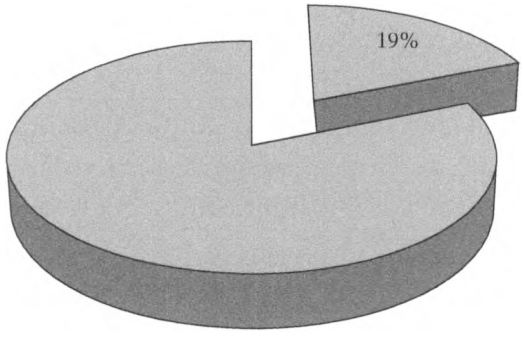
CHAPTER 15

Machine Guarding



Percentage of OSHA General Industry citations addressing this subject

Most people think of a machine guard when industrial safety is mentioned, and for good reason. More efforts and resources have been expended to guard machines than for any other industrial safety and health endeavor. To modify or guard a single machine is generally not a major project when compared with installing a ventilation system or a noise-abatement system. However, although each machine-guarding modification is usually small, the aggregate becomes a major undertaking involving plant maintenance, operations, purchasing, scheduling, and, of course, the safety and health manager. The safety and health manager should take a leadership role in the implementation of machine guards—enumerating problem areas, setting priorities, selecting safeguarding alternatives, and ensuring compliance with standards.

GENERAL MACHINE GUARDING

If safety and health managers are to be able to "enumerate problem areas" and "set priorities" as just suggested, they need to be knowledgeable about what makes a machine dangerous. Despite wide differences between machines, some mechanical hazards seem to be shared by machines in general, and these mechanical hazards will be discussed first.

Mechanical Hazards

The following are general machine mechanical hazards listed in approximate order of importance:

1. Point of operation
2. Power transmission
3. In-running nip points
4. Rotating or reciprocating machine parts
5. Flying chips, sparks, or parts

In addition to the mechanical hazards listed are others, such as electrical, noise, and burn hazards. These hazards are usually controlled by other methods, however, and are covered elsewhere in this book. It is predominantly the mechanical hazards that are controlled by machine guards, the subject of this chapter.

Although the sequence of priority in the foregoing list is only approximate, there is no question about which hazard should be at the top of the list. By far the largest number of injuries from machines occur at the point of operation, where the tool engages the work. This machine hazard is so important that it is discussed later in a separate section detailing various strategies and guarding devices in controlling the hazard.

The power transmission apparatus of the machine, typically belts and pulleys, is the second most important general machine hazard. Belts and pulleys are usually easier to guard than is the point of operation. Access to the belts and pulleys is usually necessary only for machine maintenance, whereas the point of operation must be accessible, at least to the workpiece, every time the machine is used. Although belts and pulleys are easier to guard, they also are easily overlooked by the safety and health manager. A later section is devoted to belts and pulleys, due to their overall importance to safety.

Machines that feed themselves from continuous stock generate a hazard where the moving material passes adjacent to or in contact with machine parts. This hazard is called an *in-running nip point* or an *ingoing nip point.* Even on machines not equipped with automatic feed, in-running nip points occur where belts contact pulleys and gears mesh. Figure 15.1 shows examples of in-running nip points. In-running nip points are not only direct hazards, but also can cause injury indirectly by catching loose clothing and drawing the worker into the machine.

Rotating or reciprocating moving parts can present hazards similar to those of belts and pulleys and in-running nip points—in truth, there is overlap between these categories. However, rotating or reciprocating moving parts bring to mind other parts of the machine that might need guarding. Particularly dangerous is a part of the machine that moves *intermittently.* During the motionless part of the cycle, workers might forget that the machine will later move. Material-handling apparatus, clamps, and positioners are in this category, as are robots and computer-controlled machinery. The most intermittent motion of all is *accidental* motion. It pays to consider what would happen in the event of a hydraulic failure, broken cotter pin, loosened nut, or some other accidental occurrence. Would the guard on the machine protect workers

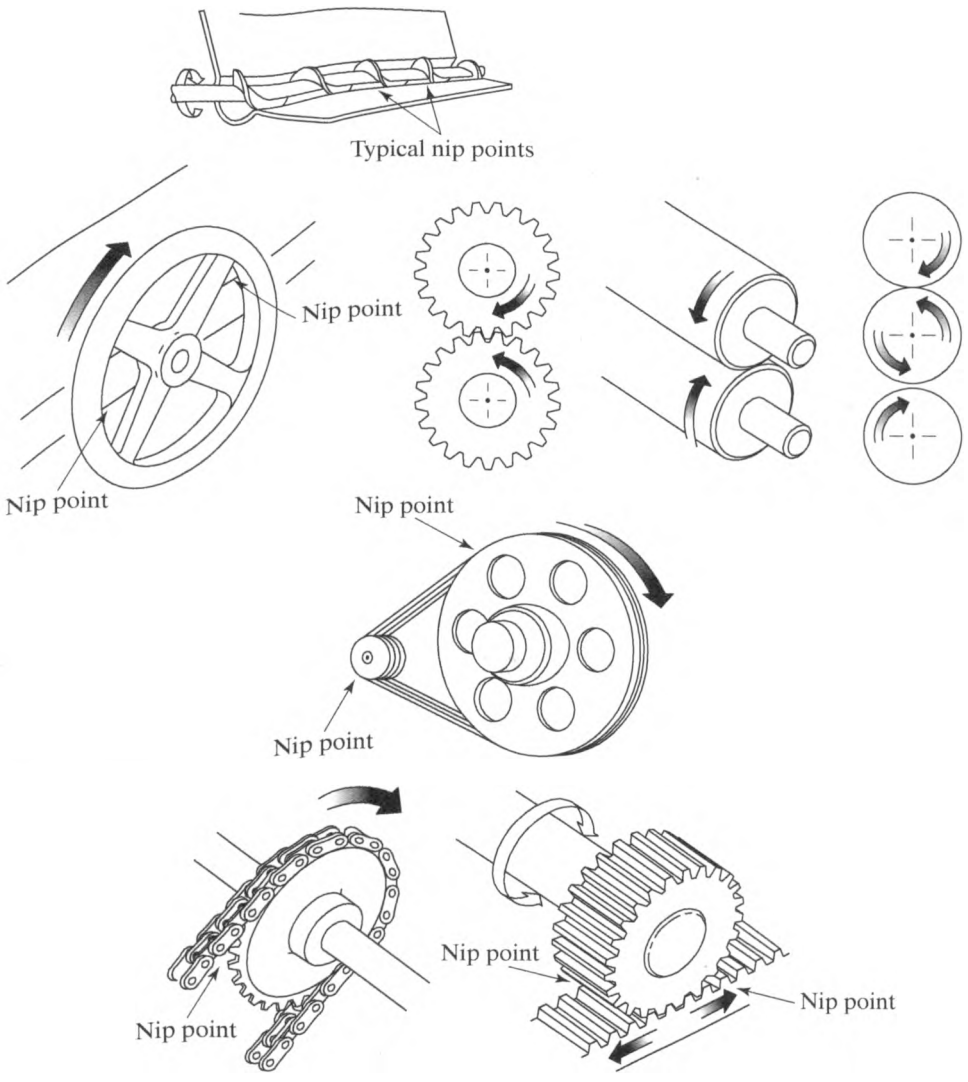


FIGURE 15.1

In-running nip points.

in these circumstances? Is the risk of occurrence of enough significance to warrant installing a guard?

The fifth item listed earlier, flying chips, sparks, or parts, is not necessarily the least significant; it merely stands alone as a somewhat different category. Many machines obviously throw off chips or sparks from the area of the point of operation. Flying objects should also be included because sometimes the product being manufactured actually breaks, and pieces may be hurled at the operator. It is also possible for parts of the machine to break and fall on or be thrown at the operator. One means of protecting workers from flying chips and sparks is with personal protective equipment. However, this is not nearly as effective as using machine guards to protect the operator and other

workers in the vicinity. Often, the term *shield* or *shield guard* is used to describe guards that protect the operator from flying chips, sparks, or parts.

Guarding by Location or Distance

The easiest and cleverest way to guard a machine is not to use any physical guard at all, but rather to design the machine or operation so as to position the dangerous parts where no one will be exposed to the danger. This is usually in the realm of machine design, and more and more attention is being given to safety in modern machine designs. However, even without altering a machine, the machine can be turned and backed into a corner so that its belts, pulleys, and drive motor are impossible to reach during normal operation. A good example would be a portable concrete mixer. Admittedly, this strategy makes the motor and drive difficult to reach for maintenance, but on the other hand, so do ordinary bolt-on guards.

Turning the machine to make the hazard remote to operators is identified in the industry as "guarding by location." It can be very effective, but it is not a positive means of preventing the worker from trespassing into the danger zone. If a worker does get hurt, either by failing to follow proper procedure or by performing a necessary, but unusual task, the employer is in the position of defending the method to an OSHA Compliance Officer. While OSHA does recognize guarding by location, such a defense may be difficult in light of the actual occurrence of injury.

Guarding "by distance" refers to the protection of the operator from the danger zone by setting up the operation sequence such that the operator does not need to be close to the danger. For some difficult-to-guard machines, such as press brakes, the distance method of guarding the point of operation (see Figure 15.2) is expressly permissible. Press brakes are used to bend sheet metal, and their long beds make it difficult to guard their points of operation. When the workpiece is a large piece of sheet metal, the operator stands well back from the point of operation out of necessity

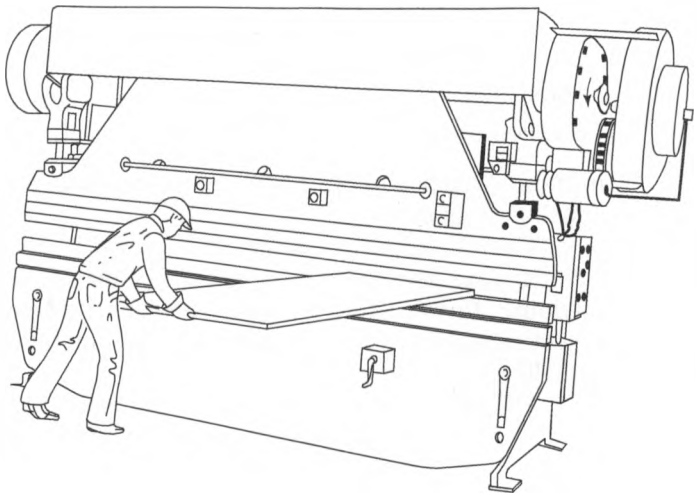


FIGURE 15.2

Press brake guarding "by distance."

and is thus safeguarded by "distance." Although guarding by distance is recognized as an acceptable method of guarding certain difficult-to-guard machines, the safety and health manager is cautioned against generalizing the concept to other types of machines. Guarding by distance is not a positive control to keep the operator or other personnel out of the danger zone at all times.

Tagouts and Lockouts

A surprising number of industrial machine accidents occur not when the machine is in operation, but when it is down for repair or cleaning. A worker simply turns a machine back on, not realizing that it is down for repair and that a maintenance worker is still close to or inside the machine!

Such accidents seem like freak occurrences, but that is because most of us are more accustomed to small machines around the home, where only a few persons, usually family members, may be in the area. However, factory machines may be large, and their repair status may not be obvious. Large numbers of personnel may have access to the machine, and a miscommunication between operating supervisors and maintenance crews can easily occur. Case Studies 15.1 and 15.2 will illustrate what can happen when multiple workers are working independently on the same piece of equipment. Human beings have been literally mangled and digested by large industrial machines.

CASE STUDY 15.1

FLOUR BATCH MIXER

A flour batch mixer is sometimes so large as to occupy several floors of a building. In this case, a trainee employee was on the third floor, reaching in to clean a flour mixer when it suddenly turned on, pulling him into the rapidly rotating blades. The start switch for the mixer was situated on the fourth floor of the building, and it was positioned next to a similar-looking switch that controlled the flow of flour from a storage bin to a scale. At the same time that the victim was cleaning the mixer on the third floor, another employee was on the fourth floor weighing out batches of flour. When the fourth-floor employee reached for the switch to weigh a batch of flour, he accidentally pushed the mixer start switch instead, fatally injuring the employee on the third floor. There was an unwritten company procedure for locking out during all maintenance. The procedure was not followed (Preamble to the OSHA Lockout/Tagout Standard, 1989).

Two simple safety procedures for preventing accidents of this type are the tagout system and the lockout system. In the tagout system, the maintenance worker places a tag on the on/off switch or control box, so that anyone who might have occasion to turn the machine back on will be warned by the tag to leave it alone. The lockout system (see Figure 15.3) provides positive protection to the maintenance worker because he or she is the only person who has the key to the lockout. Note in Figure 15.3 that the lockout

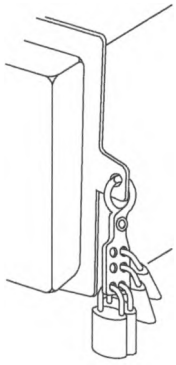


FIGURE 15.3

Lockout system for protection of maintenance workers while the machine is being repaired.

has several positions for separate padlocks for each maintenance worker exposed. Each maintenance worker, therefore, has an element of personal responsibility and control for his or her safety while working on the machine.

CASE STUDY 15.2

SHEAR HAZARD

An employee was cleaning scrap from beneath a large shear when a fellow employee hit the control button activating the blade. The blade came down and decapitated the employee cleaning scrap (Preamble to the OSHA Lockout/Tagout Standard, 1989).

The tagout system is simpler, but the lockout system is required when feasible. It would seem that a lock would not be necessary, because, after all, who would turn on a machine when a maintenance worker's tag warned not to do so? However, factories are operated by humans, and various mistakes can lead to a tagout accident. For instance, the maintenance worker can forget to remove the tag after the repair work is complete. Operating personnel may think that the maintenance personnel have forgotten to remove the tag and ignore it. The reader can no doubt think of other scenarios that would lead to an accident with tagouts, but that would have been prevented with the lockout. When the maintenance worker has the only key to the lock, there is no way for an operator to turn the machine back on—that is, with the assumption that the maintenance worker was careful enough to actually use the lock. The tragic accident described in Case Study 15.2 was ironically repeated in a similar accident that killed a 17-year old worker in July, 2016, only two weeks after he started his job (OSHA cites Wisconsin metal fabrication company for safety failures after investigation of teenaged worker's fatal injuries, two weeks after starting job, 2016).

Some types of switches are good for normal starting and stopping of a machine, but they are inadequate for assuring that the machine cannot be turned on accidentally. Push-button switches and selector switches, for instance, do not qualify as *energy isolation devices*, since they cannot safely be locked off. To qualify for lockout, a disconnect

switch or circuit breaker should be locked off to nullify the effect of a normal push-button or selector start switch.

Federal standards for lockout/tagout are among the most frequently cited standards in the nation. Not adopted in the beginning as a National Consensus Standard, the OSHA lockout/tagout standard was promulgated in 1989 and quickly rose to near the top of the frequently cited standards list in the early 1990s. Today it remains a high priority for enforcement. Perhaps even more significant is the seriousness of the citations. Nearly 80% of the alleged violations in a single year have been classified as "serious." Proposed OSHA penalties for violation have totaled millions of dollars per year. A majority of the OSHA citations for lockout/tagout have been for lack of proper training and documentation. Thus with the lockout/tagout standard, it is seen once again that the primary problem in complying with many OSHA standards is not the physical control of the hazards, but the failure to provide employee training and documentation of compliance.

Zero Mechanical State

One of the more insidious hazards of machines is that they can quietly hold dangerous energy even when they are turned off. Various forms of energy can be stored, such as pneumatic or hydraulic pressure, electrically charged capacitors, spring tension or compression, or kinetic energy from flywheel rotation. Flywheels are massive wheels that rotate continuously to deliver a uniform source of energy to a machine while running. Flywheels continue to rotate by their own momentum after the power is turned off until the energy of rotation gradually dissipates owing to friction. This momentum is sometimes available to operate the machine partially, even after the power is turned off! The great mass of the flywheel often makes it impractical to brake the wheel to bring it to an abrupt stop. However, the stored energy in the rotating flywheel still represents a hazard to maintenance workers. Case Study 15.3 demonstrates what the tremendous energy of an unleashed rotating flywheel can do.

CASE STUDY 15.3

FLYWHEEL ACCIDENT

Two employees were repairing a press brake. The power had been shut off for *10 minutes!* They positioned a metal bar in a notch on the outer flywheel casing so that the flywheel could be turned manually. The flywheel *had not stopped completely*. The men lost control of the bar, which flew across the workplace and struck and killed another employee who was observing the operation from a ladder (Preamble to the OSHA Lockout/Tagout Standard, 1989).

The hazards of stored energy in machines, even when they have been turned off, have led to a safety concept known as *zero mechanical state*. To reduce a machine to zero mechanical state, the residual sources of energy still in the machine after it is turned off must be relieved or restrained in such a way as to render them harmless. Pressure

must be relieved, springs released, counterweights lowered or locked, and flywheels stopped so that they cannot continue to power the moving parts of the machine. Zero mechanical state thus goes beyond lockout or tagout of the power switch.

At this point, the reader should recognize that the concept of zero mechanical state relates to the general fail-safe principle studied in Chapter 3. The fact that some machines can retain dangerous energy in various forms after being turned off or after accidentally losing power is a hazard to be considered in the design of the machine.

Interlocks

Contrasted with the lockout is a safety device called an *interlock*. Modern clothes dryers stop rotation as soon as the door is opened, and thus comply with industry safety standards for revolving drums, barrels, and containers. Even if the drum itself is closed, its rotation can present a hazard unless it is guarded by an enclosure. An interlock between the enclosure and the drive mechanism is specified to prevent rotation whenever the guard enclosure is not in place.

A tumbling machine is a popular industrial machine that uses a revolving drum to rotate metal parts in the presence of an abrasive tumbling medium to improve their surface characteristics. Tumbling machines found in industry may not have interlocked enclosure guards, and safety and health managers should check for such deficiencies.

