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Safety-related Machine Controls for Maintenance Risk Reduction

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Abstract

A well-rounded safety professional should be able to systematically communicate the fundamentals of safe machine maintenance. This means being able to:

- coordinate with electrical engineers and maintenance personnel to oversee the selection of controls, interlocks, and disconnects;
- evaluate with a vendor why their device does or does not match your safeguarding need;
- describe for your boss why a safeguard should be purchased;
- specify to your purchasing agent the exact kind of safety devices needed on a new machine; and
- help a line worker understand how to avoid doing something that could degrade the performance of a machine safeguard.

In this presentation, you will learn why a machine's start and stop control functions are vital for machine risk reduction evaluators to consider, especially as safer machine maintenance becomes a global concern. Specifying machine control devices that fit well with lockout procedures can help prevent an unexpected startup when machine maintenance personnel are in a dangerous location. Workers often forget, or are unaware, that when a jam partially stops a machine, restart may occur the instant the jam is cleared. Start and stop controls take two forms: human-operated devices (push buttons, foot switches, etc.) and built-in, automatic controls (sensors, safety devices, process control interlocks, etc.). The presentation will include: systematic methodology for evaluating sufficiency of safety measures; descriptions of the operating principles of machine safeguards; illustrations of applications they are suited for; and basic design analysis to verify that safeguards are suited for intended applications.

The following terms will be used in the problems presented:

Ds = safety distance

K = maximum speed that a person can approach a hazard

T = total time it takes to stop hazardous motion

S = minimum size object detectable by a presence sensing device

Ts = stopping mechanisms time to stop hazardous motion

Tc = control system logic execution time

Tr = response time of presence sensing device

Tspm = stopping performance monitor time

Dpf = penetration factor distance

Introduction

The consequences are often grim for maintenance personnel when, in the course of performing machine maintenance tasks, the machine starts up unexpectedly. A recent example illustrates what can happen.

A 44 year-old male maintenance repairman died when a piece of metal struck him in the chest. The victim was working on an ironworker punch press after he removed a jammed piece of metal from the punch assembly. The victim did not follow his employer's policies and procedures when removing the jam. The victim removed the front cover plate of the punch slide assembly without first de-energizing, locking out, or blocking the machine. The machine went through a punch cycle after the victim removed the cover plate. A piece of metal from the punch broke off and struck the victim in the chest. It is not known how the cycle was initiated (FACE, 2000).

Maintenance-related injuries are a subset within the total machine problem. Between 1996 and 1998, there were 464 occupational fatalities (an average of 155 per year) reported to the U.S. Department of Labor's Bureau of Labor Statistics involving caught-in-running-machines. For the 1995-97 period, there were 92,932 cases of nonfatal injury of this type involving lost workdays. The majority of these (65%) were in the manufacturing industry. The 1996 total incidence rate (cases involving days-away-from-work/10,000 full-time workers) for the manufacturing industry was 238.3 compared to 212.3 for all private industry. The rate for machine injury in manufacturing was 27.7 (11% of the total rate.)

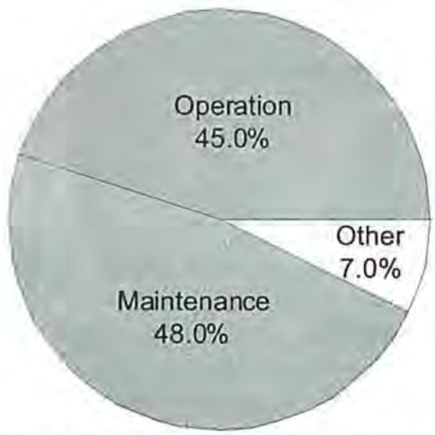


Figure 1. Activity performed by workers fatally caught in machines, 1997 (Source:Windau (1999))

Unexpected startup can have various causes: automatic restart; a person presses a cycle control button; another person turns the machine power on; or an interlock is cleared when stuck material is pulled free. This presentation is a review of principles for the selection, installation, and maintenance of controls for safer machine maintenance. The topics covered are: 1) *machine maintenance injury risk* with respect to the severity and probabilities of injury (risk) posed by the task(s); 2) *risk control devices* (safeguarding and safety-related controls) that can stop hazardous machine motion before injury can occur; and 3) *systematic risk reduction*, going into the selection of risk reduction measures that are reliable enough, by their design, installation, and expected use, for the severity and exposure probabilities of the task.

Lockout

The primary solution against dangerous restart of machines is lockout/tagout training and implementation (Grund, 1995). Lockout/tagout (required by OSHA Standard 29 CFR 1910.147) is the protective procedure workers must perform to remove hazardous energy from machines prior to performing maintenance and servicing tasks (Figure 2). Energy sources that could cause an unexpected hazardous event must be turned off or disconnected, and the disconnecting device, switch, or valve locked with a tag warning individuals not to use the machinery. All hazardous trapped energy must be released before working on the machine. As the first line of defense for protecting machine maintenance workers, lockout/tagout procedures must reliably account for how machines are shut down and put back into service. These procedures ensure that hazardous energy will not be released while a person is inside a machine; that is, with the hazard being eliminated before entry.

