent the improper retraction of these devices.*
>
> ***4.10.3 Unintended Retraction of Outriggers or Stabilizers.*** *Hydraulically or pneumatically actuated outriggers or stabilizers, or both, shall be so constructed as to prevent their retraction in the event of failure of a hydraulic or pneumatic line.*

The features that were incorporated into the hydraulic circuit, in order to attempt to comply with the letter of the standard, were four outrigger cylinders, each equipped with pilot-operated check valves at the cylinder to prevent collapse of the cylinder "in the event of failure of a hydraulic or pneumatic line". Pressure switches in the lines were interlocked with the lifting controls in such a way that pressure was required in each of the four outrigger cylinders before lifting above a certain height was allowed.

Several safety concepts were overlooked however, in the implementation of the safety systems calculated to prevent tipover of the unit.

Although the work platform was designed to be operated over rough terrain with the platform lowered, it was also designed in such a manner as to allow the outriggers to be extended well below the plane of the tire/ground interface. This allows the operator to set up the unit on extremely rough terrain, using the outriggers to level out the unit. There was nothing designed into the circuit to turn off outrigger extension once the pressure in the cylinder was sensed. In the subject incident, the operator, while on a perfectly flat, level surface, extended the outriggers fully, lifting the platform and tires well above the concrete surface. In the subject instance, the operator thought he was being safe by extending the outriggers fully, effectively leveling the unit perfectly.

However, the failure of a single pilot-operated check valve seal, located in the hydraulic line to the outrigger cylinder, allowed hydraulic oil to pass from the outrigger cylinder back to the hydraulic tank, resulting in outrigger collapse on one corner, and subsequent platform tipover. The hydraulic schematic for the subject work platform reveals a path for hydraulic oil to flow, in the event of check valve seal failure, from the pressure side of the outrigger cylinder back to tank via the pilot line vent circuit. Given the existing design which allows for the work platform to be lifted off of its tires so far as to rely solely on the integrity of the hydraulic system to prevent tip over, a single mode failure such as a check valve that produces such a catastrophic event is unacceptable. There were no mandatory maintenance intervals for the replacement of the check valve seals, and the condition of the seals was undetectable without their removal for inspection. Mechanical interlocking to prevent retraction is necessary if the manufacturer finds it necessary to provide unfettered outrigger cylinder extension. For example, in the automotive industry, it is well recognized that an automobile lifted with hydraulic jacks must always be mechanically blocked to prevent collapse of the jack and automobile. Hydraulic lifts, which are used to lift vehicles for service, are required to have mechanical locking devices to prevent unintended collapse of the vehicle. Certainly, lifting personnel 19 or more feet up into the air necessitates the same level of safety. By becoming familiar with the safety concepts and requirements presented in other safety standards covering similar components and safety goals, developers of safety standards can evaluate whether or not a transfer of safety technology is desirable for their standard.

Poorly worded safety standards can result in products that not only do not meet the spirit of the code, but that can present dangers that would otherwise have not existed. While in the subject case a careful reading of the safety standard reveals the true spirit of what is intended (the improper retraction of the outrigger), its true safety intent was not met with the current design. The manufacturer contended that the unit met the safety standard because the check valves met the specific requirement of preventing outrigger retraction in the event of the failure of a hydraulic line. However, the pilot operated check valve, while not a "hydraulic line", is clearly part of the hydraulic system intended to prevent **unintended outrigger retraction**, which is the safety concept that the designer should have addressed. In fact, the way the check valve was implemented into the hydraulic system allowed a single seal failure to vent hydraulic oil to the tank, essentially creating a new hazard. It has long been recognized that a safety device should not, in and of itself, present a new hazard.

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Human Factors / Ergonomics: Some Basic Concepts

by
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This paper on Human Factors is written as a survey paper to introduce some of the basic concepts of human factors, to provide a better understanding of the role human factors plays in safe equipment design, and to highlight how human safety performance is in part based on human factors theories and mechanisms.

What is Human Factors? Human Factors Engineering?
The website (www.hfes.org) of the Human Factor's and Ergonomics Society (HFES) describes Human Factors/ Ergonomics in their introductory text as the study of:
"…human cognitive and physical capabilities and then applying the knowledge gained from that research to systems, tools, products, and environments"
to…" *help to ensure that people's interactions with technology will be productive, comfortable, and effective."*

One of the key basis human factors publications "Human Factors Design Handbook," by W. Woodson (1992) describes the area as:
".. the intent of human factors engineering on the whole is to focus on and resolve human-product interface problems and solutions wherever or whatever they are. Philosophically then, human factors engineering looks at a design from the standpoint of user efficiency, or total human-product effectiveness."

