# 9
# Machine Safeguarding

*John W. Mroszczyk*

## 9.1
## Introduction

Machinery has been an important part of the economy from the early days of the Industrial Revolution up to the present day. Machines are used by individuals, small businesses, and large manufacturers. Machinery has become more complex with advances in technology and the push for higher production rates. These advances have introduced new hazards in addition to the common, well-known hazards. For example, special eyewear and precautions must be applied during laser machining. Water jet machining introduces yet another set of hazards related to high-pressure water.

Machines by their very nature are designed to perform an operation on a raw material or to move, stack, and package material. This can involve any one or a number of operations such as bending, cutting, shearing, stamping, rolling, forming, drilling, and machining. Basic machine mechanical motions include rotary, reciprocating, and transverse motion. Power transmission equipment such as motors, belts, drives, gears, and pulleys is often used to power machines. All of these components that make up a ‘‘machine’’ will invariably create a pinch point or other hazards that can cause severe injury to the operator(s). The injuries can range from minor cuts to amputation and death.

The goal of machine safeguarding is to provide a safety device(s) to prevent the operator from contacting the dangerous moving parts or other hazards such as electrical, thermal, or fluids under pressure. Safeguards can range from a simple barrier guard which prevents the operator from accessing the dangerous area to a complicated control system that stops the machine if the operator enters a dangerous area and prevents the machine from starting until the operator is clear of that area.

This chapter provides a basic understanding of machine safeguarding. The ‘‘human interface’’ is discussed along with the nature and types of hazards. Standards and regulations are presented. Risk assessment, design methodology, and basic design guidelines are considered. Finally, some basic classes of machines and their hazards are discussed (OSHA, 2007).

*Handbook of Loss Prevention Engineering,* First Edition. Edited by J. M. Haight.

## 9.2
## Regulations and Standards

The Occupational Safety and Health Administration (OSHA) is the enforcement agency for workplace safety and health in the United States. The Code of Federal Regulations CFR 1910.212 provides general safeguarding requirements for all machines. OSHA requirements for specific types of machines are listed in Table 9.1.

The American National Standards Institute (ANSI) promulgates detailed safety standards for specific types of machines (Table 9.2). In particular, the ANSI B11 series cover safeguards for a range of machines. Underwriters Laboratories (UL) and the National Fire Protection Association (NFPA) standards address machine safety devices. Machines sold in the United States must comply with OSHA, ANSI, UL, and NFPA.

Machinery marketed in the European Union (EU) must comply with the European Machinery Directive (EMD). This is a legal requirement. The EMD requires that machinery meets the requirements as defined by the existing and emerging European standard or ''European Norm.'' The CE symbol is applied to a machine when the manufacturer certifies the machine conforms to the EMD. Within the EU there are three separate levels of machine safeguarding standards.

Type A standards are fundamental safety standards that provide basic concepts for machinery. Type B standards are group safety standards that address a specific safety aspect (Type B1), or one type of safety device (Type B2). Type C standards are machine-specific standards that provide detailed safety requirements for a particular type of machine. Table 9.3 gives a partial list of the EU standards. For a complete list of standards, see Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on Machinery at *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:284:0001:0047:EN:PDF*.

**Table 9.1** OSHA general industrial requirements for specific types of machines.

| Title | Section |
|---|---|
| Woodworking | 1910.213 |
| Abrasive wheels | 1910.215 |
| Mills and calendars | 1910.216 |
| Mechanical power presses | 1910.217 |
| Forging machines | 1910.218 |
| Mechanical power transmission apparatus | 1910.219 |
| Portable power tools | 1910.243 |
| Pulp, paper, paperboard mills | 1910.261 |
| Textiles | 1910.262 |
| Bakery equipment | 1910.263 |
| Laundry machines | 1910.264 |
| Sawmills | 1910.265 |
| Logging | 1910.266 |