Trip Bars

Large machinery layouts are often difficult to guard, but can be provided with trip bars that stop the machine if the operator falls into or trespasses into the danger zone. The operator's hand or body deflects the bar that trips a switch. Figure 15.4 illustrates an emergency trip bar on a rubber mill, a very dangerous machine.

It is sometimes impractical to place the trip bar such that any time the worker falls into the danger zone the bar will trip automatically. An alternative in these situations is to provide a trip rod or trip wire for the worker to grab to switch off the machine. Examples are shown in Figure 15.5. Such devices deserve some careful study and experimentation to be sure that workers are able to reach the trip rod or trip wire if they get into trouble.

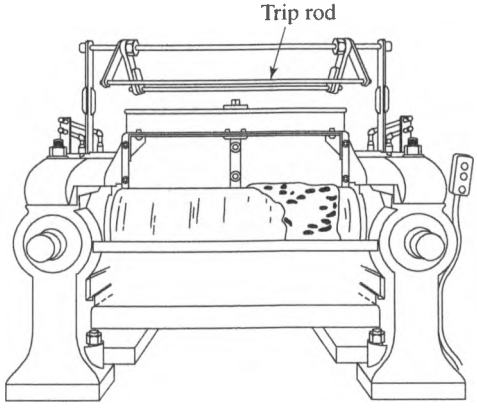


FIGURE 15.4
Pressure-sensitive body bar on a rubber mill.

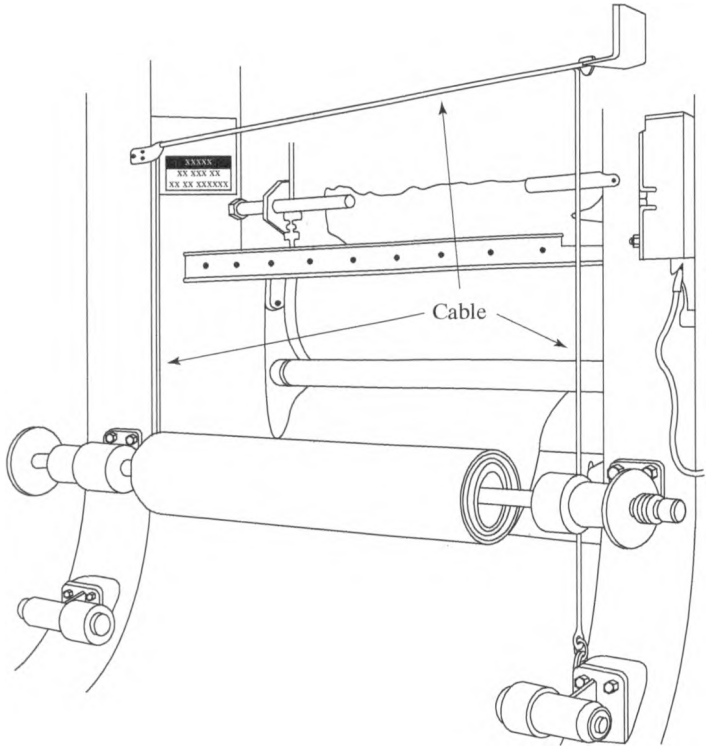
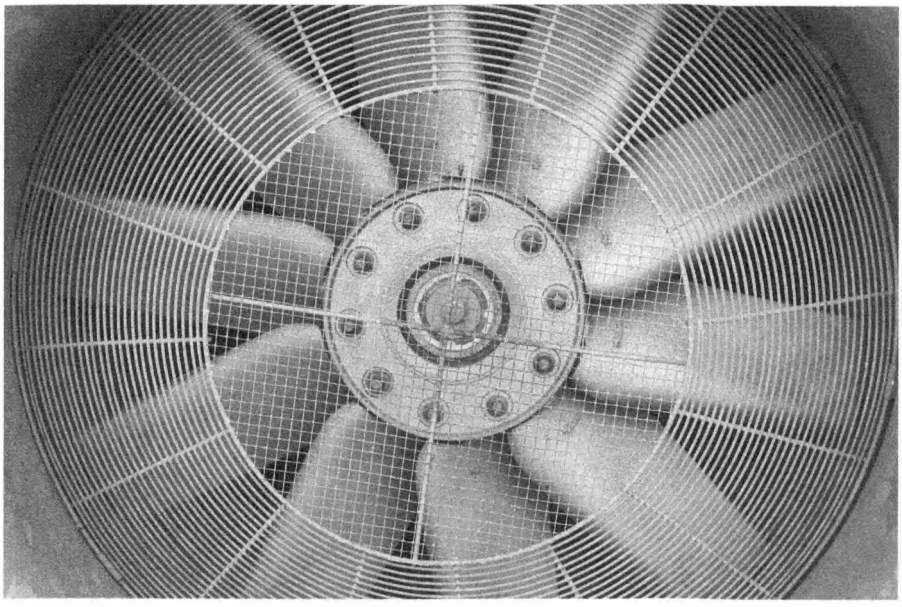


FIGURE 15.5
Safety trip rods and trip wires.

Fan Blade Guards

A very prominent safety standard is the one that requires fan blades to have guards whose openings do not exceed 1/2 inch. Literally millions of ventilation fans are distributed throughout industries all over the world, and many of them have guards with openings larger than 1/2 inch. New fan designs are generally built according to the latest standard, but a principal problem is the retrofit of old fans to meet the 1/2-inch-opening-size standard.



Thomas Smith/Alamy Stock Photo

FIGURE 15.6
Guard for ventilation fan blades.

To deal with the fan blade guard dilemma, many innovative guard and fan blade designs have been designed and an example of such can be seen in Figure 15.6. Some of the new guards are removable for easy washing, and some small plastic-bladed fans have no guards at all. A very light-weight fan with plastic blades, powered by a small motor, presents no hazard to personnel. With no guard at all, the increased efficiency can go a long way toward making up for the low-power motor on such an unguarded fan.

Anchoring Machines

Another troublesome machine-guarding standard is the rule for anchoring fixed machinery to the floor to keep it from "walking," or moving. Such anchoring is required for all machines *designed for a fixed location*. Machines that have reciprocating motions, such as presses, have a tendency to "walk" unless securely anchored. Drill presses and grinding machines can also be hazardous unless anchored.

One interpretation of the phrase "designed for a fixed location" is any machine that has mounting holes in the feet or bases of the legs. It is true that these holes are for the purpose of anchoring machines, but the mere presence of the holes is not proof that the machine must be anchored. The mounting holes might simply be a convenience feature for ease in shipping or to permit the machine to be mounted at the discretion of the user for whatever reason, such as security purposes instead of safety.

SAFEGUARDING THE POINT OF OPERATION

Injury statistics bear witness to the fact that the point of operation is the most dangerous part of machines in general. On some machines, the point of operation is so dangerous that some type of safeguarding is required for every setup; mechanical power presses are one example. Taking guidance from the specific rules for mechanical power presses, the safety and health manager can extend the principles to other machines because most of the safeguarding methods specified will work also for other machines.

A general classification of methods of safeguarding the point of operation is into guards and devices as follows:

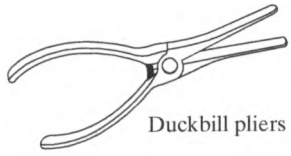
1. Guards
   - Die enclosures
   - Fixed barriers
   - Interlocked barriers
   - Adjustable barriers
2. Devices
   - Gates
   - Presence-sensing devices
   - Pullbacks
   - Sweeps (no longer accepted for mechanical power presses)
   - Hold-outs
   - Two-hand controls
   - Two-hand trips

The reader will note that nowhere in this list do hand-feeding tools such as tongs appear. Hand-feeding tools (see Figure 15.7) are helpful in eliminating the *need* for operators to place their hands in the danger zone, but it must be emphasized that these tools do *not* qualify as guards or devices for safeguarding the point of operation.

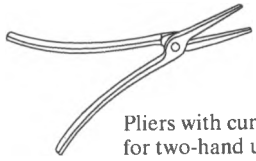
Guards

The function of a guard is obviously to keep the worker out of the danger area, but many guards do not succeed in this function. Some guards merely screen part of the danger area around the point of operation, but this can be hazardous. Too many workers will defeat the purpose of the guard by reaching through, over, under, or around it, exposing themselves to perhaps a greater hazard than if the guard were not present. Of course, every guard has to be removable between jobs for maintenance or setup purposes, but even this must be kept inconvenient, or operators will take it upon themselves to unfasten the guard to get it out of their way. Wing nuts or quick-release devices should not be used to secure guards. Nuts and bolts are better, but even better than ordinary nuts and bolts are recessed head fasteners, such as Allen screws.

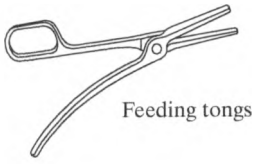
Most guards are metal, and popular design uses expanded metal, sheet metal, perforated metal, or wire mesh as filler material. A secure frame is needed to maintain the structural integrity of the guard. When a guard panel becomes larger than 12 square feet,



Duckbill pliers

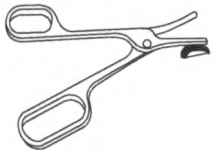


Pliers with curved handles for two-hand usage

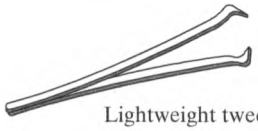


Feeding tongs

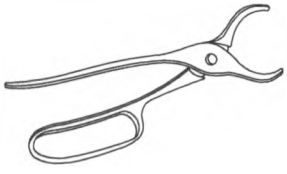
Right angle jaw tongs for handling flanged or cup-shaped workpieces



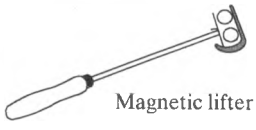
Vacu-tongs for feeding, positioning, and retrieving heavy formed parts



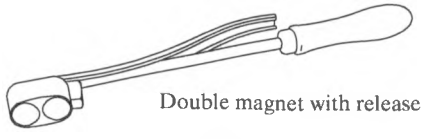
Lightweight tweezer made of steel spring



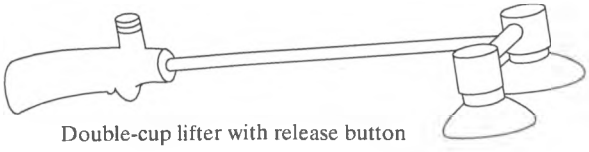
Tong devised to fit tube or cup



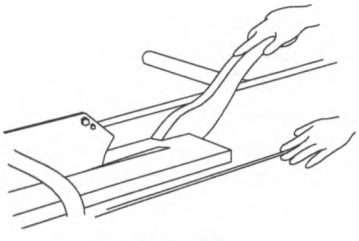
Magnetic lifter—"twist-off"



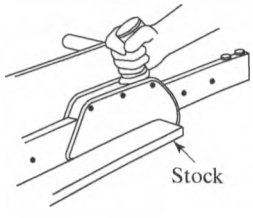
Double magnet with release lever



Double-cup lifter with release button



Push stick



Push block

FIGURE 15.7

Hand-feeding tools help with, but do not replace, the function of a point-of-operation guard.

the rigidity of the guard is in jeopardy, and additional frame components are needed. Many types of ordinary wire mesh are unsuitable because the wires are not secure at the cross points. Ordinary window screen would be in this category. Galvanized screen is better as are some types that are welded or soldered at the cross points.

One principle of machine guarding borrowed from the power press standard is the maximum permissible opening size. A contemplation of human anatomy results in the conclusion that the farther away from the danger zone, the larger can be the openings in the guard without creating a hazard. If the guard is at arm's length from the danger zone, an opening of several inches still might not be dangerous. However, if the guard is immediately adjacent to the danger zone, no opening should be large enough to permit a finger to reach through. Standard guard opening sizes are specified in Table 15.1. The principle behind the standard openings is illustrated in Figure 15.8. Some companies have made available a simple go/no-go guard gauge (see Figure 15.9): Insert the point of the gauge through the guard. If the gauge reaches the danger zone, the guard opening is too large.

TABLE 15.1 OSHA's Specification for Maximum Permissible Guard Opening Size versus Distance from the Point of Operation

Distance of opening from point-of-operation hazard (in.)	Maximum width of opening (in.)
$\frac{1}{2} - 1\frac{1}{2}$	$\frac{1}{4}$
$1\frac{1}{2} - 2\frac{1}{2}$	$\frac{3}{8}$
$2\frac{1}{2} - 3\frac{1}{2}$	$\frac{1}{2}$
$3\frac{1}{2} - 5\frac{1}{2}$	$\frac{5}{8}$
$5\frac{1}{2} - 6\frac{1}{2}$	$\frac{3}{4}$
$6\frac{1}{2} - 7\frac{1}{2}$	$\frac{7}{8}$
$7\frac{1}{2} - 12\frac{1}{2}$	$1\frac{1}{4}$
$12\frac{1}{2} - 15\frac{1}{2}$	$1\frac{1}{2}$
$15\frac{1}{2} - 17\frac{1}{2}$	$1\frac{7}{8}$
$17\frac{1}{2} - 31\frac{1}{2}$	$2\frac{1}{8}$

Source: OSHA Standard 1910.217, Table 0–10.

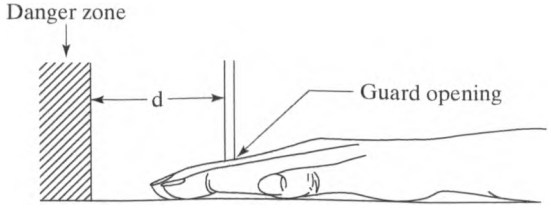


FIGURE 15.8

Maximum permissible guard opening should depend on distance to the danger zone.

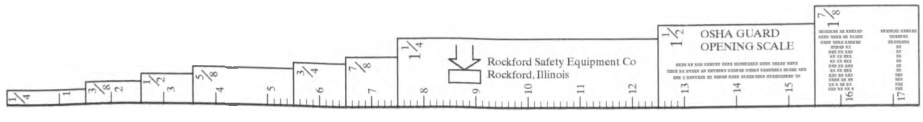


FIGURE 15.9

Guard opening size gauge.

Visibility through the guard is a problem with some guards. An old practice was to paint all guards orange. However, the bright orange color makes it difficult to see through the guard to the point of operation of the machine; black is by far the superior color for point-of-operation guards. Even better than the color black would be a transparent material. An example of such a machine guard can be seen in Figure 15.10. The machine guard is composed of square tubing with a transparent, plastic barrier. The barrier allows the operator complete visibility but guards the point of operation.

Die Enclosures

Punch presses and similar machines have mating dies that close on each other to act as the point of operation. The space between the upper and lower dies is the danger area, and the die enclosure guard is designed to enclose only this small area. The advantage over other guard types is that the die enclosure guard is small, but still it is not the most popular guard. Since dies vary widely in size and shape, the

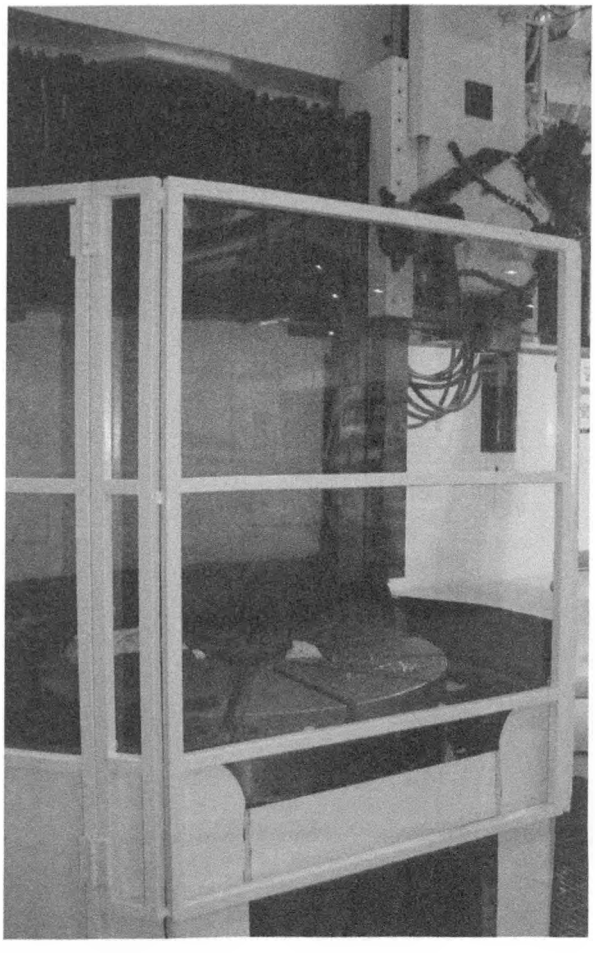


FIGURE 15.10

Transparent machine guard (*courtesy*: Pratt & Whitney).

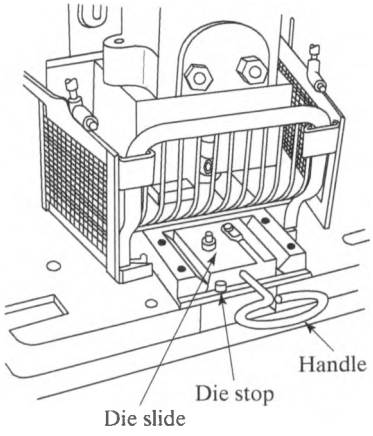


FIGURE 15.11
Die enclosure guard used with sliding die for feeding.

die enclosure guard must be essentially custom-made to fit the die or at least the die "shoe" that acts as a base to hold the die. Another disadvantage is that the die enclosure guard is essentially right at the point of operation, which permits no latitude for the guard mesh size or grillwork spacing. The maximum permissible opening size at this point is 1/4 inch, and this may limit visibility. Figure 15.11 illustrates a die enclosure guard.