What is the difference between Human Factors and Ergonomics?
In a general sense, there is no meaningful difference between the two terms, other than in their origins and academic usages (and therefore we will use the term "human factors" to refer to both terms in the balance of this article).

The term "ergonomics" has its origins in Europe, whereas the term Human Factors was more commonly used in the Americas. In the early years of the development of this area, there was some separation of the two terms, mostly in the context of professional societies and journal terminology; but in the last two decades the terms have been used interchangeable and the primary professional association (HFES) has incorporated both terms in their name. In some academic circles, the term ergonomics may have a greater association with industrial situations, but has been broadened to include "consumer products, the home, road traffic and safety."[1]

While these two terms have merged together, there is some natural division between: 1) the terms and measurements associated with humans, and 2) the cognitive actions of people in negotiating their environment.

Human Dimensions vs Cognitive Actions; Are They a Part of Human Factors?

Some of the early and basic concerns of human factors addressed the size, magnitude, and physical dimensions of humans, and their needs, not the cognitive basis for human actions.

In the Eastman Kodak publication from the early 1980's "Ergonomic Design for People at Work", an emphasis is placed on the physical parameters of humans in terms of ".. *striving to assemble information on people's capacities and capabilities for use in designing jobs, products, workplaces and equipment."*[2]

Publications like "Humanscale"[3] and the extensive U.S. government's library of measurements of military and service personnel support the importance and continued utility of knowing how big, small we are; how flexible and strong we are; and how our environment needs to be dimensioned for safety and efficiency reasons. This collection of information is often referred to anthropometry and is the basis for the size of buttons to the height of handrails.

Such dimensional information may be useful when performing such tasks as designing a seatbelt to accommodate both the 5%tile and 95 %tile height of car users. (Note: In this context, 5%tile represents a size where only 5% of the population is smaller; 95%tile represents a size where 5% are larger). Numerous other data sets contain 5 and 95%tile data for a broad range of humans. Hand dimensions, for example, are the basis of determining the opening sizes allowed in OSHA approved guards.

These dimensional considerations mean it is important to remember that a railing that is too low and not in compliance with an OSHA rail code, may be the perfect height for a person of short stature.

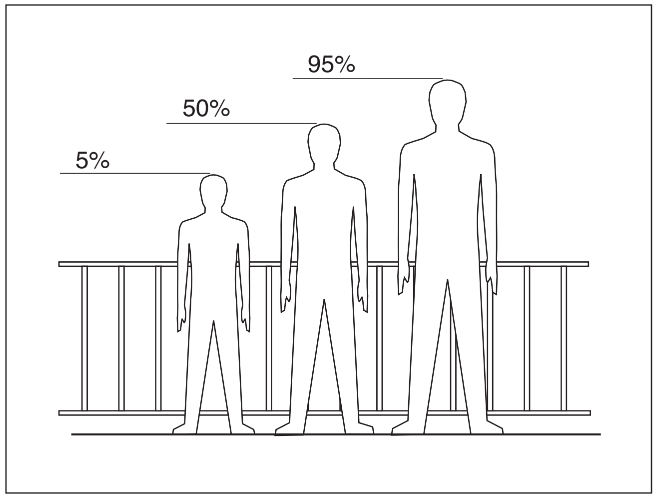

Fig. 1 "Standard" height railing may not be the best height for different height people.

"Cognitive Action" concepts in human factors most often refer to the mental/ logic nature of humans; that is not just how well we see, but how well we can detect a target by vision; not just the warning on the equipment, but how we understand the meaning of the warning; not that we simply made a safety decision but if it was the appropriate decision. Wickens, in the second edition of "Engineering Psychology and Human Performance"[5] , dedicates twelve chapters to cognitive aspects of human factors; including issues ranging from perception to human errors. Mark Sanders, et. al., merges both the dimensional and cognitive in "Human Factors in Engineering Design."[6] with chapters on human error, accidents, and safety.

In many ways these "cognitive actions" and their impact on both worker and user safety are the more interesting issues in human factors from a safety perspective. With the increased dependence on OSHA "procedural" safety criteria[7], an appreciation of these cognitive human factors considerations is more important for equipment designers, providers, and are appearing in various code text.