The OSHA standard (29 CFR 1910.147) for controlling hazardous energy

Six steps must occur, in the following sequence, prior to service or maintenance on machinery:

1. **Preparation for shutdown**: The authorized employee must know the type and magnitude of energy, hazards of the energy, and method or means to control the energy.

2. **Shutdown**: The machine shall be shutdown using orderly and established procedures.

3. **Isolation**: Electrical circuit interrupters or similar devices shall isolate the machine from the energy source.

4. **Lockout/Tagout device application**: Lockout devices shall be affixed to each energy isolating device by authorized employees unless tagout devices can be demonstrated to provide equal protection.

5. **Energy due to gravity or hydraulic pressure**: All potentially hazardous stored energy shall be relieved, disconnected, restrained, or otherwise rendered safe.

6. **Verification of isolation**: Prior to working on the machine, the authorized employee must verify that the machine has been isolated and deenergized.

Two steps must occur prior to machinery startup.

1. **No human exposure**: Verify that no one is in the path of hazardous machinery motion.

2. **Power on**: Remove lockout devices and operate controls to restore power to the machine.

Figure 2

For several reasons, more needs to be done to improve lockout/tagout compliance in industry. To begin with, in 2000, lockout/tagout violations ranked fifth on OSHA's top 10 list of most frequently cited standards (3,875 violations) and fourth on the top 10 list of serious violations (3,023 serious violations). A strict lockout requirement has its limitations. Defining and neutralizing all energy sources to achieve zero risk can create unrealistic or impossible maintenance tasks. Zero risk may not be attainable. Risks that remain need to be controlled. Another problem is that minor tool changes and adjustments, and other minor servicing activities, which take place during normal production operations, are not covered by the OSHA lockout standard. These tasks are routine, repetitive, and integral to the use of the equipment for production, and are not covered by the standard *provided that* *the work is performed using alternative measures which provide effective protection.* Lastly, lockout/tagout is a procedure that relies on human behavior. The steps in the procedure must be performed correctly every time. Safety behavior management tries to influence actions that an individual can take to separate themselves from hazardous energy. In such situations, when workers are putting their safety on the line, they can be asking themselves, "Will this safety measure always work?" If it does not work, then how bad are the consequences? But the shortcomings of behavior lie with the unconcern, ignorance of danger, and forgetfulness of people.

Ultimately, safety engineering can provide designs and devices that prevent the worker and the energy from coming in contact with one another. As an example, on a long conveyor line a worker may have to walk a great distance to reach and apply a lock to the electrical disconnect. A safety engineering alternative could be high reliability, lockable emergency stops at intermediate locations along the line. The main controller could also have indicators to identify which stop has been actuated.

Determining if task risks are acceptable

Let's evaluate how safety engineering approaches to eliminating maintenance injuries may complement a good lockout program. We will use risk assessment to communicate how risks can be acceptably controlled. Determining the level of maintenance risk for which different safety-related controls can be effective is part of risk assessment. Selection and use of individual safety components must fit within a comprehensive risk reduction scheme.

Four task-risk categories of protection have been established in the consensus safety guideline ANSI B11-TR3 "Risk Assessment - A Guideline to Estimate, Evaluate and Reduce Risks Associated with Machine Tools." In the guideline, risk is evaluated, via a risk assessment matrix, as a combination of probability and severity of injury. The principles developed are of interest for the safety of machines in addition to machine tools. The US approach places more risk reduction responsibility on the machine user than European machine risk levels and associated protection.

The first step in risk assessment is to list task-hazard pairs with the help of operating and maintenance personnel. Then, consider the details of potential injury severity and probability of injury. The severity of maintenance injuries can be comparatively high, with amputation or fatality being possible outcomes. The probability of occurrence in assessing the risks of a task (Figure 3), relates to

Factors considered important in estimating the probability of occurrence of harm

- exposure to a hazard
- personnel who perform tasks
- machine/task history
- workplace environment
- human factors
- reliability of safety functions
- possibility to defeat or circumvent protective measures
- ability to maintain protective measures

(ANSI B11-TR3, 2000)

Figure 3

whether too many factors increase the probability of harm. If they do, then there is reason to alter the process by introducing safeguards. Knowing past injuries and current tasks can give insight on whether there are injuries waiting to happen.

As an example of the use of risk assessment, consider the analysis in Figure 4. It leads to the risk assessment matrix in Figure 5 that indicates a "medium" risk. If the process itself could be changed so that the severity of harm could be reduced below the "catastrophic" level, then it might be possible to reduce this task risk to "negligible". However, that may not be an option, so safeguarding alternatives should be investigated to see if the risk can at least be reduced to "low".

Initial Risk Assessment

Maintenance task: The task is to clear a part that has jammed in the die of a mechanical power press. The press has 25 ton capacity and is equipped with a part revolution clutch. The reason that the part has jammed is that a piece of scrap was in the die when the next part was struck. A foot control is used to actuate each stroke. The safeguard being used is a polycarbonate barrier. The barrier must be removed to perform the clearing task.

Hazard: Closure of the die.

Potential Severity: Amputation of the hand - catastrophic.