**Table 9.2** ANSI B11 series of machinery standards.

| Standard | Title |
|---|---|
| ANSI B11.1 | Safety Requirements for the Construction, Care, and Use of Mechanical Power Presses |
| ANSI B11.2 | Safety Requirements for the Construction, Care, and Use of Hydraulic Power Presses |
| ANSI B11.3 | Safety Requirements for the Construction, Care, and Use of Mechanical Power Press Brakes |
| ANSI B11.4 | Safety Requirements for the Construction, Care, and Use of Shears |
| ANSI B11.5 | Safety Requirements for the Construction, Care, and Use of Ironworkers |
| ANSI B11.6 | Safety Requirements for the Construction, Care, and Use of Lathes |
| ANSI B11.7 | Safety Requirements for the Construction, Care, and Use of Cold Headers and Cold Formers |
| ANSI B11.8 | Safety Requirements for the Construction, Care, and Use of Drilling, Milling, and Boring Machines |
| ANSI B11.9 | Safety Requirements for the Construction, Care, and Use of Grinding Machines |
| ANSI B11.10 | Safety Requirements for the Construction, Care, and Use of Metal Sawing Machines |
| ANSI B11.11 | Safety Requirements for Gear and Spline Cutting Machines |
| ANSI B11.12 | Safety Requirements for Roll-Forming and Roll-Bending Machines |
| ANSI B11.13 | Safety Requirements for the Construction, Care, and Use of Single- and Multiple-Spindle Automatic Screw/Bar and Chucking Machines |
| ANSI B11.14 | Coil Slitting Machines – Safety Requirements for Construction, Care, and Use |
| ANSI B11.15 | Safety Requirements for Pipe, Tube, and Shape Bending Machines |
| ANSI B11.16 | Safety Requirements for Powder/Metal Compacting Presses |
| ANSI B11.17 | Safety Requirements for Horizontal Hydraulic Extrusion Presses |
| ANSI B11.18 | Safety Requirements for Construction, Care, and Use of Machines and Machinery Systems for Processing Strip, Sheet, or Plate From Coiled Configuration |
| ANSI B11.19 | Performance Criteria for Safeguarding |
| ANSI B11.20 | Safety Requirements for Integrated Manufacturing Systems |
| ANSI B11.21 | Safety Requirements for Design, Construction, Care, and Use of Lasers for Processing Materials |
| ANSI B11.22 | Safety Requirements for Turning Centers and Automatic, Numerically Controlled Turning Machines |
| ANSI B11.23 | Safety Requirements for Machining Centers and Automatic, Numerically Controlled Milling, Drilling and Boring Machines |
| ANSI B11.24 | Safety Requirements for Transfer Machines |

## 9.3 Machine Motion Hazards

There are fundamental machine motions and actions that give rise to mechanical hazards which are illustrated in Figure 9.1. *Rotary motion* is common to a large number of machines such as shafts, cams, clutches, flywheels, power transmission

**Table 9.3** Partial list of European Union (EU) Standards.

| Standard | Title |
|---|---|
| *Type A standards* | |
| EN ISO 14121-1:2007 | Safety of machinery. Risk assessment Part 1: Principles (which supersedes EN 1050:1996) |
| EN ISO 12100-1:2003 | Safety of machinery. Basic concepts, general principles for design. Basic terminology, methodology |
| EN ISO 12100-2:2003 | Safety of machinery. Basic concepts, general principles for design. Technical principles |
| *Type B standards* | |
| BS EN ISO 13857 | Safety of machinery. Safety distances to prevent hazard zones being reached by upper and lower limbs |
| BS EN ISO 13850:2006 | Safety of machinery. Emergency stop. Principles for design |
| EN 574 | Safety of machinery. Two-hand controls |
| BS EN 953:1997 + A1:2009 | Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards |
| BS EN 954-1:1997 (replaced by BS EN ISO 13849-1:2006) | Safety of machinery. Safety-related parts of control systems. General principles for design |
| EN ISO 13849-1:2006 | Safety of machinery. Safety-related parts of control systems. General principles for design |
| ISO 13849-2:2008 | Safety of machinery. Safety-related parts of control systems. Validation |
| EN 981 | Safety of machinery. System of auditory and visual danger and information signals |
| BS EN 999:1998 + A1:2008 | Safety of machinery. The positioning of protective equipment in respect of approach speeds of parts of the human body |
| BS EN 1037:1995 + A1:2008 | Safety of machinery. Prevention of unexpected startup |
| EN 1088 | Safety of machinery. Interlocking devices associated with guards. Principles for design and selection |
| EN 60204-1 | Safety of machinery. Electrical equipment of machines. Specification for general requirements |
| *Type C standards (examples)* | |
| BS EN 692 | Mechanical presses – safety |
| BS EN 693 | Hydraulic presses – Safety |
| BS EN 422 | Rubber and plastics machines |
| BS EN 1034 | Paper making and finishing |
| BS EN 415 | Packaging machines |