The recent edition of the National Fire Protection Agency (NFPA), for example, provides criteria in NFPA 79, "Electrical Standard for Industrial Machinery" on several human factors issues of perception, mental modeling, consistency, and compatibility. Paragraphs; 3.50) defines "insight" distances; 3.74) a "safe working procedure"; 4.3.3) the need for "block diagrams" to facilitate the mental understanding of the equip-

1 Etienne Grandjean, " Fitting the Task to the Man", Taylor and Francis, 4th Edition, pg ix
2 Eastman Kodak Company, "Ergonomic Design for People at Work", vol. 1, Van Nostrand Reinhold, 1983
3 N. Diffrient, et,al., "Humanscale" MIT Press, 1983
4 G. Hutter, " Safeguarding Machines with an Ergonomic Spin", Stamping Journal, an FMA Publication, June 2004
5 C. Wickens, et. al., "Engineering Psychology and Human Performance", Harper Collins, 1992
6 M. Sanders, et. al., "Human Factors in Engineering and Design", 7th Edition, McGraw-Hill, 1993
7 OSHA 29CFR 1910. Example sections on Confined Space, Lockout & Tagout; Multi-employer Safety Responsibility

ment; and 7.8) the consistent location "mounting" of disconnecting means. In several recent machine accidents, the lack of a consistent human factors approach for electrical disconnects, resulted in workers relying on emergency stop controls for lockout and tag out safety.

Exemplar Human Factors Concepts based on Cognitive Skills

A) Avoidance Behavior

A significant percentage of equipment users will "learn" to avoid hazards that they can appreciate. This "learning" can be in the form of "instructional training", and/ or "experience (hands on) training". Some tasks can be only taught through an introductory training effort, while other activities require hours of experienced-based training. The necessary avoidance behavior to safely operate a car cannot be fully taught in a instructional classroom, and requires the actual behind the wheel experience training. Both learning processes take time, and are key components in preventing injuries to workers who are new on the job. It is reasonable to expect workers to avoid dangers if they have the incumbent training and experience with the specific hazard, and OSHA's "General Duty Clause" requires employees to follow their safety training and recognize and avoid hazards. Hahn[8] conceptualizes this "avoidance of hazards" behavior in terms of an "avoidance gradient" where the avoidance behavior changes as one approaches a negative goal. Just as a college student may work harder in the last days of a semester in an attempt to prevent a poor grade; workers tend to put more attention assets into recovering from a bad situation, as that situation continues to deteriorate.

B) Compatibility/ Incompatibility.

Sanders[9] defines "compatibility" in terms of human expectations; humans have certain expectations, and when processes and/ or equipment does not follow these expectations, an incompatibility problem may manifest itself in an error or accident. He simply states "…people like things that work the way they expect them to." When electrical plugs and receptacles do not match because of a 3-prong configuration, or flared prong, there is an incompatibility problem. Sometimes "incompatibilities" are resolved by unsafe behaviors, like the removal of a grounding prong. The lack of a convenient lockout and tagout (LOTO) location on a large machine may result in an incompatibility problem and alternatives to LOTO may tend to be employed. Incompatibility can cause accident causing behaviors; designs incorporating compatibility can result in fewer errors.

C) Consistency/ Inconsistency

Consistency is a sub-element in user expectations. Even if a design does not always match user expectations (see below), the repeated exposure to a particular consistent configuration offers some safety characteristics. Hence e-stops which are color-coded "red." Mixtures among safety configurations/

Fig. 2: Lumber mill conveyor lockout/tagout with tags available.

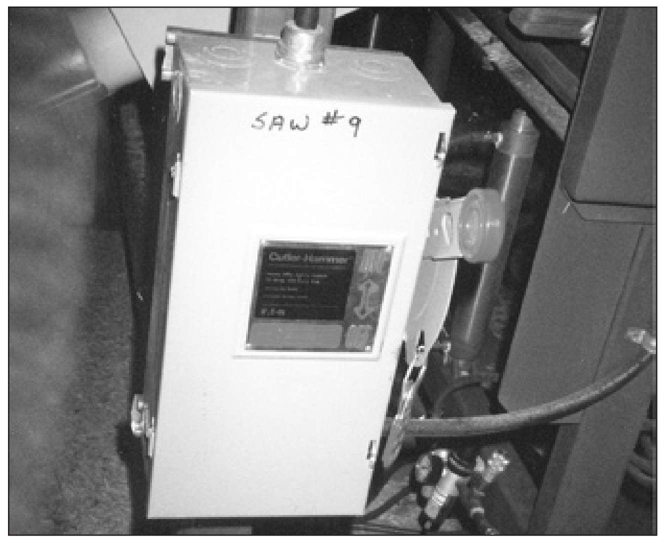

Fig. 3: Traditional lockout/tagout box with lever and hasp for lock (used on industrial saw).