Probability of occurrence of harm:

Factor important in estimating probability	Estimated probability	Reason
exposure to the hazard	likely	they sometimes reach in
personnel who perform tasks	unlikely	well-experienced
machine/task history	unlikely	but, presses are high frequency in BLS data
workplace environment	unlikely	a strong emphasis is placed on the safety program
human factors	likely	can be in a hurry
reliability of safety functions	likely	from observation, lockout is only used 50% of the time
possibility to defeat or circumvent protective measures	likely	easily circumvented
ability to maintain protective measures	likely	supervision is busy with many responsibilities

Figure 4

Initial Risk Estimation Matrix

	Severity of Harm			
Probability of Occurrence of Harm	**Catastrophic**	**Serious**	**Moderate**	**Minor**
Very Likely	High	High	High	Medium
Likely	High	High	Medium	Low
Unlikely	Medium	Medium	Low	Negligible
Remote	Low	Low	Negligible	Negligible

Now that the risk has been assessed, the goal is to see if risk can be reduced from "medium" to "low".

Figure 5

RISK REDUCTION STRATEGIES

A fundamental tenet of risk assessment is to see to it that high risk tasks, such as workpiece or scrap jam-clearing, are matched with high reliability protective measures. The hierarchy of risk control measures is to 1) eliminate the hazardous task; i.e., no jams or fewer jams; 2) provide a well-engineered safeguard; i.e., not easily bypassed; and 3) train. If training is to be used, *it must be highly reliable.* Well-trained and supervised personnel can be a solution. Unfortunately, they are often the weakest link.

Because of these shortcomings with the training solution, the two strategies that are higher on the risk control hierarchy warrant further consideration. NIOSH and industry partners, within the framework of the National Occupational Research Agenda (NORA), have developed priorities for finding such alternative measures (NIOSH, 1998). The NORA Traumatic Injury research agenda calls for:

1) designing workplaces, machines, and equipment to remove the possibility of making unsafe choices or actions (engineer-out hazards); and
2) in designing and modifying workplaces to improve safety, "passive controls," those which do not require choices or actions by workers in order to be protective, should take priority over "active controls," which require workers to take action or change behavior.

Because countermeasure operational characteristics and limitations should be reviewed, the next section will look at potential flaws to be aware of.

Some safety-related machine controls that may reduce maintenance risk

Safety devices and safety-related controls can enhance maintenance safety. Presence sensing safeguarding devices can detect when a person is in a dangerous location and initiate stopping, or not let the machine start a cycle. Electro-optical presence sensing devices, scanning devices, and mats are in this class of safeguard. Two-hand devices are safeguards that require contact with the actuator. Stopping during the hazardous motion of the machine is initiated when contact with the actuating means is released.

Safeguarding Devices

As was stated earlier, lockout is not required when there are frequent interventions into the hazardous areas of the machine. In these cases, maintenance and trouble-shooting are being performed with power available. To provide maintenance worker protection, machine safeguarding devices can be used. These devices rely on a machine's control circuit to either not let the machine cycle start or stop motion before human contact. Human approach or entry into dangerous areas can be detected by sensors, or kept at a safe distance by location of manual controls (ANSI B11.19, latest revision).

Presence sensing devices

These devices generate a sensing field that detects an interruption by a person or object. They are installed and adjusted to initiate stopping of hazardous motion before someone can reach the hazard. They only are applicable on machines that can be stopped anywhere in its cycle. There are two main types: electro-optical and capacitance (radio frequency (RF)). Both types require a safety distance from the hazard which is the distance at which they signal the machine to stop when interrupted (Etherton et al., 1982). Presence sensing devices have several limitations (Figure 7).

Electro-optical principle of operation

Usually, a plane of light is established between a light source (or a line of sources) at a fixed location and a receptor (or a line of receptors) that detects the light emitted by the source.

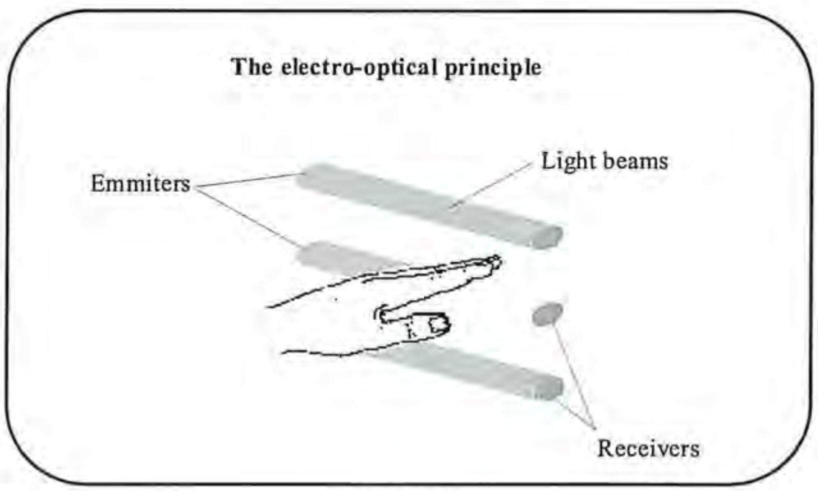


Figure 6

Capacitance principle of operation

For capacitance devices, an electromagnetic field is established by an antenna placed near the hazardous location. A certain amount of human intrusion beyond the set distance triggers a stop signal to the machine control.