Fixed Barriers

Fixed-barrier guard is a general term for a wide variety of guards that can be attached to the frame of the machine. Figure 15.12 shows one example of a fixed-barrier guard, but remember that there is no set style or shape for such guards. Even the mesh or spacing of the bars is variable, depending on the distance of the guard to the point of operation (refer to Table 15.1). Large fixed-barrier guards can permit large distances between the guard and the point of operation and a coarser mesh for the guard material.

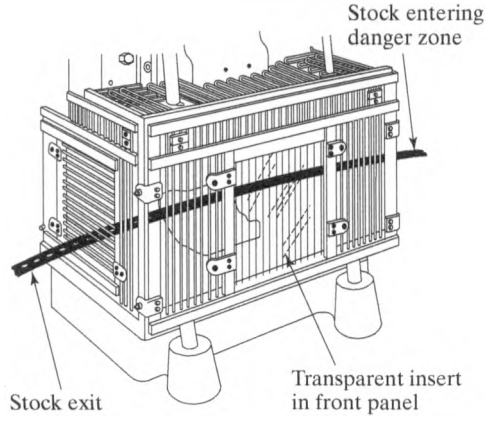


FIGURE 15.12
Fixed-barrier guard.

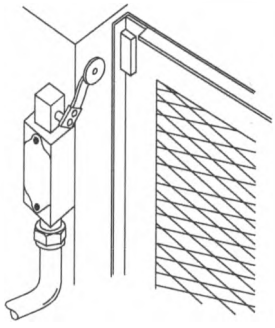


FIGURE 15.13
Interlocked-barrier guard.

Interlocked Barriers

More sophisticated is the interlocked-barrier guard shown in Figure 15.13. An interlock, typically electrical, disables the actuating mechanism whenever the guard is opened. However, the interlock is not required to stop the machine if it has already been tripped, and thus it usually affords inadequate protection to an operator who is attempting to hand feed the machine. If the barrier is so easy to open and close that the operator can open it and reach in while the machine is still moving, the interlocked barrier is not doing its job. Instead of a guard, such an arrangement would be more properly labeled a gate, a device that will be discussed later.

Adjustable Barriers

Guard manufacturers have devised some clever ways for guards to be adjusted to individual applications during the setup. Unlike the fixed-barrier guard, the adjustment is temporary, and the same guard can be reshaped later for a different setup. The trick with adjustable barriers is to make them easy enough to adjust to be practical, but not so easy as to tempt an unauthorized person to tamper with them or gain access to the danger zone. Figure 15.14 shows one type of adjustable-barrier guard.

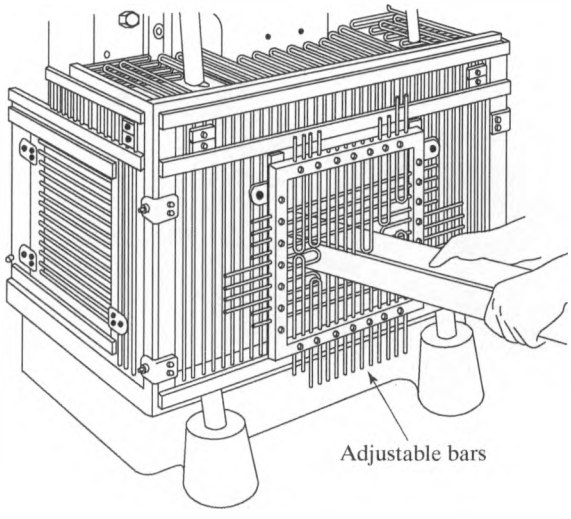


FIGURE 15.14
Adjustable-barrier guard.

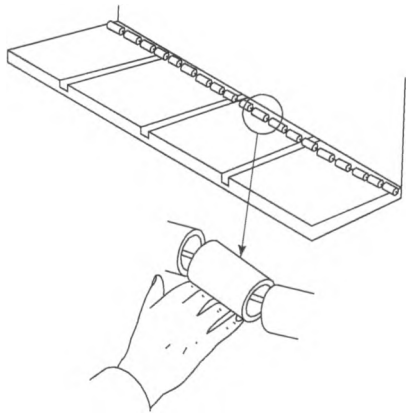


FIGURE 15.15
Awareness barrier installed on a shear.

Awareness Barriers

Some people confuse the term *adjustable-barrier guard* with the term *awareness barrier.* An awareness barrier (Figure 15.15) is not recognized as a guard and does not meet the guarding criteria of keeping the operator's hands or fingers out of the danger zone. Although the awareness barrier is not a guard, it does provide a reminder that the hands are in danger. In the style pictured in the figure, metal rings or cylinders lie on the table and are lifted by the operator's fingers when the fingers are too close to danger. The operator at that point could go on to reach further into the machine, which could result in injury, but training and good judgment should inhibit him or her from taking this action. Contact with the awareness barrier should be a learned cue to immediately withdraw the hands. The effectiveness of awareness barriers remains in doubt, as some feel that a mere deterrent is not enough to protect the operator. An added complication is that the awareness barrier may obscure the real danger from view. Many operators believe that it is not only a matter of convenience, but also one of safety to be able to see the actual point of operation.

Sometimes the term *awareness barrier* is also used to describe a simple rope or chain suspended in front of a danger area with perhaps a sign hanging on it to warn personnel to keep out. An example is the back side of a metal shear, as shown in Figure 15.16. The chain will not ensure that personnel will stay out of the point of operation or danger zone, but it will warn employees of the danger.

Jig Guards

The design of a jig guard is integral to the engineering of the manufacturing operation. The guard has the function of both protecting the operator and facilitating the operation to increase productivity. There is nothing standard about a jig guard because it is designed to fit the individual workpiece and hold it in place while the machine performs the cut or other operation. Jig guards usually move with the work while the operation is performed. The jig guard depicted in Figure 15.17 is being used to notch cross members in the manufacture of four-way pallets. This clever guard keeps the circular table saw blade covered at all times, either by the jig guard between cuts or by the workpiece itself during the cut.

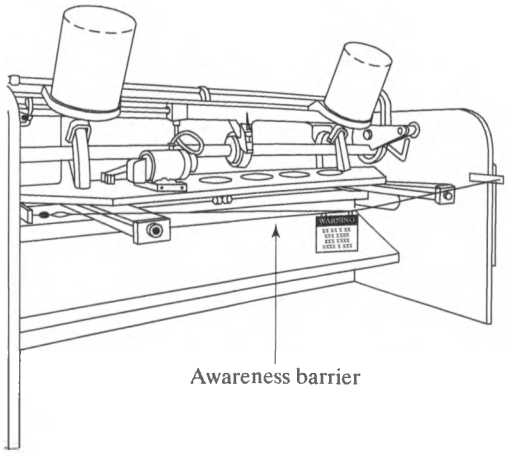


FIGURE 15.16
Rear view of power-squaring shear.

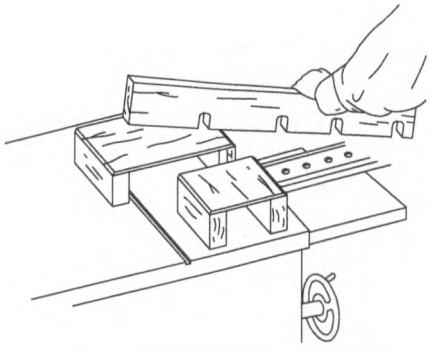
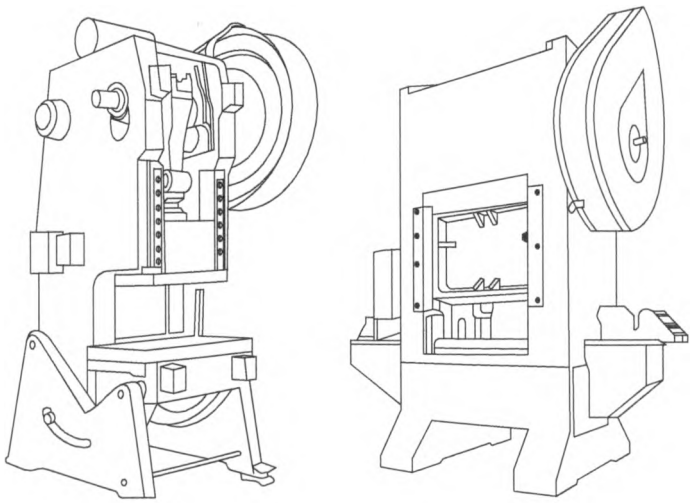


FIGURE 15.17
Jig guard for notching cross members of a four-way shipping pallet (Based on Idea credited to the Occupational Center of Central Kansas, Inc.).

Point-of-operation guards are excellent when the machine can be fed effectively by automatic means or through a guard window without the operator's having to reach into the danger zone. However, the only feasible way to feed some machines is manually, and some of these machines are very dangerous. This class of machine is typified by the mechanical power press, to be discussed next. The only way to assure protection of the operator while hand feeding these very dangerous machines is to use some kind of *device* that keeps the operator's hands out of the danger zone while the machine cycles and does its work. Some ingenious devices have been developed for this purpose, as will be seen in the next section.

POWER PRESSES

Punch presses are at the same time one of the most inherently dangerous and most useful production machines in industry. The epitome of mass-production machines, the press excels when huge volumes of identical products are required. Mass production depends on interchangeable manufacture, which in turn requires machines that successively produce parts that are essentially identical. The power press is superbly qualified for this task.



(a) (b)

FIGURE 15.18

Typical power presses: (a) open-back inclinable (OBI) model; (b) straight-sided model.

Figure 15.18 illustrates two popular model power presses. The term *power press* is really a general one that encompasses hydraulic-powered models and forging presses in addition to the popular mechanical punch press. The outstanding feature of a power press is the set of mating dies that close on each other to cut, shape, or assemble material, or to do combinations of these operations in one or more strokes. The more subtle features of presses, such as methods of power transmission and control of the stroke, are important determinants of permissible safeguarding. It is at the mechanical models, powered by flywheels, that the most restrictive press standards are aimed.

Press Hazards

There are, of course, reasons that so much importance is attached to safeguarding the point of operation of mechanical power presses. The injury record for power presses is not a good one. An estimate by Ryan in 1987 indicated that there are about 2000 press-operator work-related amputations each year in the United States (Ryan, 1987). When feeding the press by hand, the operator is close to danger every time the dies close, and this happens thousands upon thousands of times in a press operator's career. One slip and in a fraction of a second, a finger or a hand is amputated. Such accidents were commonplace in the first half of the 20th century. Shortly before World War II, there developed an awareness that even the careful operator could become a victim of the power press, and efforts were initiated to eliminate the hazard.

To understand the nature and significance of the power press hazard, it is necessary to study the interaction between human being and machine. In a hand-feed setup, the press and the operator are alternating actions in a rhythm that cycles every

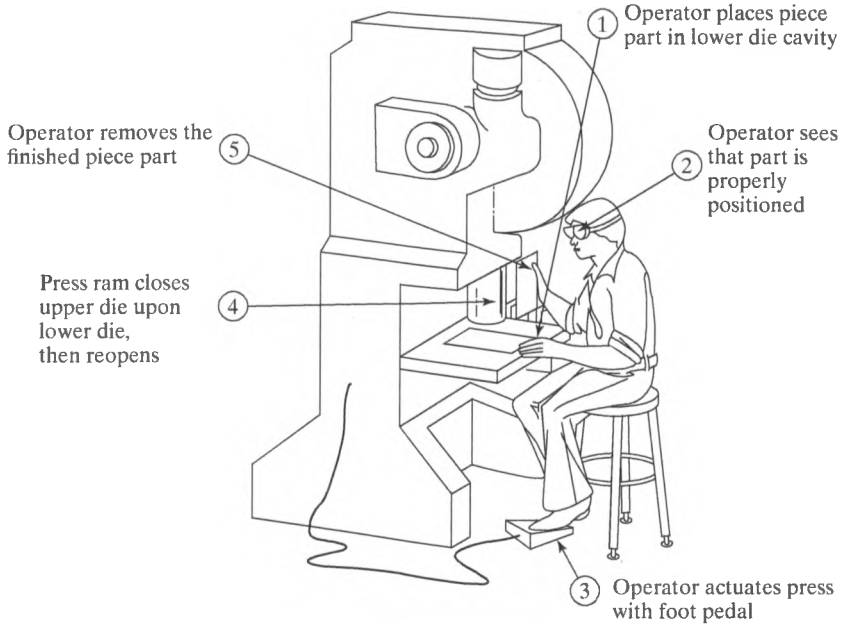


FIGURE 15.19

Press-cycle operation sequence (no safeguarding).

few seconds, and some bench press operations may cycle in a fraction of a second. Figure 15.19 depicts the sequence of actions in a typical press cycle employing hand feeding without safeguarding. Production incentives motivate the operator to higher and higher speeds as skill develops. The operator learns to develop rhythm with the press motion. The sound of the press-tripping mechanism, the closing dies, and other press motions can become cues to the operator to make a hand or foot motion. The process involves eye–hand–foot coordination every cycle. It is easy to visualize the hazards involved in hundreds of thousands of repetitive cycles.

One of the biggest causes of accidents with power presses is an attempt on the part of the operator to readjust a misaligned workpiece in the die. The motivation is a very powerful one to reach back in to correct the error even after the ram has been tripped. If the operator lets the error go, the misaligned workpiece can wreak havoc when the dies close. At the very least, the workpiece will be ruined. More likely is that the expensive dies will be broken or ruined, and it is very possible that the press frame itself will be damaged or broken. One misaligned workpiece can result in many thousands of dollars in damage to the dies and the press itself. However, even worse, the misaligned workpiece or the dies can be fragmented when the dies close, subjecting the operator to injuries from flying metal pieces. It is no wonder, then, that the operator has a powerful urge to reach back in to correct a misaligned workpiece. The operator's eye will see the error, and the hand will reach in—even though the foot may have already depressed the pedal to actuate the press.

The somewhat insidious nature of power press hazards motivated the standards writers to initiate a policy of "no hands in the dies." The theory was that tongs or other tools and devices could be used to feed workpieces, eliminating the need for the worker to put his or her hands into the danger zone. In addition to the tongs or other feeding tools, press guards or safety devices would prevent operators from placing their hands or fingers into the danger zone, even if they tried, while the dies were closing.

The theory worked for most jobs, but some applications presented awkward feeding problems that defied solution with the no-hands-in-the-dies approach. It became clear that the metal-stamping industry would not be able to comply with a rigid no-hands-in-the-dies rule in all situations, and support for the theory began to crumble. In its place, new rules were established for assuring the reliability of safeguarding devices for protecting operators at the point of operation.

Press Designs

To understand the somewhat complicated rules for safeguarding a power press, it is necessary to examine the basics of how presses work. Most presses are mechanically powered, although there are a large number of hydraulically powered models, generally recognizable by the presence of a large hydraulic cylinder above the ram. The cylinder usually resembles the large cylinder in an automobile service station lift. Hydraulic power presses are explicitly excluded from coverage by standards for mechanical power presses, as are pneumatic presses, fastener applicators, and presses working with hot metal, *even if they are mechanically powered.* Also excluded is the press brake, a power press with a long bed (refer back to Figure 15.2) that is used to bend sheet metal. Shears, because they employ blades instead of dies, are not considered within the definition of mechanical power presses.

The easiest way to distinguish a mechanical power press from other types is by the presence of a large heavy flywheel that, by its rotation, carries energy that is imparted to the ram when the press is tripped. The flywheel is *usually* mounted on one side of the press near the top, as was shown in the typical presses in Figure 15.18.

One of the most important features is whether the press is a *full-revolution* or a *part-revolution* type. This refers to the method of engaging and disengaging the flywheel to deliver power to the ram. Full-revolution types make a positive engagement that cannot be broken until the crankshaft and flywheel make one complete revolution together. During this revolution, the press ram goes down, the dies close and then reopen, and the ram returns to its full-up position to await another cycle. At the end of the revolution, the flywheel is disengaged and rotates freely under the power of the motor.

The part-revolution machine typically has a friction clutch that can be disengaged at any time during the press cycle. Compressed air is used to engage or disengage the clutch instantly at the discretion of the operator. Upon disengagement of the clutch, a brake is applied that immediately or almost immediately stops the ram. It is easy to see the advantage of being able to interrupt a press stroke at any point in the cycle, but the part-revolution advantage does not stop there. The instantaneous engagement is also valuable in causing the press to cycle quickly once engaged, giving less time for the operator to get into trouble by making an afterthought reach into the point of operation.

The safety and health manager must know which presses are full revolution and which are part revolution in order to know how to equip the press with the proper safety equipment. Thousands of dollars have been foolishly spent by purchasing the wrong safety equipment for a power press. One way to get a rough idea whether the press is full revolution is by the age of the press. Most presses, and invariably the older presses, are full revolution, unless they have gone through a renovation process. Not incidentally, the average age of mechanical power presses in the United States is steadily increasing. Statistics suggest that about half of all presses in the United States are more than 20 years old!

Since part-revolution presses employ a friction clutch, the housing on the flywheel often has a bulge to accommodate the clutch, as shown in Figure 15.20. The clutch is actuated pneumatically, and this generally means that an extra line can be seen on the outside of the flywheel cover running to the center of the clutch, as shown in the figure. Full-revolution clutch machines may also have a small line running outside the flywheel housing, but this is an oil line for lubricating purposes. None of these criteria for distinguishing machines is 100% reliable, so they should be used only as a means of preliminary screening for possible troublespots. Press engineers or the equipment manufacturer's representative can be consulted for an authoritative determination.