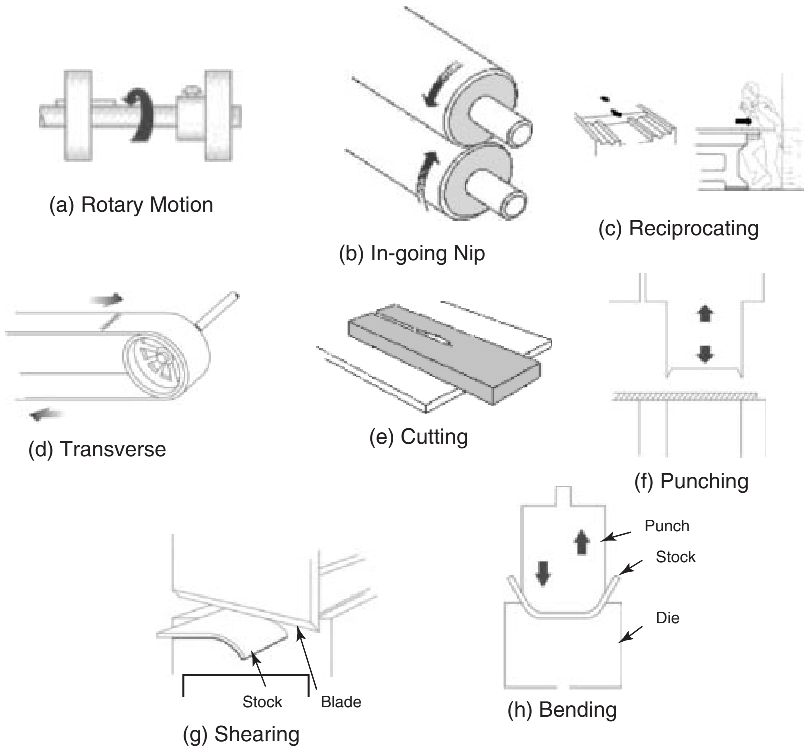


**Figure 9.1** Fundamental machine motions and actions that give rise to mechanical hazards.

equipment, belts, chain drives, gears, worm drives, power take-off systems, and spindles. Even a smooth rotating shaft can grip clothing or draw in a bare arm or hand. The hazard associated with a rotating shaft is illustrated by the following case study (NIOSH, 1994):

> A 47-year-old woman was baling hay on a windy day. After positioning the tractor throttle on idle but not disengaging the PTO, she dismounted and walked towards the back of the tractor past a rotating secondary driveline that powered the bale thrower. This driveline was located 4 ft above ground and was guarded by a tunnel guard (i.e., an inverted U-shaped guard) that left the underside of the driveline exposed. While the woman was at the rear of the baler, her hair became entangled around the driveline. The rotating driveline tore her entire scalp from her head.

Another case study also illustrates the dangerous nature of unguarded, rotating parts (NIOSH, 2009):

> A 38-year-old machine operator was strangled when his shirt got caught on a rotating knob of a printing machine. The printing machine was

not manufactured with guards over the rotating knobs, and there was no mechanism to ensure that the knobs stopped rotating when the employee checked the ink tray status.

The likelihood of entanglement in a rotating shaft is increased many-fold if the shaft has a protruding set screw or a keyway, or has an irregular shape.

An *in-running nip point* is another hazard common to rotating components and is formed when parts rotate near a stationary object, or rotate in contact or near other rotating part(s). Intermeshing gears, rolling mills, and calendars contain parts that rotate in opposite directions while their axes are parallel to each other. A rack and pinion has a nip point that is created between rotating and tangentially moving parts. Nip points can also be created between a rotating and fixed part such as spoked flywheels or screw conveyors.