HAZARD	CONTROL
An object arrives at the point of danger before the machine can stop or danger is eliminated.	Install and maintain the device so that it provides a safe distance between the effective sensing plane and the hazard. This distance (Ds) should be greater than the rate of hand movement toward the danger zone (K) times the stopping time of the machine (T) [Ds=K x T].
An object enters the danger zone through paths not covered by the sensing plane either outside its perimeter or through purposefully created gaps in areas of coverage.	Install fixed guards which conform to OSHA's safe opening criteria (See CFR 1910.217, Table 0-10). Guards should be placed over areas not protected by the safety device and when gaps are made in the sensing plane (blanking). The safeguarding should be moved to a greater distance due to the change in object sensitivity.
An object is between the sensing plane and hazard.	Install obstacles or other presence sensing between the device and the danger point so that a person cannot walk or stand between them.
An object is too small to be detected.	Select a device for which the smallest hand that might be working near the hazard will be detected.
The sensing plane is moved or distorted during machine operation.	If the location of the effective sensing plane can be adjusted by a sensitivity control on the device, select a device that generates a sensing plane which cannot fall short of the necessary safety distance once a sensitivity adjustment has been made.
The input signal is simulated while an object is in the sensing plane.	Select devices whose function is not degraded by ambient environmental factors such as light and electromagnetic radiation sources.
An object reflects the signal.	Select devices that provide some method for discriminating between operational signals and reflected signals.
No power is available to the device.	Install the device so that power is assured by locked power supplies or interlocks which prevent machine use if device is not operational.

Figure 7. Limitations with Presence Sensing Devices

Cross-sensitivity to inputs other than human presence should be evaluated. Fluctuation in the sensitivity of a RF field should be accounted for in setting safety distance. These fluctuations can be due to other objects entering the field or changes in the grounding of the protected person. At maximum cross-sensitivity, no holes should exist.

Safety mats

A safety mat is a type of presence sensing device that detects a person standing on or stepping onto it and signals hazardous motion to stop. They should be fixed to the floor; large enough not to be stepped over; and initiate stopping before someone stepping toward the hazard at a normal speed can reach the hazard.

Area Scanners

This device uses a rotating laser to map the location of objects that are normally in the area it sweeps. Distances are defined by the time it takes a reflected laser beam to return to the device. People who step into the area being swept are detected as an object that was not in the originally mapped area. The machinery control is then signaled to stop.

Two hand control

This type of device usually is comprised of machine initiation palm buttons that are a safe distance from the point of operation. After releasing the buttons, distance is so great that someone cannot reach the point of operation before the hazardous motion has stopped or the hazard is closed. The safety distance that is used equates a reach time based on hand speed (1.6 to 2 m/sec depending on waist-level or shoulder-level button location (Pizatella and Moll, 1987)) to machine response time (control signal processing time + braking time). Both buttons are pressed almost at the same time, e.g., within 500 ms of each other, and the release of either button should stop the machine during hazardous motion. Two hand trip is used on machines that cannot be stopped during a cycle. In two hand trip safeguarding, the distance between buttons and hazards must be great enough to prevent hazard contact before the hazardous portion of the machine's cycle is completed. A variation on the use of push buttons is using two sensing type devices that actuate the machine when each hand is on or near its respective sensing pad.