Point-of-Operation Safeguarding

Once having determined whether a press is a full- or a part-revolution unit, the safety and health manager or engineer can proceed to a determination of the most effective means of safeguarding its most dangerous zone, the point of operation. There are at least 10 recognized methods of power press safeguarding, but acceptability of each depends on the press configuration and method of feeding. The various safeguarding

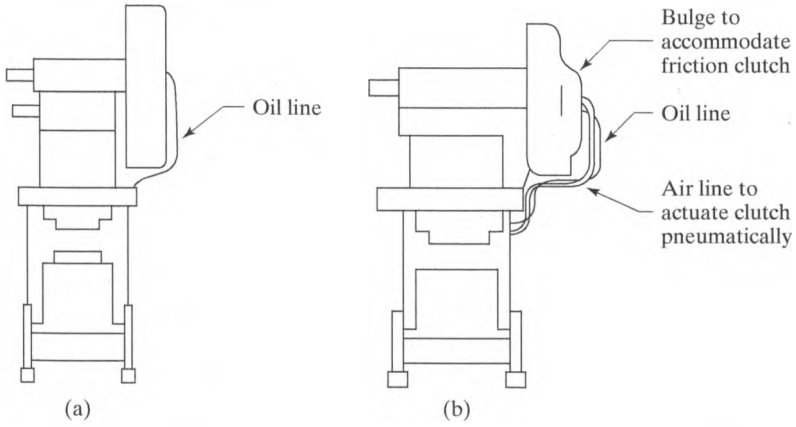


FIGURE 15.20

Full-revolution and part-revolution machines: (a) full revolution; (b) part revolution.

methods can be divided into the following four categories, ranked according to degree of security:

1. Methods that prohibit the operator from reaching into the danger zone altogether
2. Methods that prohibit the operator from reaching into the danger zone any time the ram is in motion
3. Methods that prohibit the operator from reaching into the danger zone only while the dies are closing
4. Methods that do not prohibit the operator from reaching into the danger zone, but that stop the ram before the operator can reach in

Only categories 1 and 2 are to be trusted for a full-revolution press. Some category 3 methods are permissible for full-revolution presses, but with category 3, there is exposure to the hazard that the press will "repeat." So far, no antirepeat mechanism has been found to ensure absolutely that a full-revolution press will not repeat with an extra unwanted stroke. These repeat strokes are a terrifying possibility, but fortunately that possibility has been significantly reduced in recent years. Recalling that it is likely that about half of all presses are more than 20 years old, the threat of repeats is still something to consider.

Category 4 methods of safeguarding are permitted by OSHA only for part-revolution presses, and this is where many safety and health managers go wrong. It should be obvious that any method that depends on stopping the ram to protect the operator must be installed only on part-revolution presses. Full-revolution presses, by definition, cannot be stopped. It is surprising, though, how many category 4 devices are seen in industry installed on full-revolution presses. It is true that these devices can afford some protection on full-revolution presses by locking out the tripping mechanism while the operator is in the danger zone. Once the press is tripped, however, these devices are powerless to stop the ram.

Press Guards

The earlier section on guarding described types of guards for use on machines in general. Four of these types—die enclosure, fixed barriers, interlocked barriers, and adjustable barriers—are acceptable on mechanical power presses. Indeed, the die enclosure guard is used almost exclusively on mechanical power presses, although it is not as popular as some of the other types. The fixed-barrier guard is a very popular method of guarding power presses that employ automatic feeding of coils of strip stock and automatic ejection of the finished parts. The interlocked press barrier guard is not permitted for hand feeding, but a gate *device* (not a guard) can be used. Indeed, *none* of the four types of guards is permitted for hand feeding the press (putting the hands in the dies) because by definition of a press guard, "it shall prevent the entry of hands or fingers into the point of operation by reaching through, over, under, or around the guard."

With only one exception, a guard or some type of point-of-operation safeguarding device must be installed on *every* mechanical power press. That one exception is where the full-open position of the ram results in a gap between the mating dies of less than

1/4 inch, too small to permit entry of the fingers (see Table 15.1), and thus too small to be a hazard. However, for all other mechanical power presses, even the automatic-feed models or the robot-fed setups, point-of-operation safeguarding is required. An accident can occur even with automatic feeding if a worker tending the automatic setup attempts to adjust a workpiece during operation.

We have already established that guards cannot be used where the operator feeds the press by putting his or her hand in the die. We have also stated that virtually every mechanical power press is required to have point-of-operation safeguarding. Does this make hand feeding illegal? The answer is no, and the key is the difference between the terms *guarding* and *safeguarding. Safeguarding* is a more general term and encompasses a variety of mechanical or electromechanical devices that protect the operator even when hand feeding is used. The standards are specific about which devices can be used with which types of machines and appropriate setups. Each of these configurations for mechanical power press devices will now be considered.

Gates

Gates look somewhat like a guard (see Figure 15.21), but are different in that they open and close with every machine cycle. In contrast to interlocked-barrier guards, gates *can* be used for manual feeding. Gates are used almost exclusively with mechanical power presses.

There are two types of gates: type A and type B. The *type A gate* is the safer of the two because it closes before the press stroke is initiated, and it *stays closed* until all motion of the ram has ceased. *Type B gates* are the same except that they remain closed only long enough to prevent the operator from reaching in during the more dangerous downward stroke. Although the upward stroke is less dangerous, there is still the hazard of repeats when an operator reaches in on the upward stroke. Type B gates are not forbidden for full-revolution clutch machines, but the occasional tendency of these machines to repeat is a sobering thought, and type B gates are not recommended for presses with full-revolution clutches.

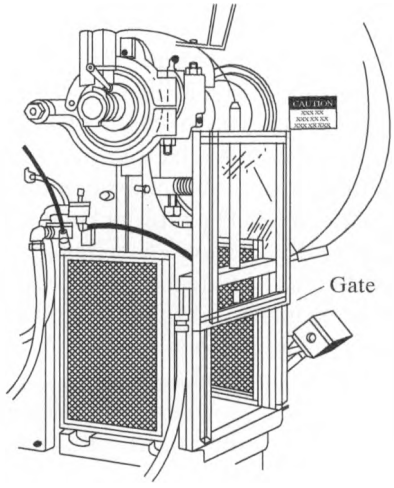


FIGURE 15.21
Gate devices.

In defense of the type B gate, however, is its efficiency over the type A gate. A substantial percentage of the press-cycle time can be saved if the operator can start reaching in as soon as the ram starts back upward. The savings may be only a fraction of a second per cycle, but over hundreds of thousands of cycles, the difference can be significant. The labor and overhead cost associated with the operator's time is saved, and also conserved are productive capacity of the press and the plant floorspace in which it is housed. It is possible for these combined costs to exceed $100 an hour. This represents an incentive to modernize the power press equipment so that it qualifies for the most efficient safeguarding systems.

Presence-Sensing Devices

Modern electronic detection devices have made their way into the machine-guarding industry, and there are several devices of this type available for protection of the point of operation. One type uses a bank of photoelectric cells to set up a light screen, the penetration of which will immediately stop the ram. Figure 15.22 illustrates this type of device.

It becomes a game for workers to defeat these devices intended for their protection. It is obvious that if a worker can reach over or around the light screen, the machine will not stop. Alternate points of entry not covered by the sensing device should be guarded so that the operator cannot reach into the point of operation without tripping the device.

Another way to defeat a photoelectric device is to use ambient light to maintain the sensors in an energized condition at all times even if the worker's hand has broken the field. To compensate for the ambient-light problem, most presence-sensing devices function in the infrared frequencies rather than in the visible-light spectrum. This makes the "light screen" invisible, and this feature may have some advantages too.

Another way to trick a light screen is to somehow squeeze between the beams. If the sources and sensors are tightly spaced, squeezing between the beams becomes

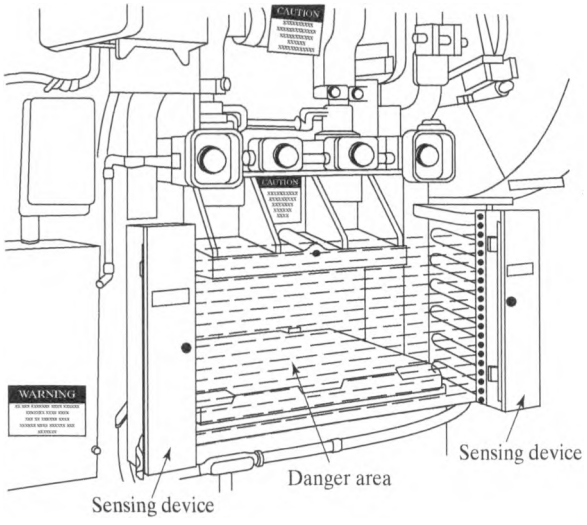


FIGURE 15.22
Photoelectric presence-sensing screen.

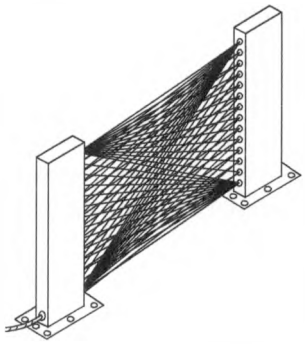


FIGURE 15.23
Programmed crisscross scan for sensing plane.

impossible for the parts of the human body. The concept can be demonstrated, however, by carefully slipping a paper or cardboard edgewise between adjacent beams. Many commercially available screens have a sophisticated programmed scan that crisscrosses the field in such a complicated fashion as to prevent defeating the device. Such crisscrossing may reduce the number of sensors required to protect a given area. The concept is illustrated in Figure 15.23.

Another type of presence-sensing device uses a conductor to set up an electromagnetic field in its vicinity. Many variables affect the tripping threshold of these devices, sometimes called *radio-frequency sensors*, and this has damaged their reputation. For instance, one person's body, due to its mass or conductivity characteristics, might trip the mechanism from a distance of 2 feet from the point of operation. Another person might not trip the device until he or she has actually entered the danger zone. If this type of device is used, it should be "tuned" to have the proper sensitivity for a given operator and setup. Figure 15.24 illustrates the electromagnetic field type of presence-sensing device. Late-model versions of this device have been found to be very effective.

Presence-sensing devices are quite practical for hand feeding in conjunction with a foot switch. Thus, if the operator's rhythm is off and the foot switch is depressed too soon (while the operator's hand is still in the sensing field), the machine will not operate. Even more important, if the operator sees a misaligned workpiece and attempts to reach in after the ram has started its downward motion, the sensing field will detect this action

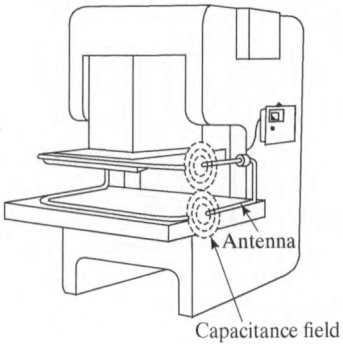


FIGURE 15.24
Electromagnetic field type of presence-sensing device.

and stop the ram. Thus, the device not only prevents operator injury, but also arrests a costly smash-up of the dies and possible damage to the press itself.

From what the reader has already learned, it should be obvious that this advantage of the presence-sensing device is feasible only for part-revolution presses. Indeed, the use of presence-sensing devices for safeguarding the point of operation on full-revolution mechanical power presses is prohibited.

Although the presence-sensing device is designed to stop the ram before the operator can reach the danger zone, the worker should not tempt the machine. The authors know of a case in which a new machine[1] equipped with a presence-sensing device was being demonstrated by a proud worker to his family during an open house. The worker repeatedly thrust his hand into the machine to prove that the photoelectric cell was quicker than his hand. Finally, he succeeded in beating the machine and lost the ends of his fingers. This "accident" actually happened.

Presence-sensing devices are like gates in that they are subject to the issue of when to return access to the point of operation to the operator. Since presence-sensing devices are permitted only for part-revolution presses, it seems sensible to afford them the same production efficiencies permitted the type B gate. Therefore, it is permissible to deactivate the sensing field on the upstroke. This process of bypassing the protective system is called *muting*. As soon as the ram reaches its home position, the system is reset to its protective mode. Muting permits the same production efficiencies that the type B gate holds over the type A gate.

While we are discussing efficiency, why not go one step further and eliminate the foot switch? It would be feasible for the press to be restrained by the control system for as long as the operator's hand or arm breaks the sensing field during hand feeding. Then, as soon as the operator withdraws his or her hand from the danger zone, the press would *automatically* cycle without a signal from the operator! Feasible? Yes. Legal? No. The presence-sensing device is prohibited as a press-tripping mechanism, although many European factories do employ this highly productive mode of operation for power presses.

There is a way that a presence-sensing device *can* be used to trip the press—when the presence-sensing device is used in conjunction with another safeguarding device, such as a gate. Thus, the gate represents the safety device, and the presence-sensing field acts as a tripping device. This would be a complicated and expensive system and should be considered rare.

Presence-sensing devices must be designed to adhere to the general fail-safe principle stated in Chapter 3. Thus, if the presence-sensing device itself fails, the system must remain in a protective mode. A failure in the device must prevent the press from operating additional cycles until the failure is corrected. However, such a failure must not deactivate the clutch and brake mechanisms, which are essential in stopping the press. If a failure in the device causes an interruption of the main power supply to the machine, the clutch must automatically disengage. Of course, the clutch and brake system should have this characteristic, regardless of the choice of safeguarding devices; the clutch and brake are simply additional examples of systems that should be designed in accordance with the general fail-safe principle.

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[1] A printing press, not a punch press, in this instance.

One final note about failures in the presence-sensing system should be mentioned. It is not enough that the failure inhibits the operation of the press; the system must also indicate that a failure has occurred. This is usually done with a trouble light on the panel.

Pullbacks

A very popular method of safeguarding a power press is by means of cables mechanically linked to the travel of the ram. These cables are attached to wristlets which pull the operator's hands out of the danger area as the ram makes its downward stroke. Figure 15.25 shows one example setup of *pullbacks*, or *pull-outs* as they are sometimes called.

One reason for the popularity of pullbacks is their versatility. They can be used with virtually any power press, regardless of power source or type of clutch. However, pullbacks do have their disadvantages.

Proper adjustment is very important to the effectiveness of pullbacks, especially with respect to close work done on bench model machines. Even the method of attachment to the wrists is important because ordinary wristlets permit too much variation in reach. Figure 15.26 is a close-up of a wristlet assembly that minimizes variations in an operator's restricted reach. Even with properly designed wristlets, proper adjustment is critical. Differences in operators' hand sizes can be a factor, but much more important are variations in die setups. A large die set will of course have a danger zone that extends closer to the operator, requiring an adjustment in the pullback limit of reach.

Recognizing the hazard of improper adjustment of pullbacks, safety standards require an inspection for proper adjustment at the start of each operator shift, following a new die setup, and when operators are changed. This inspection requirement, and especially the *frequency* of the inspections, decidedly cools the interest of employers

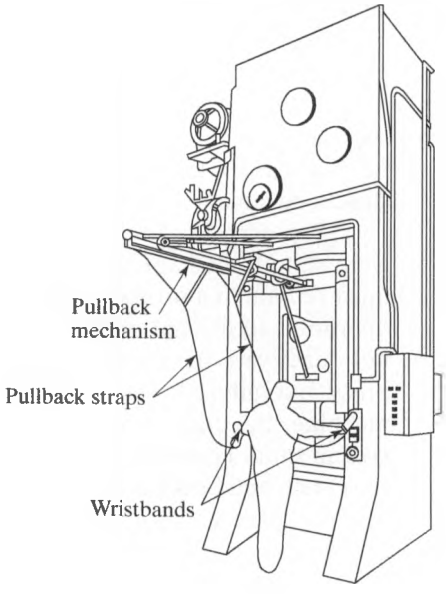


FIGURE 15.25

Pullback devices for safeguarding the point of operation.

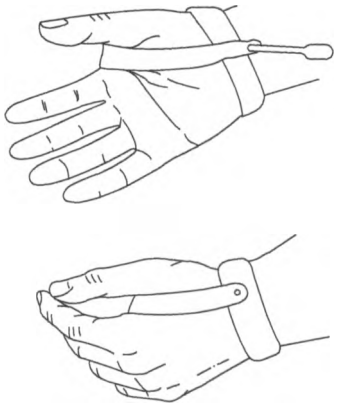


FIGURE 15.26
Close-ups of wristlet assembly for pullback device.

in the use of pullback devices. Were it not for this problem and the fact that many workers dislike wearing pullbacks, these devices would be extremely popular. These drawbacks notwithstanding, the pullback device remains one of the most popular press-safeguarding devices.

It is usually the diesetter or operating supervisor who makes the actual check of the pullbacks for proper adjustment. The concern of the safety and health manager should be that the job is done effectively and that a record is made of the inspections. Simplicity is the key to the inspection record system for pullback devices. Simplicity will help to ensure that the job gets done and will also minimize the impact on production efficiency. One convenient method is to use a tag attached to the pullback device itself, with blank lines for indicating "date inspected" and "initials" by the responsible party. In multiple-shift operations, in new die setups, or in operator changes, more than one line would be initialed in one day on the tag, but the tag still could be easily designed to accommodate multiple entries on the same day.

Sweeps

Very popular in the past, and still seen on some power presses, are devices that sweep away the operator's hands or arms as the dies close. These devices, illustrated in Figure 15.27, have fallen into disfavor as a means of protecting the operator. Operators even fear injury from the sweep device itself as it comes swinging down in front of the machine. The design dilemma of these devices is that they must be powerful enough to inflict injury themselves in order to be effective in positively removing the operator's hands from the point of operation. However, the overriding reason for their disfavor is that the design and construction of sweeps are inherently inadequate as a press-safeguarding device. Sweeps are no longer recognized as adequate point-of-operation safeguarding devices on mechanical power presses.

Hold-Outs

A simplification of pullbacks is the *hold-out* (sometimes called *restraint*) device, which is feasible only for setups in which it is unnecessary for the operator to reach into the

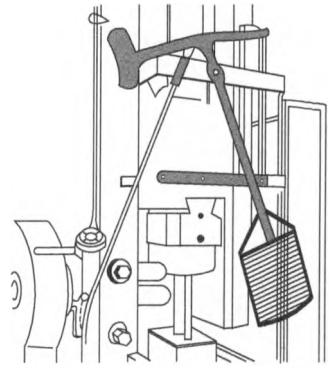


FIGURE 15.27

Sweep device. This device no longer qualifies as an acceptable safeguard for mechanical power presses.