Fig. 4: Lockout/tagout supplies.

[8] J Hahn, "An Introduction to Psychology", Doubleday, 1962, pg 142-144
[9] M. Sanders, et.al., "Human Factors in Engineering and Design", 7th Edition, McGraw, 1993, pg 58-61

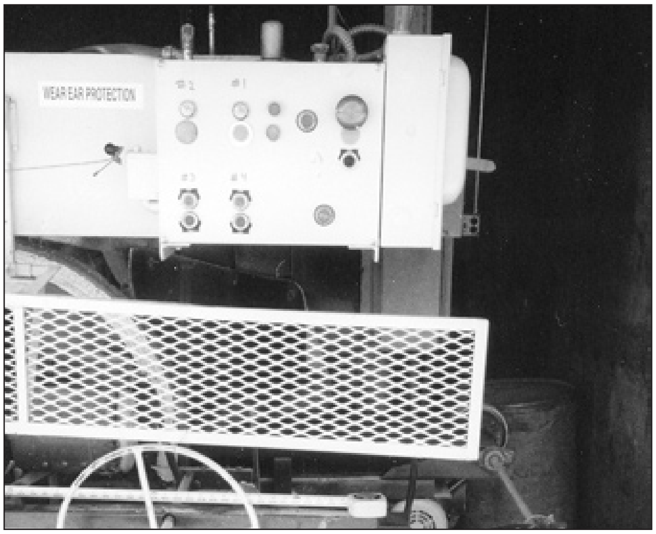

Fig. 4: Lockout/tagout adjacent to controls on large industrial saw.

hardware can result in some additional accident scenarios. In a family with a mixed fleet of cars, there is the common problem of inconsistency in control location, horn actuation points, and brake responses. In an industrial setting, there are possibilities of hazards not being consistently protected by interlocks or other safeguarding methods. A fleet of different machines each with different codes requirements about interlocks could set up a condition where workers become habituated to relying on interlocks; then encounter a non-interlocked hazard and become injured. One might question if, for consistency reasons, ground fault circuit interrupters (GFCI) should be used in bathroom wall outlets; or rather on electrical appliances used in bathrooms.

D) Decision Making

Equipment and product designs should facilitate good/ safe "decision making" by users and consumers. Appropriate safety decision making can be affected by time delays, distractions, or the misunderstanding of displayed information. Several codes and guidelines for safe design of equipment focus on providing means and facilities for good decision making for operators. For example, designs that provide timely and meaningful information can prevent accidents. In a recent accident investigation, the operator of an asphalt plant needed to remember the size of the discharged load because it was only temporarily displayed at the control panel. A truck driver would position his vehicle under the discharge silo and if the operator forgot the size of the load, and the equipment could not re-display the load size, an overloading accident was inevitable.

E) Expectations (Reasonable & Unreasonable)

If people had to evaluate each and every action they took, we would become mired down in evaluating every situation. Therefore, people have developed sets of experiences (sometimes referred to as schemas) which allow them to generalize when confronted with a situation. This generalization results in certain expectations. Increased experience typically results in our ability for more and better generalizations. Experiencing unusual conditions can result in more complicated, and perhaps better defined generalizations. Examples: If we encounter a large diameter rope, we expect that it will be stronger than a thinner rope. A knot is a rope is not necessarily perceived as significantly decreasing the strength of a rope. Users of rope need to know that the diameter of rope is not the determining factor in its strength; hence labeling of rope with tensile strength information is important. A single knot in a rope can have as much as a 33% reduction in rope strength.

F) Mental Models[10]

While expectations may be generalized appreciations of how things work; mental models are a person's concept of how a specific mechanism operates. In a recent dual carbon monoxide death; it appeared that the users may have had a mental model that the tent they were to sleep in was breathable, and hence any carbon monoxide produced inside the tent from a propane heater would be diluted and made safe by air infiltrating through the tent's walls. Mental models can be reinforced or altered based on experiences. A possible basis for such a notion of a breathable tent would be the thinness of the tent skin material, the ease with which exterior odors could penetrate into the tent, or the way sounds could permeate the skin of the tent. A mental model by the decedents as to the extent a tent's skin acted as a barrier may have been a significant explanation as to why they might consider a tent a "well ventilated" location. Terms like "meaningfulness" and "reinforcing" are used to describe how mental models may be supported or altered. Previous uses of the heater in a tent without consequences may have "reinforced" its use even though there was a written prohibition against such a use.