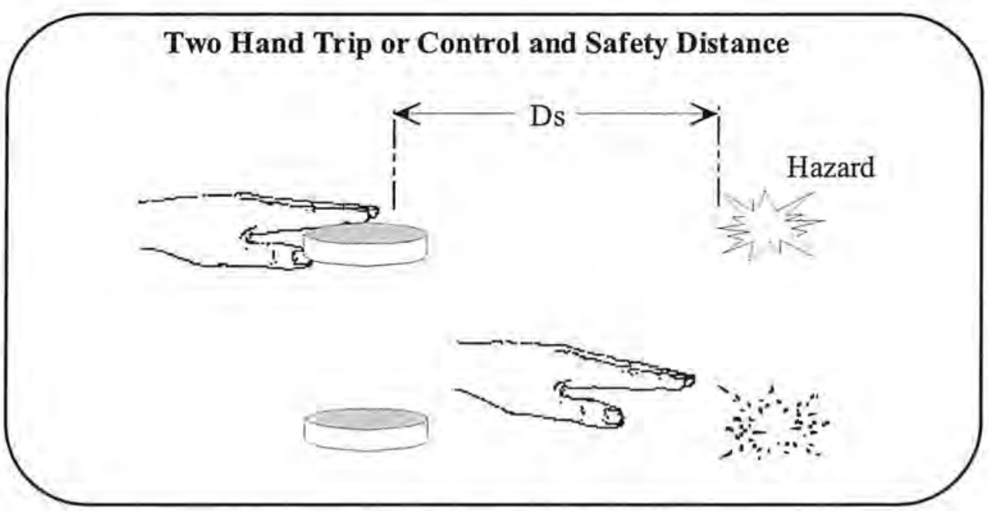


Figure 8

Checklist for two hand trip or control applications

- _____ The palm buttons are installed to meet at least the OSHA minimum safety distance requirements. Greater distances are recommended based on the operator's true hand speed, if greater than 63 in/s (1.6 m/s).
- _____ The palm buttons are installed to reduce undue operator fatigue.
- _____ The palm buttons are protected against unintended operation and are arranged so that the only probable means of operation is by both hands of a single worker, or by both hands of each operator where more than one operator is being safeguarded by dual palm buttons.
- _____ On presses with part-revolution clutches, the removal of a worker's hand from any palm button during the downstroke of the ram should quickly stop hazardous motion.
- _____ The brake monitor, if required, is operative.
- _____ All palm buttons must be released before an interrupted stroke can be resumed or the press can be cycled again.
- _____ The palm buttons are fixed in a position so that only a set-up person, supervisor, or safety engineer can move them.
- _____ The position of the palm buttons is arranged to prevent any part of the body from entering the hazard zone of the press during the machine cycle.
- _____ The operation of the press is frequently checked to ensure that operators are not bypassing or defeating the safety features of the dual palm buttons.
- _____ Safeguarding devices and procedures are available for die set-up and maintenance to prevent or arrest an inadvertent cycle of the machine.
- _____ The entire machine is routinely and frequently inspected and properly maintained.

Figure 9

Safety distance

Safety distance is the separation between the machine point of operation and the point of detection, such that the hazardous motion is brought to a stop before a person can get from the nearest detection location to the hazard. In practical terms, safety distance (Ds) is the product of the maximum speed (K) that a person can approach a hazard and the total time (T) it takes to stop hazardous motion. OSHA has only one formula for safety distance for both two hand control and presence sensing devices. OSHA also has a formula for two hand trip on full revolution clutch presses. ANSI has two formulas, one for two hand control and one for presence sensing.

Safety Distance Example

Safety distance: $Ds = K(T)$

Example: A person's hand is moving at a speed of 63 in/s as it reaches toward a hazard. If the time from the moment when the reaching hand is detected by the protection device being used to cessation of motion of tooling is 200 ms (0.200 s), then:

$Ds = 63 \times 0.2 = 12.6$ in

Figure 10

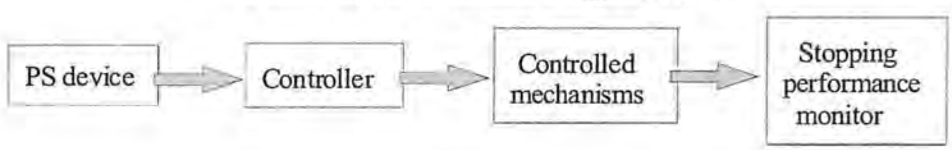
Reach speed

The average reach speed for people varies (Pizatella and Moll, 1987). An average speed that many people achieve is 63 in/s. This is the speed in current OSHA and ANSI standards. Speeds of 100 in/s have been measured when the average speed is measured starting with the hand already in motion, such as with light screens. Whether the reach is from buttons that are above-the-shoulder or at waist level also makes a difference.

Total machine stopping time

A chain of events occurs between the moment a machine is signaled to stop and the moment machine motion ceases. Total time (T) is the sum of the hazardous motion mechanism's stopping action time (Ts); the control system's logic execution time (Tc); the response time (Tr) of the presence sensing device; and the stopping performance monitor overrun time (Tspm). The stopping mechanisms for a machine may include a pneumatic valve that must close and exhaust, a clutch that must release and a friction brake that is the element that must bring the drive element (crankshaft) linked to the tooling to a stop. A brake monitor is a device that measures stopping performance (time or distance) and is set to prevent further machine cycles when an overrun limit is exceeded.

Factors in Total Machine Stopping Time



$T = Ts + Tc + Tr + Tspm$

Figure 11

Penetration depth factors

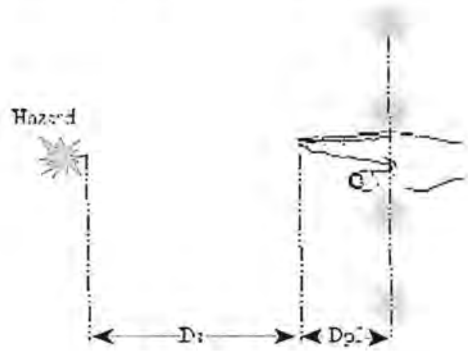
The physical location of the sensing device hardware is not usually an adequate point for measuring safety distance. An allowance for body part penetration past the hardware is usually needed. As illustrated in Figure 12, a certain distance must be accounted for inside the plane of light. A person can extend the fingers and hand a distance between light beams before being detected. This distance is related to minimum object penetration size. A penetration factor distance (Dpf) must be added to the safety distance calculation for mats, and presence sensing devices.

For light beam devices: Dpf = 3.4 (S - 0.275) in

This additional distance is added to the other factors resulting in the following safety distance relationship:

Ds =K(Ts + Tc + Tr + Tspm) + Dpf

Penetration Depth Factor Example for an Electro-optical Presence Sensing Device



A portable or control with built-in stop time meter indicates that the time from when the signal is sent to the air valve to release the clutch to the cessation of motion of the ram is 200 ms. The manufacturer of the presence sensing device lists the response time of the device as 30 ms. For the programmable logic controller (PLC) used on this press, it takes 10 ms to execute the "stop the press" logic. That is, from the moment an input signal is received from the presence sensing device, it takes 10 ms to process the program steps that produce an output signal to the air valve. For this set of dies, the stop time performance allowance is 5%. A complete cycle takes 0.5 s. Therefore, Tspm = 0.5 x 0.05 = 0.025 s. The minimum size object that can be detected is 1.0 in. Using the formula, Dpf is 2.465 in. The OSHA standards value for hand speed is 63 in/s.