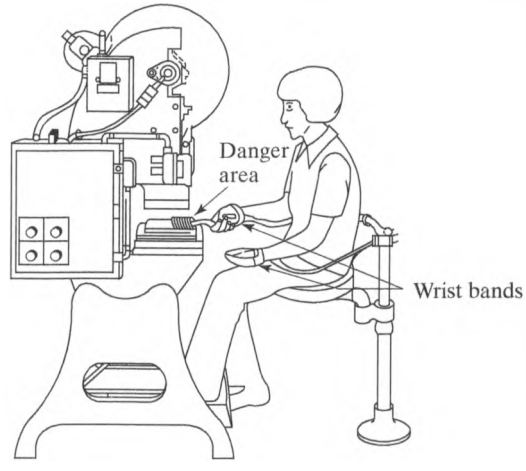


FIGURE 15.28

Hold-outs or restraints for restraining the operator's hands from reaching into the danger zone at all times (compare with pullbacks).

danger area. Figure 15.28 shows that hold-outs look almost exactly like pullbacks, the difference being that the hold-out reach is fixed and does not permit the operator to reach in at all, even between strokes of the machine. If tongs, suction cups, or other gripping devices can be used to feed a machine manually, it is feasible to use hold-outs instead of pull-outs to protect the operator. Even without these gripping devices, long workpieces can be hand fed into the machine without actually placing the hands in danger. For these applications, hold-outs are appropriate. If the operator's hands must enter the zone between the dies, however, hold-outs are infeasible as safeguarding devices.

It would seem that protection for the operator would be unnecessary for applications in which tongs or other feeding devices are used instead of the hand to feed a machine. However, this idea does not recognize the strong tendency for the worker to reach in when something goes wrong. Therefore, although hand-feeding tools are somewhat useful in promoting safety, they are not recognized as point-of-operation

safeguarding devices. Another means must be used to *ensure* safety, and hold-outs are a good method when hand tools are used.

Two-Hand Controls

Since people have only two hands, neither hand will be injured by the point of operation if the machine can require both of them to operate the controls, or so the theory goes. The theory is a good one, but some sophistication is necessary to ensure that the device achieves its goal. Workers take pride in "beating the system" or in tricking the machine to make it operate without their using the controls. One trick is to use a board or rope to tie down one control so that the operator can operate the machine with one hand and feed it with the other. Another trick is for workers to use their heads, noses, or even toes to depress one of the controls. Workers have been known to try almost anything to defeat the safety features of a machine in order to achieve a production breakthrough and receive a higher production incentive payment. This points to the power of money over personal safety in motivating workers. It may also reveal some inefficiencies in safety devices as currently designed—inefficiencies that unduly compromise productivity in the name of safety. As was pointed out in Chapter 3, industry workers and managers will tolerate some slowdown of an operation for the cause of safety, but not much.

Figure 15.29 illustrates a two-hand control device and some of the features that attempt to prevent the worker from defeating the device. Note the smooth, rounded surface of the palm button, which makes it convenient for the palm, but not for tying down. Also note the cups around the button, which are intended to foul attempts at tying down the button. Control circuitry can also be used to detect foul play and stop the machine if the buttons are not depressed concurrently and released between cycles.

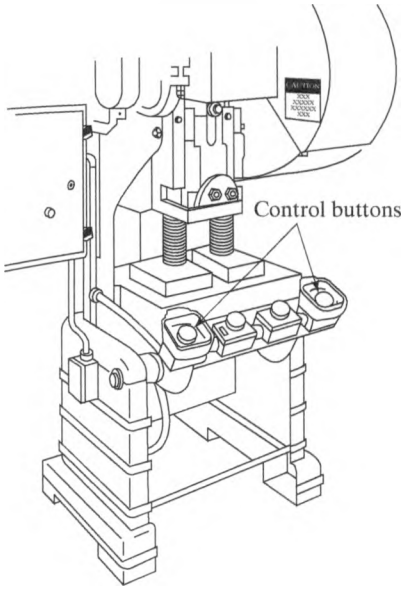


FIGURE 15.29
Two-hand control.

Controls versus Trips

The term *control* implies a more sophisticated device than a mere *trip* to actuate the machine. Within the context of safeguarding the point of operation, a two-hand control means a device that not only requires both hands concurrently to actuate the machine, but also stops the machine by interrupting its cycle if the controls are released prematurely. The nature of some machines does not permit such a degree of control over the machine cycle. Two-hand controls are infeasible for these machines.

For full-revolution presses and other machines that cannot be stopped once their cycle has begun, two-hand trips are used instead of two-hand controls. Two-hand trips require both hands to start the machine cycle, but once started there is no protection for the operator. If the machine cycle is fast, and if the operator is far enough away to stay out of danger, two-hand trips effectively protect the operator. However, if the machine is slow or the trip station is close enough, the operator can reach into the machine *after* it has been tripped. This gets into the subject of safety distances, covered in the next section. After studying the section on safety distances, it will be easy to see that controls are superior to trips.

Safety Distances

In reviewing the safeguarding devices for protection of operators from the points of operation of machines, we see that most of them protect the operator by making it impossible to reach into the danger zone after the machine cycle has begun. However, two of these devices—the presence-sensing device and the two-hand control—rely on a capability of interrupting a machine in *midcycle*. Every mechanical machine has inertia, so some time must elapse between the signal to stop and the complete cessation of motion of the machine in the point-of-operation area. If the inertia is great, an operator might be able to reach quickly into the danger zone before the protective device is able to completely stop the machine. Therefore, the operator station must be moved back from the point of operation a sufficient distance so that a reach into the danger zone before the machine stops is impossible.

In addition to the presence-sensing device and two-hand control, the two-hand trip device must also be located at a sufficient distance, as was mentioned earlier. Although the two-hand trip is not capable of stopping the machine, protection is possible if the distance to the danger zone is great enough to prevent the operator from reaching in after releasing the palm buttons.

To compute a *safe distance* for a presence-sensing device or a two-hand control, it is necessary first to compute the stopping time of the machine. Figure 15.30 shows one model of a stop-time measurement system that connects one sensor to a palm button and the other to the machine motion. Upon a signal that the palm button has been depressed, the system starts counting in fractions of a second until motion of the machine ceases. Keep in mind that we are speaking here of the motion of the machine's ram, die, cutter, or other part *at the point of operation* that could cause injury. Flywheel motion or motor rotation may continue and indeed owing to their inertia would usually be impossible to stop in time to be of any benefit. The resulting stopping time is generally displayed by the portable instrument. The reader should take care not to confuse

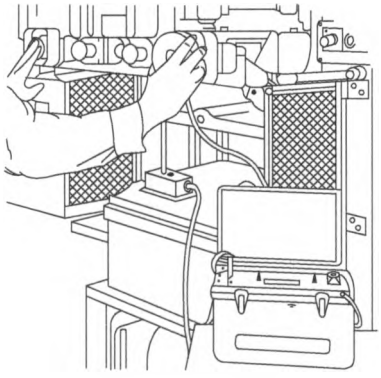


FIGURE 15.30
Brake-stop-time measurement device.

the brake stop-time measurement device in Figure 15.30 with a *brake monitor* to be discussed later.

Once the stopping time has been determined, this time must be multiplied by the maximum speed the hand can move toward the point of operation, as in the following formula:

$$\text{Safety distance} = (\text{stopping time}) \times (\text{hand-speed constant}) \qquad (15.1)$$

OSHA relies on a maximum hand movement speed of 63 inches per second, sometimes referred to as the hand-speed constant; this constant is credited to L. Lobl of Sweden. Consider the example which follows.

Example 15.1

A power press is protected by an infrared-beam-type presence-sensing device. A stop-time measurement system is used to compute the time between breaking of the infrared beam and stoppage of the press ram. This stop time is found to be 0.294 second. The safety distance then is computed to be

$$\begin{aligned}\text{Safety distance} &= 0.294 \text{ second} \times 63 \text{ inches/second} \\ &= 18.5 \text{ inches}\end{aligned}$$

Thus, all points in the plane of the infrared sensing field must be at least $18\frac{1}{2}$ inches away from the point of operation for this power press.

The calculation would have been identical if the device in the example had been a two-hand control (but not a two-hand trip!). The palm buttons of the two-hand control would have to be placed $18\frac{1}{2}$ inches away from the point of operation.

The safety distance calculation for the two-hand *trip* uses an entirely different logic from that used for the two-hand *control*. True, the same hand-speed constant of 63 inches per second is used. However, with two-hand trips, the idea is for the machine to complete the dangerous part of its cycle before the operator can reach in after releasing the palm buttons. Thus, the *slower* the machine, the more dangerous it is when

using trips. It is paradoxical that the *faster* the machine, the harder it is to stop and the greater must be the safety distance for two-hand *controls*, whereas for *trips*, it is just the opposite: the *slower* the machine, the greater must be the safety distance.

With many machines, hydraulic presses, for example, the commencement of the cycle is virtually instantaneous with the depressing of the palm buttons. However, with machines that commence the cycle with the mechanical engagement of a flywheel, there is an inevitable delay as the engagement mechanism waits for its mating engagement point on the flywheel. The delay can be considerable for a slow-rpm machine, especially if it has only one place on the flywheel suitable for making the mechanical engagement. The process is best explained by a diagram, as in Figure 15.31. Part (a) of the figure shows a very unlucky happenstance in the position of the flywheel with its engaging point just past the tripping mechanism at the moment of actuation. This follows the principle that the *worst state* of the machine should be used to determine how to make the operation safe. Since the position of the flywheel at the moment the machine is tripped is purely a matter of chance, it is equally likely that the flywheel will be in the lucky position indicated in Figure 15.31(b). However, since this position cannot be counted on, the safety distance is computed assuming the flywheel is in the position indicated in Figure 15.31(a).

One complete rotation of the flywheel completes the machine cycle for most machines. One-half of this rotation of the flywheel is the dangerous portion of the stroke, the closure motion of the machine. Thus, adding a complete revolution for engagement plus one-half revolution for closure motion, the resultant danger period is one and one-half revolutions of the flywheel for a machine whose flywheel has only one engagement point. For machines that have several engagement points evenly spaced around the flywheel, the danger period is shorter, depending on how many engagement points exist. To see this, consider an example of a machine with four engagement points. In the worst case, the farthest the engagement point could be from the tripping mechanism at the moment of tripping would be 90° or one-quarter revolution. Add this to the one-half revolution during machine closure, and the total danger period becomes three-quarters revolution.

Summarizing the calculation of safety distances for two-hand *trip* devices is the following formula:

$$\text{Safety distance} = \frac{60}{\text{rpm}}\left(\frac{1}{2} + \frac{1}{N}\right) \times 63 \tag{15.2}$$

where rpm represents the flywheel speed in revolutions per minute while engaged, and N is the number of engaging points on the flywheel.

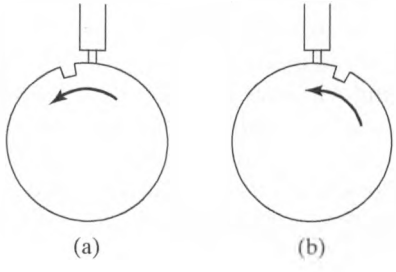


FIGURE 15.31

Two possible positions of the flywheel when a machine is tripped: (a) unlucky position—the engagement point has just passed the tripping mechanism; (b) lucky position—the engagement point is approaching and is very near the tripping mechanism.

In Equation (15.2), the factor 60/rpm is used to determine the time in seconds required for the flywheel to complete one revolution. The computation in parentheses is the worst-case number of flywheel rotations until closure, and the factor 63 is the hand-speed constant in inches per second. The computed safety distance is in inches.

It is important to remember that Equation (15.2) is to be used for two-hand *trips*, not two-hand controls. It is easy to determine that two-hand controls are superior to two-hand trips. From a production efficiency standpoint, two-hand controls can be normally placed much closer to the machine, which facilitates hand feeding. Two-hand trips can be more dangerous unless moved to a greater safety distance, which in turn impairs productivity.

Figure 15.29 was captioned "two-hand control," but the figure could also represent a two-hand trip. The device in Figure 15.29 could have been mounted on a pedestal so that it could be moved closer or farther from the point of operation, depending on the calculation of the formula for the given setup. Two-hand devices can also be mounted directly on the machine if the safety distance is short enough to permit this.

Neither Equation (15.1) nor (15.2) is constant for a given machine; both are dependent on a given setup because of variations in die dimensions and die weight, which in turn affect flywheel speed, stopping time, and dimension of the danger zone on the machine. The pedestal is movable, but only a supervisor or safety engineer should be capable of moving it. This can be accomplished by locking the pedestal in position with a key or by bolting it to the floor and forbidding operators to unbolt it, or some other means of fixing the position. Failure to fix the position results in a temptation to the operator to move the pedestal closer to the machine to speed up production.

Because of the superiority of two-hand controls over two-hand trips, both in terms of safety and productivity, many industrial plants are converting their older machines equipped with trips to the more modern two-hand controls. Such a conversion is not only a mere change in the two-hand device, but also generally represents a major modification to the machine itself and its power transmission apparatus, so that the machine can be classified as part revolution instead of full revolution. Brake monitoring and control reliability features are also required on part-revolution presses and will be explained next.

Brake Monitoring

It can be seen from the preceding discussion that the stopping time is very important in computation of permissible safety distance for part-revolution machines. However, stopping time is dependent on the brake, and unfortunately brakes are subject to wear. Stopping time is also dependent on die setup, which can change from production lot to lot. Therefore, it is naïve to apply the principle of safety distances and then to walk away and trust the press to always respond in the same way as it did the day it was tested for safety distances. So for every part-revolution press whose safeguarding device depends on the brake, a brake-monitoring system is needed to monitor the brake *every stroke*. Note how different this is from the

brake stop-time measurement system of Figure 15.30, which would be set up only occasionally to check or set safety distances. In contrast, the brake monitor is a permanent installation on the press, monitoring the overtravel of the ram past the top stop every stroke.

Since the system is mechanical, there will be some overtravel, and a tolerance must be set that permits this overtravel. Employers can set this tolerance as high as they desire, but it will not be to their advantage to set the tolerance very high because a larger overtravel means a longer stopping time, which means a greater safety distance, which means reduced efficiency. There is no safety distance for type B gates, but the employer is still allowed to reasonably establish a "normal limit" for ram overtravel.

The brake monitor can be engineered to measure either stopping time or overtravel distance. The most popular style is electromechanical, with a pair of limit switches triggered by a cam linked to the press crankshaft. This type is commonly known as a *top-stop* monitor (see Figure 15.32). The first switch signals the application of the brake, and the second signals overrun. The cam must not trigger the overrun switch until a new cycle is initiated. Sooner or later, the brake will deteriorate, and the overrun switch will be tripped, which means that brake-stopping-time tolerance has been exceeded. At that point, the monitor system must provide an indication to that effect.

In addition to the brake monitor, a control system is required to ensure that the press will cease to operate after a failure in the point-of-operation safety system occurs, *but* the brake system will *not* be shut down owing to system failure. This requirement is a direct application of the general fail-safe principle stated in Chapter 3.

The reader should be reminded that brake system monitoring and control reliability are not required on all power presses. The logic is that on many press setups, the brake monitor and control system would have marginal benefit, whereas on others, they would be of critical importance due to the selection of safeguarding methods, the mode of operation, and the construction of the press itself. Table 15.2 summarizes the various options for guarding or safeguarding presses, the need for brake monitors and control systems, and alternate permissible configurations.

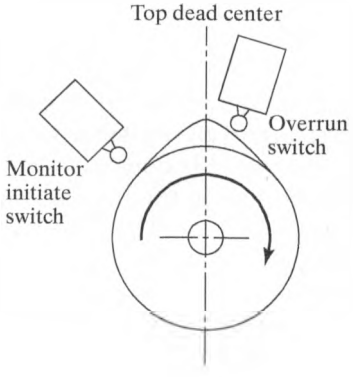


FIGURE 15.32
Top-stop-brake monitor.

TABLE 15.2 Power Press Safeguarding Summary[a]

	Full revolution		Part revolution	
Guard type or device	Hands in	Hands out	Hands in	Hands out
Guards Barrier guards (fixed, adjustable, or die enclosure)	Illegal	Inspect weekly	Illegal	Inspect weekly or Brake monitor and control system
Interlocked barrier guards	Illegal	Inspect weekly	Illegal	Inspect weekly or Brake monitor and control system
Type A gate	Inspect weekly	Inspect weekly	Inspect weekly or Brake monitor and control system	Inspect weekly or Brake monitor and control system
Type B gate	Inspect weekly	Inspect weekly	Brake monitor and control system must detect top-stop overrun beyond limits	Inspect weekly or Brake monitor and control system
Presence-sensing devices	Illegal	Illegal	Safety distance and Brake monitor and control system	Safety distance and inspect weekly or Brake monitor and control system
Pullbacks	Inspect: each shift, each die setup, each operator	Inspect: each shift, each die setup, each operator	Inspect: each shift, each die setup, each operator	Inspect: each shift, each die setup, each operator
Sweeps	Does not qualify as safeguard	Does not qualify as safeguard	Does not qualify as safeguard	Does not qualify as safeguard
Hold-outs (restraint)	Illegal	Inspect weekly	Illegal	Inspect weekly or Brake monitor and control system
Two-hand controls	*See* Two-hand trips	*See* Two-hand trips	Safety distance and Fixed control position and Brake monitor and control system	Safety distance and Fixed control position
Two-hand trips	Safety distance and Fixed trip position and Inspect weekly	Safety distance and Fixed trip position and Inspect weekly	Inspect weekly or Brake monitor and control system	Inspect weekly or Brake monitor and control system

[a]This summary compares inspections requirements, brake-monitoring and control system requirements, safety distances, and legal and illegal arrangements. The summary does not include detailed specifications, requirements for multiple operators, and other details too numerous to include in this summary. For details, see OSHA Standard 1910.217.