G) Recognition

Our ability to recognize certain features or conditions can enhance or detract from safety. A hidden sharp edge on a metal stamping may cause serious hand cuts because they are not easy to detect or even felt at the initial point of engagement. Having been exposed to "near" accidents can allow some individuals to better recognize hazards than more naive users might not appreciate. In situations where users may not "recognize" a particular hazard, signage and/or alarm mechanisms, for example, may provide added help. Signage and/or alarms also play a role in "reminding" users of already known hazards and/ or to changing conditions. Warnings signs may be less useful if the exposed individual already knew of the hazards, but the sign could be useful in a redundant fashion as a last effort to remind a potentially exposed individual of a hazard they may already recognize. Alarms can fool workers if their detection is confusing in noisy environments. Recognition influencing factors include: distractions, camouflage, haste, emergency conditions, and fatigue.

[10] Sallie Gordon, "Training Program Design", Prentice Hall, 1994, pg 51-54

[11] Neville Stanton, Editor, " Human Factors in Alarm Design", Univ. of Southhampton, Taylor & Francis, 1994

Closure

Our physical capabilities and geometry influence our personal safety status. There is a significant body of research into cognitive actions, such as how we engage hazards based on our perceptions, experiences, evaluations, and expectations. An improper matching of these cognitive actions can cause, be neutral to, or be preventative towards safety. In addition to dimensional human factors issues, designers and those responsible for equipment safety need an appreciation of both the dimensional and cognitive aspects of human factors.

Gary M. Hutter, Ph.D., P.E., C.S.P., is President of Meridian Engineering & Technology, Inc. located in Glenview, IL. He provides consulting services in certain aspects of safety, industrial hygiene, and engineering. He is an active member of the National Safety Council's committee on machine tool operations. He has been a co-author to the National Safety Council's publication on the safeguarding of equipment, and a co-author of an ANSI standard addressing Human Factors in equipment design . He can be reached at 847-297-6538 or 847-809-6538.

Codes and Standards Updates from the Authors

Dr. Hutter has recently been involved with the canvassing, voting and commenting on the following standards which may effect your products:

ANSI MH24.1"Safety Standard for Horizontal Carousel Material Handling and Associated Equipment" Version #6, second canvass round of balloting, Approval vote, October 2002

ANSI Draft "Draft Standard - The North American Performance Standard for Casters and Wheels," Version 17, January 2003, Institute of Caster Manufacturers, Charlotte, North Carolina. Approval Vote.

ANSI MH 16.1"Specifications for the Design, Testing and Utilization of Industrial Steel Storage Racks," Reviewer and solicited ballot by Rack Manufacturer's Institute/ Material Handling Institute of America, Jan 2004. Affirmative Vote w/ comments.

ASTM D3654-02"Proposed Revision to ASTM D3654-02" Revision of D3654/D3654M-02 Test Methods for Shear Adhesion of Pressure-Sensitive Tapes WK8405 Reviewer and solicited ballot by ASTM Packaging committee. Affirmative Vote, March 2005.

ANSI MH 30.1 "For the Safety, Performance and Testing of Dock Leveling Devices", July 2005 Draft Ballot MN30.1. Affirmative vote.

William G. Switalski has been active in the ANSI/ASC A14 Ladder committee since 1995. This committee oversees the following standards:

- A14.1 Portable Wood Ladders
- A14.2 Portable Metal Ladders
- A14.3 Fixed Ladders
- A14.4 Job Made Wooden Ladders
- A14.5 Portable Reinforced Plastic Ladders
- A14.7 Mobile Ladder Stands and Mobile Ladder Stand Platforms
- A14.10 Portable Special Duty Ladders

During the next year, A14.10 will be incorporated into the existing Portable Ladder standards, A14.1, A14.2 and A14.5, respectively. The A14.10 Portable Special Duty Ladder standard will then be withdrawn.

Upcoming new standards in the A14 series will include:

- A14.8 Portable Ladder Accessories
- A14.9 Ceiling-Mounted Disappearing Climbing Systems
- A14.11 Utility Step Stools

Interested parties can check the website of the American Ladder Institute, www.americanladderinstitute.org for the latest information on availability of standards and errata. Click the "Standards" link and then the "Standards FAQ" link."

R. Kevin Smith, P.E., has been actively involved in the development of the safety standard for low lift and high lift trucks since 1984. As of August 2005, the management of that standard, formerly known as ASME/ANSI B56.1 Safety Standard for Low Lift and High Lift Trucks, has been taken over by the Industrial Truck Standards Development Foundation. This Standard was reaffirmed by the B56 Standards Committee after references to ASME were changed to ITSDF. You can visit their website at http://www.itsdf.org

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