Dpf = 3.4 (S - 0.275) in
= 3.4 (1-0.275) = 2.465 in

Ds =K(Ts + Tc + Tr + Tspm) + Dpf
= 63(0.200 + 0.010 + 0.030 +0.025) + 2.465
= 19.16 in

Figure 12

Effect on Safety Distance of Using a Hand Speed Greater than OSHA's or ANSI's

In Figure 12, the hand may be moving at full speed when the sensing field is penetrated. An alternative reach speed of 100 in/s may be achieved. Using this higher average value for K:

$$
\begin{aligned}
Ds &= K(Ts + Tc + Tr + Tspm) + Dpf \\
&= 100(0.200 + 0.010 + 0.030 + 0.025) + 2.465 \\
&= 28.965 \text{ in}
\end{aligned}
$$

This is an increase of 9.8 in. in safety distance (51% greater).

Figure 13

As mentioned previously, the shape of capacitance or radio frequency-type sensing fields can change with humidity, placement of other objects near the protective area, and other electro-magnetic fields. These are known as cross-sensitivity factors. Penetration beyond an original detection point (changed sensing distance) can occur due to reshaping of the field by cross-sensitivity factors (Figure 14).

For safety mats, detection does not occur until the foot touches the mat and weight is applied. A stride can bring a person well beyond the edge of the mat (Figure 15).

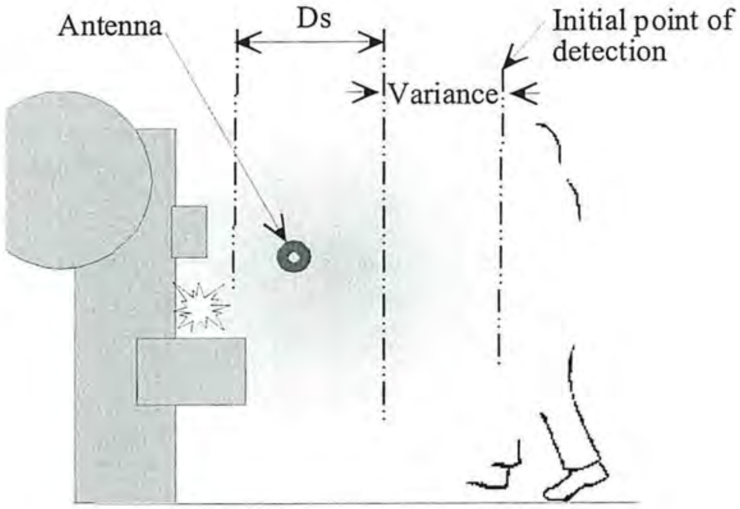
Other safety-related controls for machine maintenance

Other types of protection for maintenance safety include: safety instrumented process controls, emergency stops, foot control that is guarded properly, and trapped key systems.

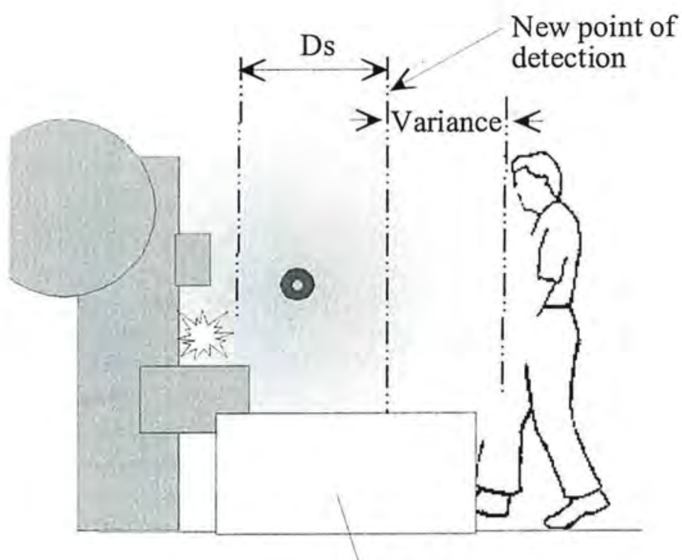
Safety instrumented process controls

Human access into dangerous machinery can be a function of problems integral to the process the machine is performing. Safety instrumented process controls perform a protective action in bringing machinery to a safe state when a process condition is detected that may lead to a dangerous human exposure. These can be controls that eliminate dangers during production disturbances. Tonnage monitoring may detect machinery conditions dangerous to humans and initiate stopping.

In the metal forming industry, as an example, new monitoring capabilities are being added to existing presses to eliminate disturbances due to parts feeding problems. Press load monitors have been used for more than 30 years to protect stamping presses and dies from damage due to overloads (Kuvin, 2001). These devices can effectively reduce operator exposure to jam-clearing hazards by detecting a problem in the die. A normal load signature can be established. During operation, the device compares the normal load signature with the actual force at that point in the stroke. Should the force exceed the normal value anywhere in the stroke, a stop signal is initiated to stop the press before the machine is damaged or a dangerous condition occurs. A great deal of testing is needed to establish a safe-signature threshold and appropriate monitor locations. At its most sophisticated level, data can be fed back to a process controller to make automatic adjustments to compensate for the out-of-tolerance conditions.