HEAT PROCESSES

Earlier in this chapter, electrical, noise, and burn hazards were mentioned as possible machine safety issues to be considered in addition to guarding the point of operation. One of these hazards, burns, needs to be considered as a point-of-operation hazard also. Recent advances in plastics and films are opening up new manufacturing applications in these areas, especially for joining components and for sealing modules. These applications are broadening the concept of point-of-operation guarding from the traditional mechanical hazards perspective. To make these processes safe, many of the same principles of safeguarding the mechanical point of operation can be applied to the heat processes. For instance, presence-sensing devices and interlocked-barrier guards can be made to effectively protect operators from burns from heat processes. When the heat processes become even more intense, and material is fused to join components, protection from radiation may be in order. Such processes are more properly classified as brazing or welding and are the subject of Chapter 16 of this book.

GRINDING MACHINES

Grinding machines are in almost every manufacturing plant—on the production line, or in a toolroom, or maintenance shop.

There are two or three items that create the most trouble as follows (shown in Figure 15.33):

- Failure to keep the workrest in close adjustment (within 1/8 inch) to the wheel on off-hand grinding machines
- Failure to keep the tongue guard adjusted to within 1/4 inch
- Failure to guard the wheel sufficiently

These rules may seem "nit-picking," but there is a grave hazard with grinding machines that most people do not know about—the breakup of the wheel while rotating at high

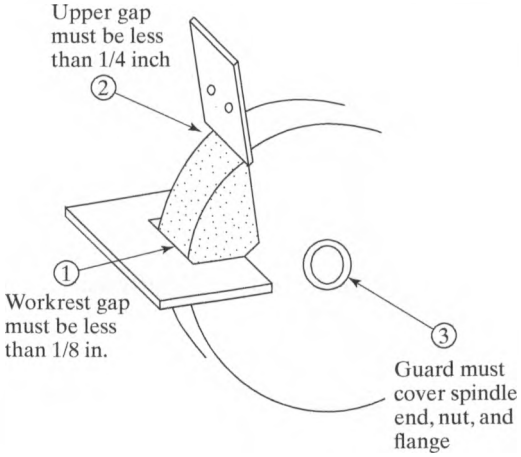


FIGURE 15.33

The three biggest troublespots on ordinary grinding machines.

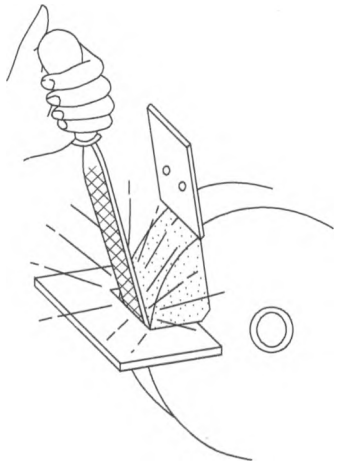


FIGURE 15.34

Severe wedging action due to a large gap between workrest and wheel.

speed. It does not happen very often, but when it does, the injuries to the operator can be fatal. It is against this hazard that all three of the items just listed are aimed, even the workrest adjustment requirement.

Severe stress can be placed on the grinding wheel if the workpiece becomes wedged between the workrest and the wheel. A large gap invites the workpiece to become pinched and then drawn down by the wheel, resulting in a severe wedging action, as illustrated in Figure 15.34. The forces of this wedging action threaten the integrity of the bonded abrasive wheel, possibly causing it to break up and hurl stone fragments at the operator at near-tangential velocities. The only protection to the operator from these flying stone fragments are a good wheel guard, a properly adjusted tongue guard, and any personal protective clothing the operator might be wearing.

It is a simple matter for anyone to check the gap adjustment on the grinding machine workrest—easy to check, but not so easy to *keep* in adjustment. Since the wear of the grinding wheel causes the gap to gradually widen, constant surveillance is needed to assure that the gap is maintained less than 1/8 inch. There is little tolerance for overcompensating for wear because 1/8 inch leaves little margin for setting the workrest closer than required. Since there is no way to avoid frequent adjustment, some convenient means should be initiated to make adjustments quickly and efficiently. To this end, a workrest gauge is recommended, as illustrated in Figure 15.35. The go/no-go character of this gauge aids in a quick and sure decision as to whether to adjust the workrest every time it is checked.

Another easy check is the maximum spindle speed; it should not exceed the maximum speed marked directly on the wheel. Operation of an abrasive wheel above its design speed subjects the wheel to dangerous centrifugal forces that also could lead to wheel breakup.

Sometimes an abrasive wheel has manufacturing imperfections or transportation damage that makes it dangerous. Before the wheel is mounted, it should be visually inspected for such damage or imperfections. Invisible imperfections can sometimes be detected by tapping the wheel gently with a nonmetallic implement such as the plastic

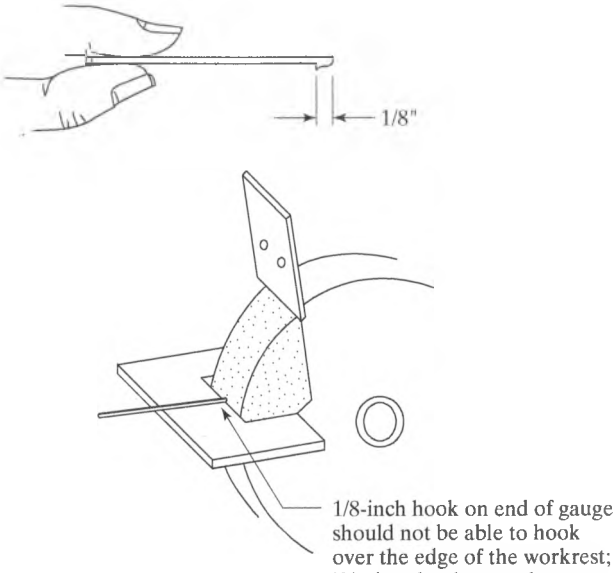


FIGURE 15.35
Grinding machine workrest gauge.

handle of a screwdriver or a wooden mallet. A good wheel typically produces a ringing sound, whereas a cracked wheel will sound dead. The reason nonmetallic objects are used to make the *ring test* is that metallic objects might themselves ring, giving the impression that a defective wheel is good.

SAWS

Saws have some obvious hazards and some not-so-obvious ones. Almost everyone respects the danger of a power saw, but serious injuries continue to occur, and acceptable means of guarding both obvious and subtle hazards from saws need to be considered.

Radial Saws

If the safety and health manager learns about no other saw, he or she should become familiar with this one. Radial saws or radial arm saws can be quite dangerous, and in addition they are difficult to guard. Figure 15.36 depicts a typical radial arm saw, but although the blade can be seen to be partially guarded on the top half, the lower portion of the blade is exposed. Figure 15.37 illustrates one type of lower blade guard for radial arm saws. The guards are very unpopular and are often removed by employees.

Another problem with radial saws is the return-to-home position. The saw should be mounted such that "the front end of the unit will be slightly higher than the rear, so as to cause the cutting head to return gently to the starting position when released by the operator." A radial saw that creeps out while running is an obvious hazard, but one that is adjusted too much at an angle will "bounce" on the home position stop—another

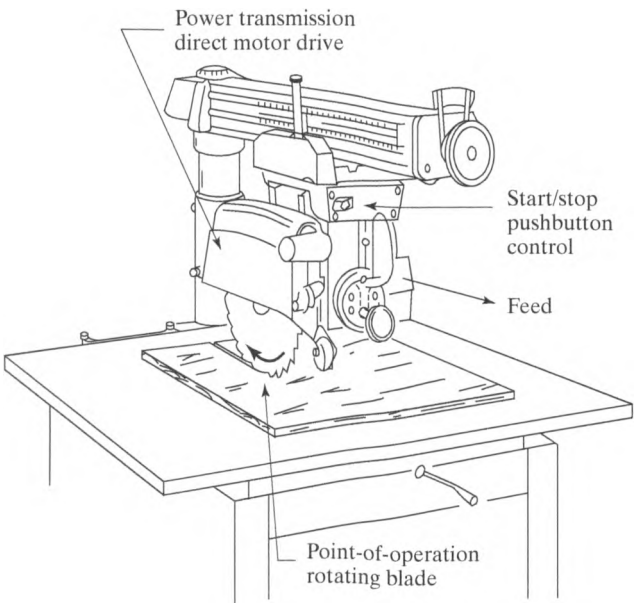


FIGURE 15.36

Typical radial saw, not properly guarded and in violation of OSHA standard (*Source*: NIOSH, Machine Guarding: Assessment Of Need, 1975).

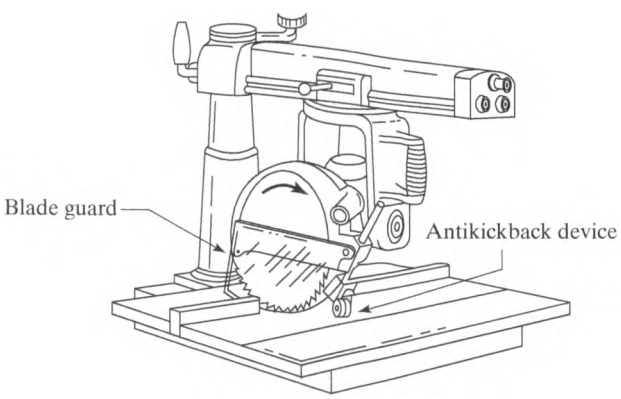


FIGURE 15.37

Radial arm saw equipped with lower blade guard.

hazard. A radial saw also will have a stop that prevents the operator from pulling the saw off the radial arm or beyond the edge of the saw table. This stop should be adjustable for limiting travel of the saw head only as far as necessary.

A radial saw is usually used as a cutoff saw and is mounted as shown in Figure 15.36. It is possible, though, to reorient the cutting head 90° so that the blade is parallel to the table and thus to convert the saw to a ripsaw for long pieces of stock. In this mode of operation, the saw head is locked into position, and the material is pushed into the saw. There is a hazard, though, if the material is fed into the saw in the wrong direction. To be safe, the material must be fed *against* the rotation of the blade. If the material is fed *with* the rotation of the blade, especially if the feed rate is fast, the saw teeth are likely to grab the workpiece and pull it into the machine at high speeds, possibly pulling the operator's hands into the blade with the material being sawed. It is not uncommon that

a radial saw fed incorrectly in this manner will hurl the workpiece through the machine and toss it across the room.

Table Saws

Table saw is an everyday term for a hand-fed saw with a circular blade mounted in a table. Unlike the radial saw, the table saw head always remains stationary during a cut while the work is fed into it. With table saws, the three biggest problem areas are hood guards, spreaders, and nonkickback fingers (see Figure 15.38). Antikickback protection is more important for ripsaws than for crosscut saws.

The hood guards present the most problems because the obstructed view makes the saw operator's job more difficult and awkward. Although most of the hood guards in the field are metal, most new machines come with transparent plastic guards. However, the rapidly rotating saw blade can cause a static charge to develop on the nonconducting plastic guard, causing it to become covered with sawdust so that the blade cannot be seen. In addition, the plastic guard is easily scratched, further reducing visibility through the guard.

It is true that hood guards will not absolutely prohibit contact of the operator's hands with the saw blade. The hood guard, with its spring action, acts more as an *awareness barrier*, as was discussed earlier in the section on safeguarding the point of operation on general machines. However, there is another reason for using a hood guard: to protect the operator from flying objects. The saw blade rotates at 3000 rpm, and this produces large centrifugal forces and high tangential velocities. Consider the following calculation for a popular make of a table saw:

Blade speed	3450 rpm
Blade diameter	10 inches

$$\begin{aligned}\text{Tangential velocity} &= (\text{rpm}) \times (\text{blade perimeter}) \\ &= 3450 \text{ rpm} \times 10 \text{ inches} \times \pi \\ &= 108{,}385 \text{ inches/minute} \\ &= 102.63 \text{ miles per hour}\end{aligned}$$

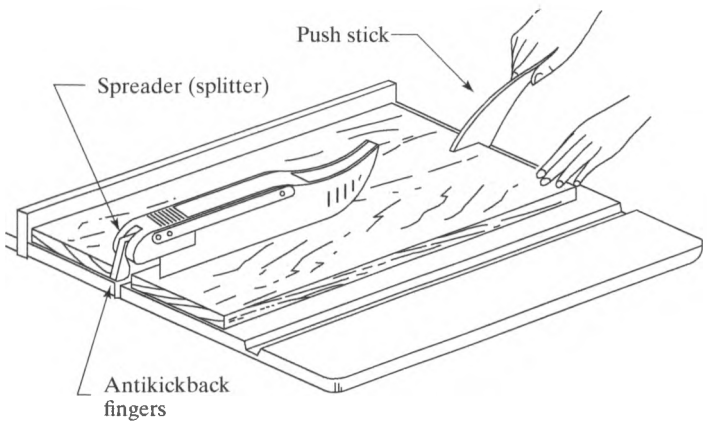


FIGURE 15.38

Hood guard, spreader, and antikickback fingers on a table saw.

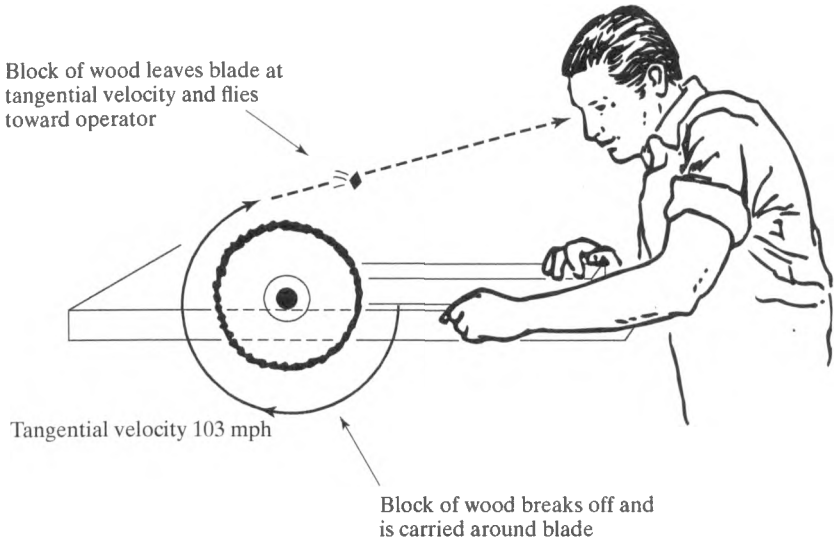


FIGURE 15.39

Broken saw tooth or chips of wood are a hazard to the saw operator.

This means that if a tooth breaks off the saw or if a small chip or block of wood breaks off and is carried on the blade for nearly a full revolution, as in Figure 15.39, it will be propelled at the face of the operator at a velocity of over 100 miles per hour. It is little wonder that eye protection is considered necessary for operating a table saw.

Kickback

Kickback is the word used to describe the situation in which the entire workpiece is picked up and thrown back at the saw operator. The energy for the kickback comes from the sawblade itself. The rotation of the blade is toward the operator. At the front of the blade where the saw first meets the work, the direction of blade motion is toward the operator and *down*. However, at the back of the blade, the direction of motion is toward the operator and *up*. Because the saw teeth are slightly wider than the blade thickness, a correctly aligned workpiece will contact the blade only at the point at which the cut is taking place. However, if the workpiece should shift slightly, the exiting portion of the cut at the back of the blade will become misaligned, causing the edge of the material adjacent to the cut to contact the blade as it emerges from the table. This contact can result in a sudden and powerful upward thrust which causes the material to break contact with the table surface. Further misalignment becomes almost inevitable at this point, and the workpiece is grabbed firmly by the blade. If the workpiece is extremely thin or fragile, it will break up at this point, with thin portions or chips continuing with the blade down under the table. However, a much more likely result is that the rigid material cannot follow the blade, and it is hurled at tangential velocity directly at the operator.

Both the spreader and the nonkickback fingers are intended to help prevent kickback. The spreader keeps the saw kerf open or spread apart in the completed portion of the cut so that the material will not contact the blade. The nonkickback fingers, or "dogs," are designed to arrest the kickback motion should it start to occur. The shape of the dog permits easy motion in the direction of the feed. A backward motion, however, causes the dog to grip the material and prevent a kickback.

Band Saws

It is essentially impossible to guard the point of operation in most band saw operations. However, the unused portion of the blade can feasibly be guarded. A sliding guard is used for this and is moved up or down to accommodate larger or smaller workpieces, respectively. This sliding guard, together with the wheel guards, permits the entire blade except for the working portion to be guarded.

Hand-Held Saws

Hand-held circular saws are subjected to a variation of the hazard of kickback, except that it is the *saw* that is kicked back instead of the material! Proper training and operator respect for the saw are important, as are a clean, sharp blade, a "dead-man" control, and a retractable guard for the lower portion of the blade. A dead-man control is simply a spring-loaded switch (button or trigger) that will immediately cut off power to the saw if the operator releases the switch.

The retractable guard for the lower portion of the blade on a hand-held circular saw is perhaps analogous to the lower blade guard on a radial saw and the hood guard on a table saw. However, on a hand-held circular saw, the retractable guard is much more important. If the operator locks the retractable guard open with a small wedge, as operators will sometimes do, the saw becomes very hazardous both before and after the cut. The blade is exposed, and direct damage or injury can result if the saw is dropped or set down on a surface.

Cutting aluminum with a hand-held circular saw can be a real problem. Hand-held circular saws are widely used to cut aluminum extrusions to length to manufacture windows, storm doors, shutters, and other architectural aluminum extrusion products. The problem is that the saw blade gets very hot, reaching the melting point of aluminum at around 1200°F; drops of molten aluminum start flying off the blade onto the guard, causing quite a mess. The aluminum later solidifies, causing the guard to stick and malfunction.