*Reciprocating motion* (back and forth or up and down motion) is another common hazard producing motion. A worker can be trapped between the reciprocating component and a fixed object. Reciprocating machine parts can be found in surface grinders, textile machines, or any machine that has a moving bed. Straight line or *transverse motion*, can draw a body part into other hazardous moving parts, a point of operation, or an in-running nip point. Conveyors are a class of machines that have transverse moving parts.

There are many points of operation actions that create machine hazards. *Cutting action* takes place when a sharp tool crosses a stationary object. Band saws, circular saws, drilling machines, lathes, and milling machines all have cutting action machine hazards. Punching, shearing, and bending actions involve machine parts coming together and resulting in a pinch point. *Punching action* occurs when power is applied to a ram and closes a die. The die can trap body parts between the closing halves. This type of machine hazard is common in the manufacture of sheet metal parts. *Shearing action* involves a slide or knife that is used to trim or shear material. *Bending action* bends metal or forms it into hollow enclosures.

Laser and water jet machining provide cutting action through concentrated light or a high-velocity water jet. In addition to cutting, these machines have additional hazards. In the case of laser machines, special eyewear and precautions must be applied. High-velocity water jet systems pose additional hazards from high-pressure water.

## 9.4 Human Factor Aspects of Machine Guarding

Machinery accidents are usually the result of a machine hazard and an operator action. Although operators rarely seek to injure themselves deliberately, there is a tendency to blame the operator after a machinery accident (Cohen and Cohen, 1991; Stern and Keller, 1991). Human operators make mistakes for a variety of reasons (Mroszczyk, 2010). The machine designer should take the human operator into account when designing a machine system and strive to design machines that are "human error proof" as much as possible. Any machine or equipment that can be used incorrectly *will* someday be used incorrectly (Hammer, 1972). It is the present author's experience that too many machine designers and builders rely on the operator always to do the right thing rather than design out hazards. The notion of addressing hazards in the design phase rather than relying on the operator's consistent obedience to safety rules is not new: it dates as far back as 1946 (NSC, 1946).

Table 9.4 lists of some of the important human characteristics that come into play in the workplace. It is by no means an exhaustive list. More information can be found in publications such as Hammer (1972), Van Cott and Kincade (1972), Stern and Keller (1991), and Woodson *et al.* (1992).

*Inattention* is exhibited by everyone at one time or another. It may be a natural trait, or the result of fatigue, boredom, or lack of motivation. Incorporating a means to attract the operator's attention is one way to reduce accidents from operator inattention. Humans are easily *distracted* and can lose their train of thought (Woodson *et al.*, 1992). Most people *hurry* from time to time. When they hurry, they do not react carefully, or may not think things through. Designing operator machine tasks that keep pace with human response should be considered (Woodson *et al.*, 1992).

Almost everyone takes some *risk* at some time. Risk taking is more typical of young people (Woodson *et al.*, 1992). Designers should anticipate risk-taking behaviors and design the machine to eliminate the hazards posed by risk taking. *Overconfident* people usually proceed without thinking (Woodson *et al.*, 1992). Everyone *forgets* occasionally. Forgetting a critical step can have drastic consequences (Woodson *et al.*, 1992). People are easily *confused* by the unfamiliar or the complex (Woodson *et al.*, 1992). A hazardous machine increases the number of functions that the operator must process. People may lack the *manual dexterity* or *physical skill* to operate equipment (Woodson *et al.*, 1992). Design machine controls that require little physical skill. There are many undesirable reactions that are the result of *fear, panic,* and *uncertainty*. *Pain* often leads to automatic recoil (Woodson *et al.*, 1992). A person may jump back after receiving an electric shock. A driver may freeze to the wheel or accelerator. People generally assume that a product or equipment is safe. As a result, they assume that the system is ready to go without performing preliminary checks (Woodson *et al.*, 1992).