For capacitance or RF device, a variance distance must be added to Ds because...



...the shape of the sensing field can be changed when cross-sensitivity factors affect the field.

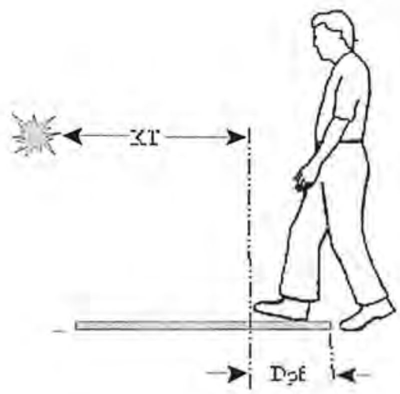
Using the field to set safety distance:

$Ds = K(Ts + Tc + Tr + Tspm) + variance$

$Ds = 100(0.200 + 0.010 + 0.030 + 0.025) + 5.0 = 31.5$ in

Figure 14

Penetration Factor Example for Safety Mats



A 4 ft width is needed for mats to discourage someone from stepping over. The 4 ft distance is also used as the Dpf. In other words, an individual can step forward approximately 4 ft (48 in) before detection occurs.

A maintenance man will, from time to time, need to correct problems in a machine that is producing bad parts. A mat is the protective device. What should be the distance from the outside edge of the mat to the hazard? The speed of approach is body speed during a rapid stride and is 63 in/s. Mat response time is 0.025 s. The machine's stopping characteristics are the same as those given in Figure 12.

$$\begin{aligned} Ds &= K(Ts + Tc + Tr + Tspm) + Dpf \\ &= 63(0.200 + 0.010 + 0.030 + 0.025) + 48 \\ &= 64.695 \text{ in} \end{aligned}$$

Figure 15

In agriculture, jams form in somewhat different ways, but present similar hazards during jam-clearing. The buildup of jams in the feed rolls of harvesting machinery such as hay balers, combines, and cornpickers depends on the forward speed at which the implement is gathering in crop stalks and the intake of extraneous weeds. Reversers on feed mechanisms on combines provide workers with a means to clear jams from the safety of the operator's control cab. Interlocks on access doors are also required, where feasible.

A general guideline on what safety instrumented process controls should do is found in EN 60204. "Movement or action of a machine or part of a machine that can result in a hazardous condition shall be monitored. On manually controlled machines, operators can provide some of this monitoring. Conditions that cannot be reasonably expected to be monitored by the operator will require means that may include over-travel limiters, motor over-speed detection, mechanical overload detection, or anti-collision devices" (EN 60204, 1997).

Power interlocking is one possible action for a safety instrumented process control to perform. Power interlocking is a means by which the main electrical, pneumatic, hydraulic, etc. power to a machine is disconnected when the interlock condition is detected. Criteria for power interlocking are set forth in the following: "The stop command from the interlocking device directly interrupts the energy supply of the machine actuators or disconnects moving parts from the machine actuators. "Directly" means that, unlike control interlocking, the control system does not play an intermediate function in the interlocking function" (EN 1088, 1995). In the context of lockout, when access is not frequent, reliance on human action to perform the power disconnect prior to lockout can be appropriate.

The methods for ensuring that safety instrumented systems will be effective include analysis of and appropriate response made for: control failure modes and effects; human factors; and safety system reliability. Safety instrumented process controls can be good for productivity because reducing the need or time of exposure for maintenance intervention is a corollary to reducing machinery downtime.

Emergency stops

Emergency stops are manually operated stop controls intended for use when a person detects that they or a co-worker have become exposed to a hazardous condition, or to prevent further injury after being caught. The common human interfaces are large mushroom-shaped buttons, safety bars, trip wires, and kick plates. Hardwiring these into the control circuit is recommended (NFPA 79 (9.6.3), 1997). The effectiveness of emergency stops depends on how easily they can be reached, how much resistance they have before actuating, and how quickly the machine actually stops after they are used. Since they are not called upon very often, a periodic check that they are functional is appropriate. Emergency stops in remote locations (away from the main machinery control station) can provide protection to personnel at risk in those locations.

Foot control guarding

When foot controls are used to cycle machinery, they can be a source of inadvertent actuation. Precautionary measures to prevent inadvertent actuations must be taken (Figure 16). Foot controls must be covered so that, as maintenance workers move around a machine, they do not inadvertently step onto a control pedal. Also, loss of balance may result in an inadvertent depression of the foot control if a foot is left on the pedal (riding the pedal) while doing maintenance in the die area with power on. Foot controls can especially be a hazard factor on machines that use fixed guards to protect the point of operation. The guards may be opened to do routine maintenance with power on and an open foot pedal can easily be stepped onto (Trump and Etherton, 1985). Whenever a foot control is active, safeguarding must be provided.