One prominent manufacturer of architectural aluminum extrusions wrestled with this problem for 5 years before turning to alternate means of protecting the operator. Reverse polarity brakes were installed on the saws, which caused the blade to come to an immediate halt as soon as the operator released the trigger. This removed most of the hazard, because it is while the blade coasts to a stop after use that the lower blade guard is most important. For added protection, the workers were provided with protective gloves and pads for the hands and wrists.

Chain Saws

Without doubt, the most hazardous hand-held saw of all is the chain saw. Binding of the blade can cause the saw to kickback and cause severe, perhaps fatal, injury to the operator. A dull or poorly lubricated chain can overheat and break, resulting in severe injury to the operator or to the other workers in the area. The Consumer Product Safety Commission is leading the effort to improve hand guards and minimize kickback.

Power Hacksaws

Power hacksaws are difficult to guard, more so than their cousins, the horizontal band saws. The band saw can be feasibly guarded with an adjustable guard along all portions of the blade except the portion actually performing the cut. Because of the reciprocating action of the power hacksaw, however, a much more complicated guard would be required to adjust back and forth *during* the cut every stroke. Guards, guardrails, or guarding by location would be appropriate for this hazard. Some modern power hacksaws are equipped with enclosures that contain the entire stroke of the reciprocating blade.

MISCELLANEOUS MACHINE GUARDING

Belts and Pulleys

Almost every industry has a wide variety of belts and pulleys and other driving systems for transmitting power from motors to machines. The hazards are well understood, and the technology is simple. Belts and pulleys represent a good target area for the safety and health manager to institute a low-cost program of in-house safety improvement.

It should be recognized that not all belts and pulleys are hazardous, and the standards acknowledge this fact by excluding certain small, slow-moving belts. The exclusions are intricate and are best represented by a decision diagram, as in Figure 15.40. A height of less than 7 feet off the floor or working platform is generally considered a working zone where personnel need protection from belts and other machine hazards.

Related to belts and pulleys are shaft couplings, such as are typically found between a pump and the motor that drives it. The preferred method of eliminating hazards with these couplings is to design them such that any bolts, nuts, and setscrews are used *parallel* to the shafting and are countersunk, as shown in Figure 15.41. If these fasteners do not extend beyond the edge of the flange as shown in the figure, it is unlikely that they will cause injury. The greatest hazard with exposed setscrew heads is that they will catch parts of loose clothing and then draw the worker into the machine. The setscrews and other projections are typically invisible on the rapidly spinning shaft or flange, adding to the hazard. The installation of U-type guards, wherever needed throughout the plant, is an objective that needs to be set by the safety and health manager. Once they are aware of the hazard, maintenance personnel can go about systematically taking measurements, having U-type guards fabricated in the sheet metal shop, and then installing these guards.

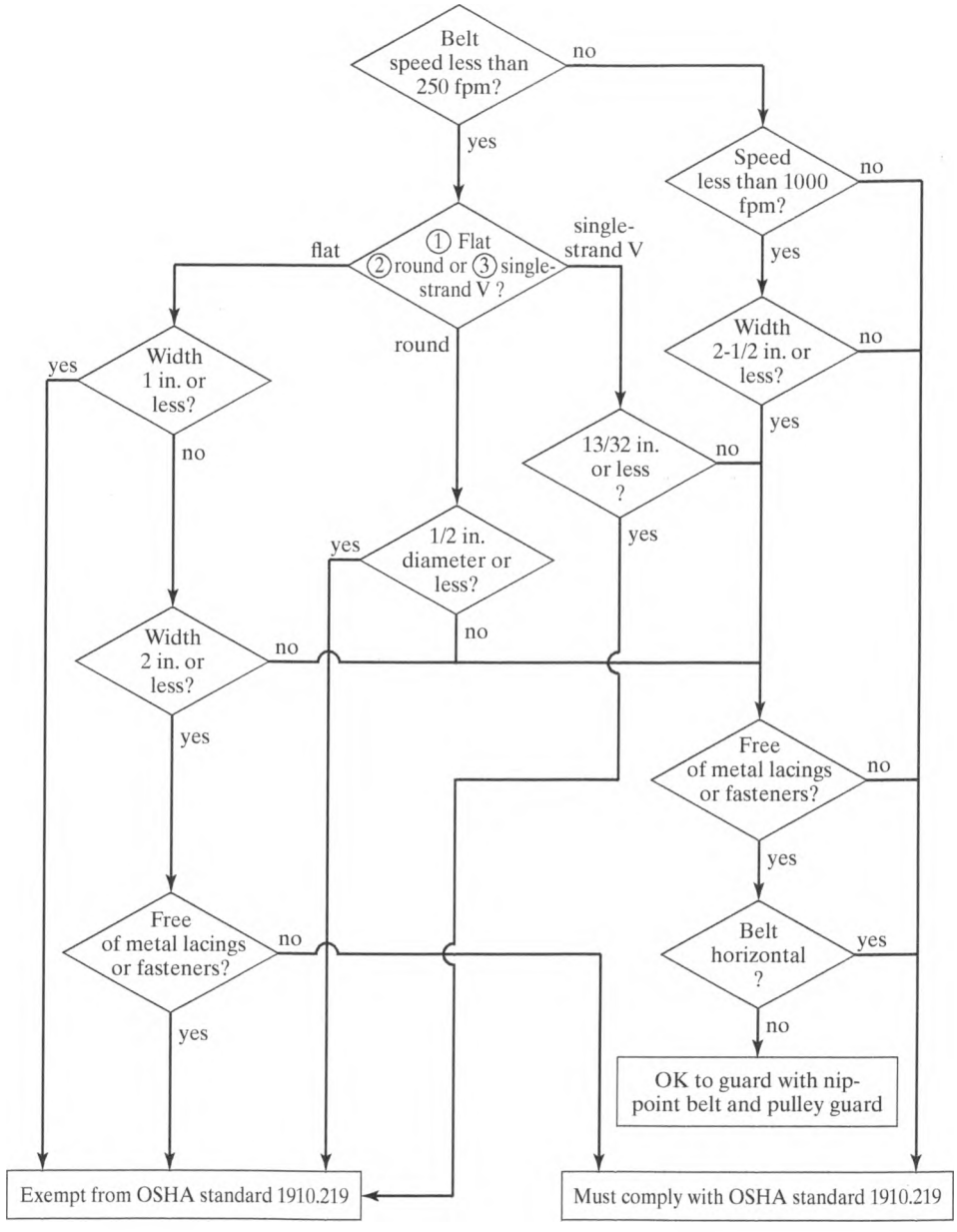


FIGURE 15.40

Decision diagram for OSHA belt guarding standard.

The possibility of safeguarding belts and pulleys by *location* should not be overlooked. Some belts and pulleys are located in a part of the machine that is protected from worker exposure. Some people believe that location is the answer to safeguarding the belt and pulley on motor-driven air compressors that operate intermittently.

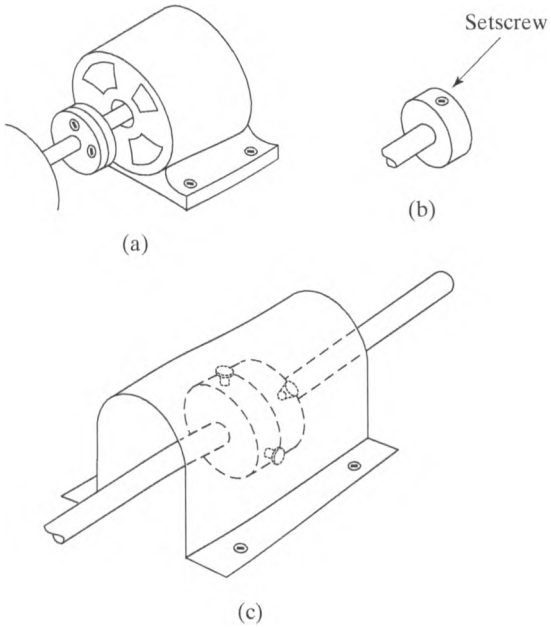


FIGURE 15.41

Safety with shaft couplings: (a) Screws or bolts are mounted parallel to the shafting and are countersunk; (b) setscrew is mounted in the periphery of the flange, but is countersunk and does not extend beyond the flange; (c) exposed setscrews present no hazard because the shaft coupling is covered by a U-shaped guard.

However, because this equipment starts automatically, safeguarding by location may not be sufficient to eliminate the hazard.

One approach to guarding large air compressors is to place them in a room by themselves. The door should be kept locked. It is best that the room be kept small if heat dissipation methods permit so that it will not be used for storage or other purposes that will result in worker exposure. The safety of maintenance personnel who must enter the room to service the compressor should not be overlooked. Administrative procedures and training can be used to reduce hazards to these personnel.

Compressed Air

It is important to call attention to the hazards of compressed air hoses used for cleaning. Compressed air hoses with nozzles are often used to spray chips away from machine areas. Safety standards specify that the air pressure used for such purposes must not exceed 30 psi. Most industrial compressed air systems operate at working pressures greater than 30 psi. Therefore, a reducer at the nozzle (see Figure 15.42a) or a reducing nozzle is used to bring the air pressure within the specified maximum of 30 psi. Figure 15.42b shows one type of nozzle for this purpose.

Excessive air pressure from these nozzles can make flying chips hazardous. Even with proper air pressure, chip guarding and personal protective equipment are needed to protect the worker. If alternate means can be used to remove chips, it is usually in the interest of safety to discontinue the use of air nozzles. Unfortunately, metal chips are very sharp and hazardous to handle, making the cleaning process somewhat of a problem.

The hazard of flying chips is fairly obvious, but most people do not realize that compressed air hoses used for cleaning can even present hazards of *fatalities*. There have been a few recorded cases of fatalities where horseplay has failed to consider the

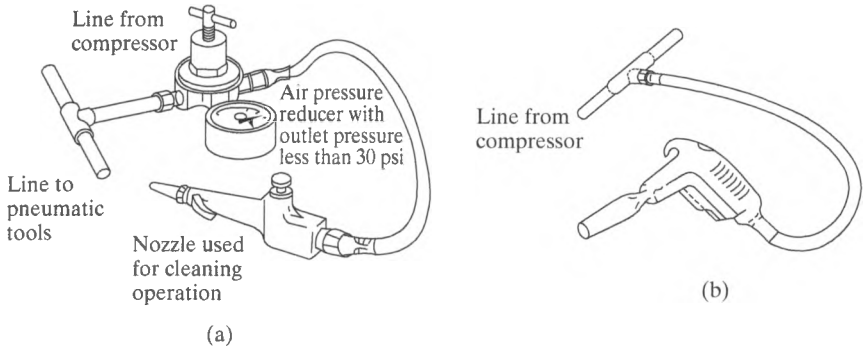


FIGURE 15.42

Two ways to comply with OSHA's requirement to reduce compressed air for cleaning to pressures less than 30 psi (a) pressure reducer in line; (b) special ventilating nozzle reduces pressure to less than 30 psi.

hazards of compressed air. There is no way that the human body can contain without serious damage internal overpressures of even 30 psi. Unfortunately, workers have rarely been trained to respect the lethal pressures presented by the ordinary and seemingly harmless compressed air nozzle used for cleaning.

MISCELLANEOUS MACHINES AND PROCESSES

Jacks

A frequent weekend accident is the familiar fatality when a "shade tree mechanic" is killed under an automobile that has fallen from the jack supporting it. A jack is essential for lifting, but the supported load is usually much more stable if transferred to secure blocks, removing the load from the jack. What is unsafe for the shade tree mechanic is also unsafe for the industrial worker as far as jacks are concerned.

As with a crane or a hoist chain, the temptation is to use a jack until failure, but the result of this policy will eventually be a catastrophic failure, an unacceptable alternative for the end of life for a jack. Therefore, the only other alternative is to inspect the jack at intervals throughout its life to watch for signs that the jack either needs repair or is worn to the danger point.

Metalworking Fluids

Metalworking fluids, as discussed in Chapter 12, have several hazards of which the safety and health manager should be aware. These factors are the toxicity of the components, fire hazards, and disposal concerns (Metalworking Fluids: Safety and Health Best Practices Manual, 2001).

In addition to the General Duty Clause, two air contaminant exposure limits exist. These 8-hour (TWA) limits are 5 mg per m^3 for mineral oil mist and 15 mg per m^3 for all other metalworking fluids (Metalworking Fluids: Safety and Health Best Practices Manual, 2001). Action should be taken to ensure that exposure remains below the PELs

through the use of environmental controls as discussed in Chapter 10. PPE is also a suitable solution for both respiratory and skin hazards, and the use of PPE to reduce skin hazards was considered in Chapter 12. Metalworking fluids may also contain carcinogens such as "PAH's, chlorinated paraffins, alkanolamines, nitrites, and formaldehyde release biocides" (PAH represents "polycyclic aromatic hydrocarbons")(Metalworking Fluids: Safety and Health Best Practices Manual, 2001).

Aside from air contaminant levels, microorganisms can grow in metalworking fluids. These microorganisms can become airborne during the machining process. Microorganisms can have adverse effects on employee health. Many metalworking fluids have biocides which can inhibit the growth of microorganisms. A regular metalworking fluid filtering and recycling program can also reduce microorganism growth (Metalworking Fluids: Safety and Health Best Practices Manual, 2001).

As some metalworking fluids have a high concentration of oil, there is also a risk of fire due to heat generated from the machining process. A fire suppression plan should be in place in the event of a fire.

Chip Removal

Chip removal and disposal can be a dangerous task. Metal chips can be razor sharp and often must be removed during the machining process itself. In most cases, chip removal can be done by the machine during the cutting process. Barriers should be in place to ensure that chips do not escape the chip bin during removal. See Figure 15.43. During the cleanup process, compressed air is often used; however, we have seen the inherent dangers of this method earlier.

INDUSTRIAL ROBOTS

Perhaps the most interesting and versatile production machine is the industrial robot. Robots most frequently handle production parts and feed them to other machines discussed in this chapter, but often they are equipped with welding or spray painting heads so that they directly perform operations on the workpiece themselves. Robots can be employed to make the workplace safer by placing machines in harm's way for hot, dirty, noisy, repetitive, and dangerous jobs, reserving for humans jobs that are ergonomically safer and more healthful. However, the safety record of industrial robots is not altogether a positive one. Robots should be considered an engineering solution to the problem of hazards elimination and control. In Chapter 3, we learned that engineering solutions have their drawbacks, and robots are no exception to this rule. As with other engineering solutions, industrial robots introduce other hazards, some of which may be worse than the hazards they eliminate. To understand these "other" hazards, it is necessary to examine the features of robots and how these features affect their safety.

The versatility of the robot is a direct result of its characteristic programmability. A robot can be programmed to move in an infinite variety of ways, and therein lies its principal safety hazard. Because it can be programmed to move in unexpected ways, varying in speed as well as position, the unsuspecting operator or other workers in the area can be struck by the robot. Accidents with industrial robots are not uncommon and occasionally even result in a fatality.

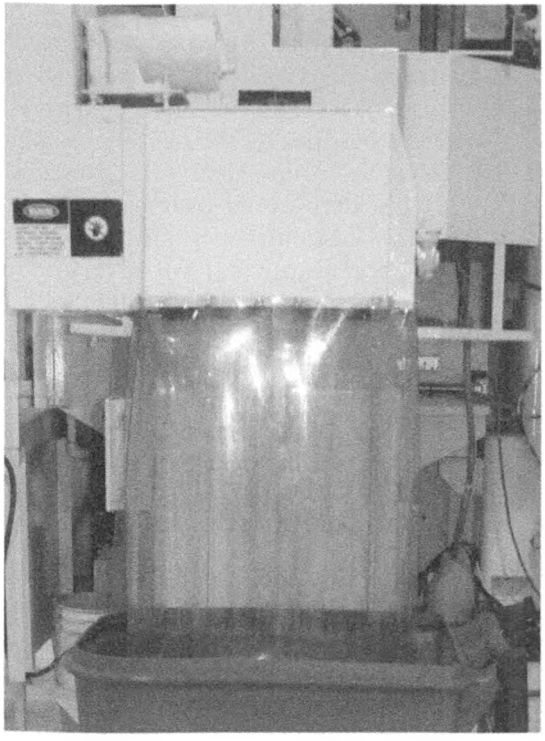


FIGURE 15.43
Chip barrier (*courtesy*: Pratt & Whitney).

When a decision is contemplated to employ an industrial robot in an industrial plant, the safety and health manager should certainly participate and is in an excellent position to provide valuable safety input. One issue to be considered is public sentiment. Robots are somewhat controversial because they are seen as a threat in their perceived role of putting a human worker out of a job. It is one thing for the public to accept possible work injury as a necessary risk of any job; it is another thing for the public to accept possible work injury by a robot that has already taken away another worker's job. Further aggravating the problem is the familiar theme used by the entertainment industry depicting robots as warriors or sinister instruments of technology used by space aliens or forces of evil.

A general rule of safety with robots is to keep human workers out of the work envelope, the geometric space within which the robot is capable of moving. Figure 15.44 illustrates an industrial robot equipped with a work envelope enclosure guard complete with an interlock to control access to the danger zone. During the initial planning phase the safety and health manager should consider what guards, interlocks, alarm routines, emergency power-offs (EPOs), and other safety measures may be needed to make the application safe. Most of these measures apply to the production phase after all programming and testing have been completed. The production phase, however, is not the most dangerous stage in the development of a robot application. Even though most of

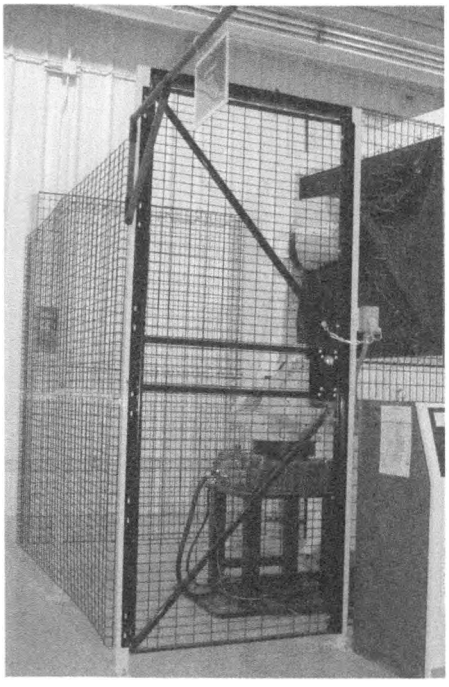


FIGURE 15.44

Robot work envelope barrier (*courtesy*: Pratt & Whitney).

the time of a robot's operational life is spent in the production phase, most accidents occur during programming, setup, and subsequent maintenance (Asfahl, 1992).