## 9.5 Machine Safeguarding Methodology

The most effective and economical time to design safety into machines is in the initial design stage (Ridley and Pearce, 2006). The first step in machine safeguarding is to identify the hazard(s) and assess the risk associated with each hazard. If the risk is unacceptable, then the design protocol, also known as the *hierarchy of engineering controls* (see Table 9.5), is first to eliminate the hazard in the design process (highest priority). If this cannot be done, then the risk should be reduced to an acceptable level. In most cases involving machines, this will not be possible.

**Table 9.4** Basic human characteristics [based on Van Cott and Kincade (1972), Stern and Keller (1991), and Woodson *et al*. (1992).

| Behavior | Safety implications | Design considerations |
|---|---|---|
| Lack of attention | Attention lapses can result in failure to recognize a hazardous situation, understand an instruction, or see a warning light | Anticipate the possibility of inattention. Take steps to preclude misuse and provide a means to attract attention |
| Boredom | Boredom degrades performance | Strive to design machine tasks that reduce the onset of boredom and/or reduce its severity or consequences. Avoid repetitive tasks |
| Distraction | Distraction from the primary task may cause users to miss an important step | Consider potential use procedures to eliminate distractions and/or provide a stimulus to maintain procedural continuity |
| Lack of physical ability | Humans differ in strength, sensory abilities, and the capacity to withstand stress | Consider these variables when designing equipment |
| Deliberate risks and shortcuts | When a risk taken by the user cannot be fully evaluated, a failure will occur. Usually the user has neither the time or the knowledge to make an evaluation of the risk | Anticipate possible risk taking and short-cutting. Design the machine to preclude short-cutting or make the consequences less severe |
| Humans can be in a hurry | When people hurry that tend not to observe or react carefully | Recognize the possibility that the user will be in a hurry. Design procedures that keep pace with the user's response |
| Performing steps out of sequence | An operator may conduct a step or execute a control switch out of order, which may cause an injury | Design controls that prohibit an operator from executing a control out of order, and/or minimize the risk of an injury from performing a step out of sequence |
| Variations in individual skill, experience, training | There is a greater opportunity for error if the operation of the machine is highly dependent on individual skill, experience, or training | Try to design machines that do not require great dexterity, lower physical and mental strain |
| Forgetting | Users may forget a critical step which can have disastrous consequences. Users can also forget about something they know is dangerous | Anticipate the possibility of forgetfulness and design out crucial features where such omissions could lead to injury |
| Confusion | Users are easily confused by complexity. This increases the time required to respond resulting in an unsafe condition | Simplify the involvement of the operator |

**Table 9.5** Hierarchy of engineering controls (Hagan, 2009).

| | |
|---|---|
| 1. | Eliminate the hazard or design for minimum risk |
| 2. | Incorporate safety devices |
| 3. | Provide warnings |
| 4. | Operating procedures and training |
| 5. | Provide personal protective equipment |

**Figure 9.2** A turret winder used in the plastics industry.

For example, in the case of a metal shearing machine, the hazard is the pinch point created by the stationary and moving blades. Eliminating the hazard would require elimination of the blades, which would render the machine unusable. The next design intervention would be to provide or design safety devices. These might include, for example, a barrier guard, two-hand controls, or other safety devices. The risk is then reassessed and the design process repeated until an acceptable level of risk is reached. Warnings should then be provided to warn the user of any residual risks. Operating procedures, training, and personal protective equipment should be considered when eliminating the hazard (or reducing the risk) and safety devices are not practical (lowest priority).

An example of an instance where an operating or administrative procedure may be relied upon is in the design of a turret winder as shown in Figure 9.2. A turret winder is an arrangement of two or more parallel winding positions spaced around a common axis. They are commonly used in the plastics industry to wind webs of plastic film and sheet. Operators need access to the turret winder to thread a new or broken web and to remove full rolls. Completely surrounding the machine with a fixed barrier guard may not be practical. Safety mats and light curtains can be effective in disabling the winder when the operator steps into a hazardous area. However, there are instances where the operator must start a new web by manually attaching the sheet to a rotating core. Under these circumstances, safety devices may not be practical and administrative or special procedures should be put into place. For example, two operators should be present. The core rotation rate is slowed and it is coated with adhesive or double-sided tape. The first operator attaches the web to the surface of the core. The second operator is positioned at an emergency stop button and monitors the first operator. The second operator immediately stops the machine if the first operator becomes entangled (ANSI, 2000a).