Trapped key

The trapped key method (Figure 17) is designed to combine a safe-stop control with lockout in a manner that avoids human error. In a trapped key control system, power must be shut off before access can be gained through an interlocked door. Both the door and the power switch incorporate a lock. A removable key is trapped in either the door lock or the switch lock. The lock on the door is arranged so that the key can only be released when the door has been closed and locked. This allows transfer of the key from the door to the switch lock. Closing the switch traps the key, so that it cannot be removed while the switch is in the on position. A key exchange box is used if several sources of power are involved. To be most effective, duplicate keys should not be permitted. This form of basic interlock is often used for the mechanical interlocking of electrical switchgear.

Checklist for foot control applications

_____ Safeguards are in place which will prevent injury if the foot control is inadvertently depressed.

_____ A guard or cover is over the foot switch to prevent activation by fallen objects.

_____ The working posture is as nonfatiguing as possible. Seating is provided where possible.

_____ Presence-sensing devices, if used with a foot control, are properly maintained and adjusted to ensure that the sensing field effectively safeguards the point of operation.

_____ Work rules have been established against riding the foot pedal.

_____ A check has been made to see if operators inadvertently push the foot switch because they are working at a high cycling rate with the foot control.

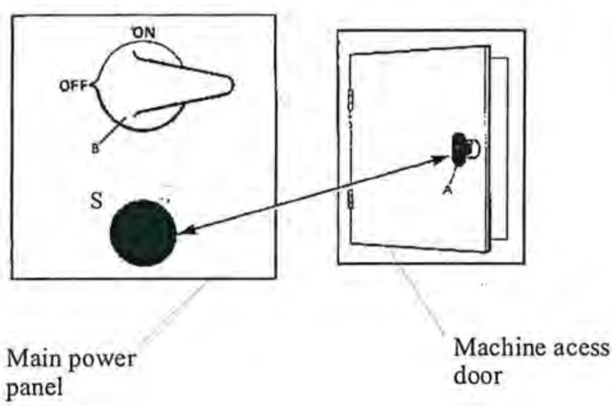
_____ The brake monitor, if required, is operative and properly adjusted.

_____ The foot control must be depressed and released for each cycle of the machine.

_____ Safeguarding devices and procedures are available for die set-up and maintenance personnel to prevent or arrest an inadvertent cycling of the machine.

_____ The machine is routinely and frequently inspected and properly maintained.

Figure 16



Key A is trapped in the door and can only be turned and removed when the door is closed, thus locking the door. Switch B cannot be turned to the On position until key A has been inserted, turned, and trapped in lock S. Key A can only be removed from S when B is in the OFF position.

Figure 17

Systematic risk reduction for maintenance tasks

Now that safeguarding options have been reviewed, the maintenance risk problem that was presented at the beginning of this article will be taken up anew. Consider again the risk assessment and matrix of Figures 4 and 5. As you will recall the task involves clearing a jam normally guarded with fixed barriers and the maintenance worker being trained to lockout machine power when the guards are removed. To reduce the risk, we will consider using a properly installed safety mat in front of the access path used to perform the jam clearing task and providing a better hand tool for loosening the jammed material. A second risk assessment and matrix will be constructed to see if the alternative safety measure will reduce risk for the maintenance task-hazard pair.

Second Risk Assessment

Maintenance task: The task is to clear a part that has jammed in the die of a mechanical power press. The press has 25 ton capacity and is equipped with a part revolution clutch. The reason that the part has jammed is that a piece of scrap was in the die when the part was struck. A foot control is used to actuate each stroke. *The safeguard now being considered is a safety mat.*

Hazard: Closure of the die.

Potential Severity: Amputation of the hand - catastrophic.

Probability of occurrence of harm:

Factor important in estimating probability	Estimated probability	Reason
exposure to the hazard	likely	they sometimes reach in
personnel who perform tasks	unlikely	well-experienced
machine/task history	unlikely	but, presses are high in BLS data
workplace environment	unlikely	a strong emphasis is placed on the safety program
human factors	likely	can be in a hurry
reliability of safety functions	remote	dual channel, monitored mat control is used
possibility to defeat or circumvent protective measures	remote	correct safety distance is used
ability to maintain protective measures	remote	does not need frequent adjustment

Figure 18

Second Risk Estimation Matrix

	Severity of Harm			
Probability of Occurrence of Harm	**Catastrophic**	**Serious**	**Moderate**	**Minor**
Very Likely	High	High	High	Medium
Likely	High	High	Medium	Low
Unlikely	Medium	Medium	Low	Negligible
Remote	Low	Low	Negligible	Negligible

Now that a method to reduce the risk has been identified, the goal is to see if the method can be implemented. Cost and machine operating factors will play a role in making the transition to an implemented risk reduction.

Figure 19

Conclusion

The preceding sections of this article have introduced the risk assessment methodology, shown its application to an initial task-hazard pair, discussed the details of different safeguarding options, and then repeated the risk assessment using a more reliable safeguard. The comparison indicates that using the new safeguard would produce a less risky task. Now, come the practicalities of safety management. Safeguarding devices have monetary costs, but when the risk of human error is high (low education, high turnover), then the cost of reducing that risk can be justified.

A valuable and practical purpose of this presentation was to provide information that can be exchanged with operating personnel on proper use of start/stop controls to reduce the incidence of injury. Such exchanges will avoid the installation of safety-related controls that are 1) not used as intended because the design does not fit the tasks for that application, or 2) ineffective because the design permits dangerous exposure. This review should help your company reach goals in making machinery maintenance a safer activity for workers.

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