During the programming of an industrial robot, the best protection against injuries is a well-trained technician and the availability of EPOs. Keeping personnel out of the work envelope is a good rule, but the authors have direct, personal experience witnessing the difficulty of enforcing the work envelope rule during the programming of the robot. Recalling the weaknesses in the enforcement approach discussed in Chapter 3, a rule that is ignored is worse than no rule at all. Only the person actively engaged in the programming and setup of the robot should be permitted within the work envelope during programming. The robot programmer should have immediate control of robot motion power at all times via a hand-held "teach pendant" while programming.

During the production phase of robot operation, the work envelope rule should be enforced, and some sort of safeguarding method is necessary to maintain security. Two popular methods of safeguarding robot work envelopes are interlocked-barrier guards and presence-sensing devices discussed earlier in this chapter. Fixed-barrier guards can also be used, but have an element of risk for maintenance workers who may remove the barrier periodically for necessary maintenance. It is preferable to have an interlock that interrupts power to the robot arm whenever the barrier is removed. Awareness barriers leave too much to worker judgment and can lead to accidents in light of the unexpected movements that can be made by the robot arm. Case Study 15.4 is an example of such

an instance where workers within the robot's work envelope can be injured or killed when safeguarding methods are not used.

Case Study 15.4

WORKER STRUCK BY ROBOT

During a work stoppage caused by a sensor fault, a worker was struck by a robot. The worker and three others had entered the robot station without properly locking out the robot. The robot reactivated abruptly killing the worker. It was later discovered by OSHA that the company had failed to utilize procedures to control potentially hazardous energy during maintenance and servicing. The companies involved were fined $2.5 million (Alabama auto parts supplier to Kia and Hyundai, staffing agencies face $2.5M in fines after robot fatally crushes young bride-to-be, 2016).

Sometimes a human worker and a robot need to share a work station in which the robot performs a segment of the operation and the human worker performs another step in the process. One example might have the worker break down packaging and place parts to be processed into a positioning jig. The robot then might remove the piece part from the jig and position it in a machining station for further processing. Such a setup has efficiencies in that the human worker can perform the unload and load operations while the robot is busy with its own cycle. However, this arrangement introduces a risk of the robot injuring the worker, since both share the same space. The problem can be alleviated by a sliding feed mechanism, similar to the sliding die shown earlier in this chapter for die enclosure guards for power presses.

In conclusion, industrial robots offer many advantages for advances in production efficiency and can potentially make a positive contribution to the safety and health of workers in any operation. To actually realize these gains without introducing different and perhaps worse hazards to the workplace, the safety and health manager will need to be aware of new hazards that the robot can bring to the work station, especially the hazard of the robot work envelope. Using the principles of machine guarding covered in this chapter and by recognizing the strengths and weaknesses of both the engineering and enforcement approaches discussed in Chapter 3, a satisfactory and productive solution can be achieved.

EVOLUTION IN ROBOTICS AND INTELLIGENT MACHINES

As technology continues to advance, the complexity of human–machine interactions will increase with it. On January 25, 1979, Robert Williams became the first fatality as a result of human–robot interactions. Mr. Williams was asked to operate in the workspace of the robot due to production rate concerns. While within the workspace, he was struck in the head and killed instantly ($10 million awarded to family of plant worker killed by a robot, 1983). Since then, interactions with robots have become more and more commonplace and safeguards have been developed to improve the safety of those interactions. It is now not unusual to have robotic vacuum cleaners, smart appliances,

self-driving cars, and smart homes. The number of items connected to the Internet far surpasses the number of humans connected to the Internet. Gartner (2017) research reported that in 2016, there were 6.4 billion things connected to the Internet and soon this number could double or even triple.

This is not all. The transportation industry is experiencing rapid change as self-driving cars, automated drones, and other machines take the place of traditionally human-roles. In fact, the first fatality from a self-driving car occurred to Joshua Brown when he put his car into self-driving mode. He impacted a tractor trailer and was killed (Tesla driver dies in first fatal crash while using autopilot mode, 2016). That same article stated that self-driving car proponents were quick to call out that the fatality rate of normal human-operated vehicles was 1 fatality in every 94 million miles driven and this fatality was the first fatality in roughly 130 million miles driven by self-driving cars. Self-driving cars are relatively new and one would think that the safety rate will continue to improve.

The safety professional of the future will need to consider the implications of human and intelligent machine interaction. Processes will have to consider whether appropriate safeguards are in-place and per the General Duty Clause sufficient to ensure that the workplace "is free from recognizable hazards that are causing or likely to cause death or serious harm to employees."

SUMMARY

Machine guarding is a term almost synonymous with industrial safety and is a high-priority item for safety and health managers. Although passed off by some health and safety professionals as old fashioned and nontechnical, machine guarding is actually a challenging task with new guarding technologies pressing the state of the art.

The most dangerous part of most machines is the point of operation, where the tool meets the workpiece. Unfortunately, it is also the most difficult part of the machine to guard in most cases. When guarding becomes impractical or infeasible, electromechanical devices have been devised for protecting the operator from the point of operation. Not to be overlooked are the indirect hazards at the point of operation such as flying chips or sparks.

Next in importance to the point of operation are belts, pulleys, and other power transmission apparatus. Usually more easily guarded than the point of operation, belts, pulleys, gears, shafts, and chains should receive plantwide attention. Guards often can be fabricated in-house with supervision of the safety and health manager. Remember to consider the possibility of guarding by location. Not to be confused with guarding by location is guarding by *distance*. Guarding by distance is intended for point-of-operation guarding for machines, such as press brakes, that fabricate large workpieces.

One of the most important and dangerous of production machines is the mechanical power press. Safety requirements for guarding the point of operation of presses can be quite technical and complicated. Many of the guarding methods specified for presses can be used as principles for guarding machines in general, including heat processes.

The hazards of radial saws are exemplary of those of other types of saws. Kickback is a hazard with most saws, and various mechanical devices, in addition to training workers in the mechanism of kickback, are viable remedies.

OSHA's abrasive wheel machinery standard is quite complicated, but the principal problems are short and simple—guarding the wheel, nut, and flange; adjustment of the workrests on grinding machines; and adjustment of the tongue guards.

Additionally, there are many miscellaneous processes of which the safety and health manager should be aware. Among these are hand-held power tools, compressed air equipment, jacks, metalworking fluid, chip removal, and industrial robots.

EXERCISES AND STUDY QUESTIONS

15.1 Explain the term *point of operation.*

15.2 Name several types of mechanical hazards on machines in general. Which is the most important from a safety standpoint?

15.3 Identify several examples of in-running nip points.

15.4 Name two ways of safeguarding a machine that require no physical guard or device at all. What is the difference between these two methods of safeguarding?

15.5 What is a lockout? How does it differ from an interlock?

15.6 What are the disadvantages of nylon mesh guards for fans?

15.7 The stopping time of the ram on a certain part-revolution press has been measured to be 0.333 second. At what minimum safety distance should a presence-sensing device be placed?

15.8 A popular mechanical power press has a full-revolution clutch and 14 engagement points on the flywheel, which rotates at 90 rpm. At what minimum distance from the point of operation on this press should a two-hand trip device be placed?

15.9 Name some reasons why a machine might have bolt holes in its feet.

15.10 Name several types of safeguarding devices for the point of operation.

15.11 What is the difference between an interlocked-barrier guard and a gate?

15.12 What is the difference between two-hand controls and two-hand trips?

15.13 What is the difference between type A and B gates?

15.14 What is the advantage of Allen-head screws over wing nuts for machine guards?

15.15 A guard has a maximum opening size of 3/4 inch. The guard openings are 6 inches from the danger zone. Does the opening size meet requirements?

15.16 What is an awareness barrier? What is a jig guard?

15.17 Explain the terms *full revolution* and *part revolution* as applied to press clutches. Which is safer?

15.18 What is muting of safeguarding devices, and when is it permitted?

15.19 What is the principal reason that galvanized wire mesh is a better material for constructing machine guards than is ordinary screen mesh? (*Hint*: The answer is not rust prevention.)

15.20 What is the biggest disadvantage of pullbacks?

15.21 What is the difference between pullbacks and restraints?

15.22 A part-revolution clutch press has a brake stop time of 0.37 second. At what minimum distance should two-hand controls be placed?

15.23 Where should a presence-sensing device be placed on the press of Exercise 15.22?

15.24 If the press of Exercise 15.22 had been a full-revolution press operating at 60 rpm and having four engagement points, at what distance should a two-hand trip device be placed?

15.25 Would a two-hand control offer any improvement in the press of Exercise 15.24? What about a presence-sensing device?

15.26 What are the three biggest problems with grinding machines? Why are they so important from a safety standpoint?
15.27 What single characteristic of the point of operation can exempt a mechanical power press from the requirement for guarding or safeguarding?
15.28 Compare hazards for table saws that are used as ripsaws versus those used as crosscut saws.
15.29 What is the ring test?
15.30 How can compressed air used for cleaning be dangerous? Under what circumstances is it permitted?
15.31 When do shaft couplings need no guards?
15.32 The expanded metal mesh in a machine guard has a maximum opening size of 3/8 inch. What minimum distance from the point of operation can this guard be legally placed?
15.33 Describe the nature of frequent OSHA citations involving lockout/tagout.
15.34 Explain how a machine designed to be started and stopped with push-button on/off switches can be modified to qualify for lockout.
15.35 What is the meaning of guarding by location? How does guarding by location differ from guarding by distance?
15.36 Explain the term *zero mechanical state.*
15.37 Explain the term *energy isolation device.*
15.38 The term *shield guard* applies to which type of machine hazard?
15.39 Which of the fail-safe principles discussed in Chapter 3 applies to the term *zero mechanical state*?
15.40 What is generally the best color for a point-of-operation guard? Explain why.
15.41 Comment on the suitability of hand-feeding tools or tongs for safeguarding the point of operation.
15.42 Name the types of machine guards that are inappropriate for hand feeding the point of operation.
15.43 Discuss the comparative advantages of die enclosure guards versus fixed-barrier guards.
15.44 Explain likely outcomes when punch press dies close on a misaligned workpiece.
15.45 One recognized method of safeguarding the point of operation can be made safe for hand feeding if facilitated with hand tools or tongs. Name this method of safeguarding.
15.46 Is it legal to use a type B gate on a full-revolution press? Is it advisable? What is the potential hazard in using a type B gate on a full-revolution press?
15.47 Discuss at least two advantages of a friction clutch drive on a punch press versus a positive mechanical drive engagement.
15.48 List and describe all mechanical press setups for which a brake monitor and control system are required by standards.
15.49 List and describe all mechanical press setups for which it is legal to use hand feeding.
15.50 **Design Case Study.** A full-revolution press has 100 rpm flywheel rotation. The press is equipped with two-hand palm buttons mounted on the machine at a distance of 20 inches from the point of operation. How many engagement points on the flywheel would be necessary to make this machine safe?
15.51 What optional feature of presence-sensing devices is permissible to give the presence-sensing device the same production advantage that the type B gate has over the type A gate? Explain the advantage.
15.52 Explain the difference between the terms "brake monitor" and "brake-stop-time measurement device."
15.53 Relate at least two advantages of using infrared instead of visible light as the medium for presence-sensing devices.
15.54 What happens when the top-stop overtravel limit switch is tripped at the end of a press cycle?

15.55 The top-stop overtravel limit switch on a brake monitor for a mechanical power press is adjustable. What is the advantage of adjusting the overtravel high? What is the advantage of adjusting the overtravel low?

15.56 What characteristic of a hand-held circular saw makes the retractable blade guard even more important than it is on table saws or radial saws?

15.57 Describe two required features on a table saw that are intended to prevent kickback. Which one prevents kickback from starting and which one arrests the kickback motion if it does start?

15.58 Explain why large fixed-barrier guards can permit large distances between the guard and the point of operation and a coarser mesh for the guard material.

15.59 What is the difference between a power hacksaw and a band saw? Which is more difficult to guard? Why?

15.60 Explain the benefits of using a footswitch to trip a press in which the point of operation is protected by an infrared light screen.

15.61 Describe the disadvantages of awareness barriers in lieu of machine guards.

15.62 What design features of a presence-sensing system are permitted to improve system efficiency in the same way that type B gates improve workstation efficiency over type A gates?

15.63 Describe two advantages of using infrared light instead of visible light as the medium for a presence-sensing device.

15.64 Why should control pedestals, if used for punch presses, be rigidly fixed to the floor?

15.65 Comment on the relationship between the speed of a punch press and its safety. When is a slower machine usually better and when is a fast one better?

15.66 Identify a point of operation for which the hazard is not mechanical. What means of point of operation safeguarding can be applied to a point of operation that is not mechanical?

15.67 Do industrial robots make operations safer or more dangerous? Explain your reasoning.

15.68 What is the principal hazard of robots in the workplace? How can this hazard be mitigated?

15.69 Why might the public be less tolerant of injuries to workers caused by industrial robots than for injuries caused by other industrial machines?

15.70 Do safety standards require that a machine be bolted to the floor if the machine has bolt holes in its feet?

15.71 Is it illegal for press operators to place their hands in the dies to feed a punch press? Why is it so dangerous to feed a press by hand? What can be (and must be) done to deal with this hazard?

15.72 When servicing a robot and entering the work envelope, what must happen to ensure employee safety?

15.73 There is a reluctance to trust automation and self-driving cars. How do the fatality rates between self-driving cars and human-driven cars compare?

15.74 When was the first fatality due to a robot? When was the first fatality due to a self-driving car?

15.75 Why are barriers often needed for machines that remove chips during the cutting process?

15.76 Why might metalworking fluids contain biocides?

15.77 **Design Case Study.** A dirty process at a hot workstation requires a small ventilation fan to cool the face of the operator who is seated close to the point of operation. The problem is that the fan blades and wire mesh guard around the blades collect dirt and lint and frequently have to be taken apart and cleaned. Using the principles of engineering design from this chapter and also Chapter 3, specify a design change to more effectively deal with this hazard, protecting the operator while reducing production maintenance costs.

15.78 **Design Case Study.** A full-revolution press with two engagement points on the flywheel has two-hand palm buttons installed at a distance of 16 inches from the point of operation. Calculate the minimum flywheel speed that will permit this press to be in compliance with standards. Explain why a slower flywheel speed would be more dangerous.

15.79 **Design Case Study.** A workstation is being redesigned to increase its production rate to make it more competitive in an industry that competes in the global marketplace. The old workstation is a punch press operation, utilizing a full-revolution flywheel press employing a type A gate. By utilizing robot feeding, the production standard for this workstation is 600 units per hour. Describe three alternative designs for this workstation and explain why they should be capable of substantially increasing the production rate without violating safety standards. Qualify each alternative with a description of the disadvantages of each approach.

15.80 **Design Case Study.** In the press design of Exercise 15.79, suppose that the maximum available number of flywheel engagement points is 14. What modification of the mechanical drive would be needed to make the press setup described in Exercise 15.79 safe?

STANDARDS RESEARCH QUESTIONS

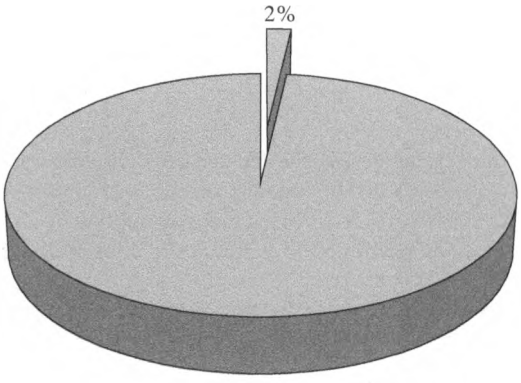
15.81 Review OSHA enforcement statistics to determine the frequency of citation for "general point-of-operation guarding." How does the OSHA standard for general point-of-operation guarding rank among all OSHA standards in terms of frequency of citation?

15.82 Review OSHA enforcement statistics to determine the frequency of citation for "point-of-operation guarding" on mechanical power presses.

15.83 Review OSHA enforcement statistics to determine the top three most frequently cited standards in the abrasive wheel machinery standard.

CHAPTER 16

Welding



Percentage of OSHA General Industry citations addressing this subject

After as broad a subject as machine guarding, it may seem ridiculously specific to address a field as narrow as welding. However, it may surprise some to learn that welding processes present some of the greatest hazards to both safety and health. In terms of breadth of hazard, this chapter encompasses even more than the chapter on machine guarding, and for that matter, more than any other chapter of this book.

The term *welding* is to be taken in a very broad sense to include gas welding, electric-arc welding, resistance welding, and even related processes such as soldering and brazing, which technically are not welding processes at all. Welding processes are so diverse that before addressing the hazards of these processes, it is necessary to name them and to provide the necessary background in welding process terminology.

PROCESS TERMINOLOGY

The key to understanding welding hazards is to know how the process itself works, and unless safety and health managers have this knowledge, their credibility with their manufacturing and operations counterparts will be minimal. Everyone knows that welding requires that material melt or fuse to form a rigid joint. The first question to ask to determine the process is "What material melts?" If the melted material is of the parts