In many cases, a combination of measures may be required. However, a lower priority design intervention should not be chosen until all higher level priority interventions have been exhausted. Under no circumstances should the application of warnings, operating procedures, or training be relied upon as the sole injury prevention measure if designing out the hazard(s) and/or the application of safety devices are possible and practical.

A risk assessment should be made to ensure that a machine design will be safe throughout its operational lifetime. A hazard is defined as any situation that can cause harm or damage. Risk is the product of the severity of the harm and the probability of an occurrence. Risk assessment is generally a subjective analysis except in those cases where failure rates and/or statistical data are available for the machine components. All aspects of a machine's operation should be included in the risk assessment. This would include:

- normal operation of the machine as defined by the specifications and operating manual
- malfunction or failure of any of the components
- ergonomic hazards
- alternative uses of the machine
- cleaning and maintenance of the machine
- foreseeable misuse of the machine
- operator error
- human behavior
- hazards that may arise if maintenance is not done or not done properly
- hazards that may arise if the machine is not assembled or reassembled properly
- wear and tear
- failure to follow operating instructions
- hazards that may arise due to a power failure
- machine adjustments or set points that may vary or degrade over time.

There are a number of analytical techniques that can be used to identify hazards, and some of these techniques are listed below. More information on methodologies on hazard identification can be found in other chapters in this book and the references in this chapter such as Hammer (1972), MacDonald (2004), Ridley and Pearce (2006), and Mroszczyk (2010).

- **''What if'' analysis** – A ''what if'' analysis is basically a structured brainstorming session. The analysis starts with assembling an experienced, knowledgeable team. The individuals chosen for the team should be experienced in design, standards, regulations, previous maintenance issues, previous assembly problems, power failures, field problems, past history, potential failure modes, foreseeable use,

**Table 9.6** Hazard severity and probability of occurrence levels for risk assessment.

| Hazard severity | Probability of occurrence |
|---|---|
| *Catastrophic* – death, amputation, permanent disability | *Frequent* – likely to occur often |
| *Serious* – serious debilitating injury, able to return to work after a period | *Probable* – will occur several times |
| *Marginal* – significant injury requiring more than first aid, able to return to work at same job | *Occasional* – likely to occur sometime |
| *Negligible* – no injury or injury requiring no more than first aid, little, or no lost work time | *Remote* – unlikely, but possible |
| | *Improbable* – so unlikely as to be near zero |

and misuse. Questions are posed. The answers to the questions can shed light on the potential hazards of the system.

- **Fault simulation of control systems (FSCSs)** – FSCSs determine the potential hazards that may arise from a failure or malfunction of the control system.
- **Fault tree analysis (FTA)** – FTA is a top-down logic analysis in which the hazards and faults can be traced.
- **Failure mode and effects analysis (FMEA)** – FMEA is a systematic list that includes the failure mode, the effects of each failure, the safeguards that exist, and the additional actions that can be taken.

Information regarding hazards can also be found from:

- examining accident reports on identical or similar machines
- industry trade magazines and journals
- observing the machine or a prototype machine during operation
- following up with end users.

A very popular and simple method to assess risk is the use of qualitative assessments of severity and probability of occurrence together with a risk matrix. Table 9.6 lists the hazard severity and probability of occurrence levels that can be used with this method.

The risk can be estimated using the matrix provided in Table 9.7 once the severity of harm and the probability of occurrence have been estimated.

EN ISO 14121-1:2007 Safety of Machinery – Risk Assessment expands hazard identification to include transport, assembly and installation; commissioning; use; and decommissioning, dismantling, and disposal. Levels of training of the operators, maintenance personnel, trainees, and the general public are included, in addition to exposure of operators to adjacent machinery, non-operators in the adjacent area, and visitors.

**Table 9.7** Matrix that can be used to assess risk once the severity and probability have been estimated.

| | Severity of harm | | | |
|---|---|---|---|---|
| **Probability of harm** | **Catastrophic** | **Serious** | **Marginal** | **Negligible** |
| Frequent | 1A | 2A | 3A | 4A |
| Probable | 1B | 2B | 3B | 4B |
| Occasional | 1C | 2C | 3C | 4C |
| Remote | 1D | 2D | 3D | 4D |
| Improbable | 1E | 2E | 3E | 4E |

| Hazard risk assessment | Suggested action |
|---|---|
| 1A, 1B, 1C, 2A, 2b, 3A | Unacceptable, risk reduction is necessary |
| 1D, 2C, 2D, 3B, 3C | Unacceptable if personnel exposed to hazard |
| 1E, 2E, 3D, 3E, 4A, 4B | Acceptable with management review |
| 4C, 4D, 4E | Acceptable without management review |

## 9.6 Basic Machine Guarding Principles

There are a number of basic machine guarding principles that should be considered. These principles come from the author's many years of experience in machine guarding and the references in this chapter.

- A guard should prevent hands, fingers, arms, and other body parts from making contact with the dangerous areas of the machine.
- The guard should be secured and designed so that it cannot easily be removed by the operator. A guard that is easily removed or falls off will not protect the operator.
- A guard should ensure that objects will not fall into the moving parts of the machine. A small tool or object that falls into the moving parts of a machine can become a projectile. The guard should also protect the operator from chips of metal, wood, broken tools, or objects that may be ejected from the work piece area.
- A guard should not interfere with the operation of the machine. Such a guard does no good if a frustrated operator removes it.
- The guard should not create its own hazards. Sharp or jagged edges should be ground down or the edges should be rolled to eliminate the chance of a laceration injury. A guard should not create its own nip points.
- A guarding system should be well constructed and thought out. It should be an integral part of the machine, not a last-minute afterthought. Such a guard would

require special tools to remove it and should render the machine inoperable if it is removed. A manual restart should be required to resume operation when the guard is put back in place.
- It should be difficult to remove the guard or bypass the system. The guarding system should be fail-safe. The system should require a default condition to be cleared before the operation can be resumed. A manual restart should be required.
- In many machine operations, the guard should accommodate work piece feeding and ejection.

The following case study illustrates the design principle that a guard should not create a pinch point (NIOSH, 2000):

> A 33-year-old textile worker (the victim) died after being pinned between a bobbin lift/dump and a guardrail upright. The victim was operating the bobbin lift/dump in the yarn preparation department of the plant. Empty bobbins were collected in hoppers that were manually pushed up a ramp on to the lift/dump. The lift/dump was then raised and rotated in a counterclockwise direction, dumping the bobbins into a hopper equipped with a belt conveyor that transferred the bobbins to another area of the plant. A guardrail was placed 4 inches in front of the lift dumper. The machine was operated by reaching through the guardrail and pushing the control lever to the left or right to raise or lower the lift/dump. When released, the control lever would return to center. The lift/dump would not move unless the control lever was placed in the raise or lower position.
>
> The machine involved in this incident was guarded in front to provide a barrier between the moving parts of the machine and the machine operator; however, a pinch point existed between the guardrail and the side of the lift/dump. When the victim placed himself between the guardrail and the side of the machine and lowered the dumper, he was pinned between the two surfaces.

## 9.7 Types of Machine Safeguarding

There a number of guards and devices that can be chosen to prevent contact with machine hazards. Barrier guards prevent access to moving parts by placing a physical barrier between the operator and the hazard. Fixed guards can be adequate when access to the dangerous area is normally not required. A fixed guard should be held in place with fasteners that require a tool to remove. The fasteners should not loosen under machine operation or vibration. Figure 9.3 shows a fixed barrier guard secured with bolts on a bakery dough processing machine.

An interlocked guard stops the machine when the guard is moved out of the way, for example, to clear a jam. The guard must be put back in place to restart the machine. The controls should be configured so that the machine will not start up again after the guard is replaced without a manual restart. Figure 9.4 shows an interlocked guard on a pizza dough machine. The machine stopped when the

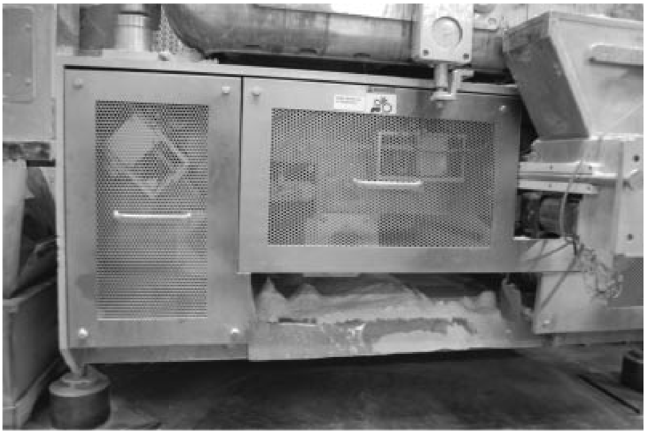

**Figure 9.3** A fixed barrier guard secured by bolts, screws, or nuts may be sufficient when access to moving parts is not normally required, or is required only on an infrequent basis.

**Figure 9.4** An interlocked guard over the rollers of a pizza dough machine. A manual restart should be required to start the machine after the guard is put back in place.

guard was removed. However, the machine started again when the guard was replaced because the machine controls did not have a manual restart. A worker received a serious injury when a cleaning rag that he was holding was pulled into the machine along with his arm after he replaced the guard. Interlocking switches should be designed to fail in a ''fail-safe'' mode, that is, a switch failure stops the machine. Figure 9.5 shows an example of an interlocked cover that was used on a duct cleanout port to prevent the operator from contacting moving parts when the cover is removed. This particular interlock has a time delay which prevents removal of the cover until the motor has stopped. The following incident is a situation where a fence with an interlocked gate would have prevented a fatality (NIOSH, 2002):

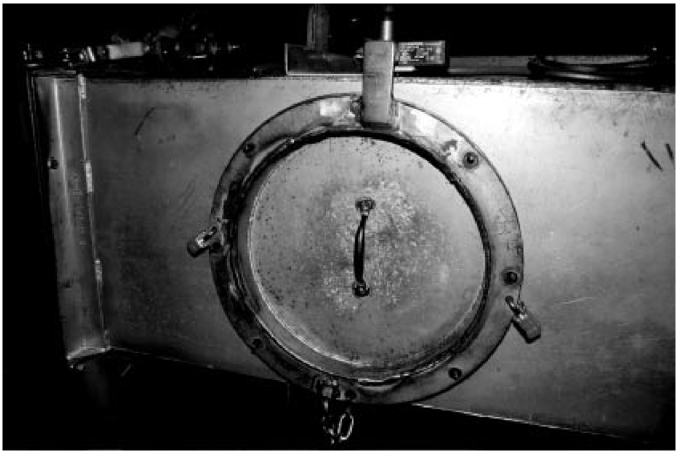

**Figure 9.5** An interlocked cover is used on a duct cleanout port to prevent the operator from contacting moving parts if the cover is removed.

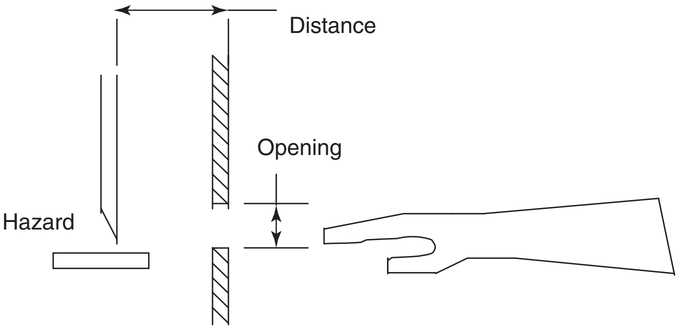


**Figure 9.6** An opening in a guard should be placed at a distance from the hazard that prevents the operator from reaching into the danger area.

> A worker was fatally injured in an automatic masonry block-making machine. Concrete mix is poured into molds. The molds are transported into a kiln for curing. The blocks are then removed from the molds and conveyed to a patternizer and cuber, two interconnected machines that arrange the blocks into a pattern so that they can be neatly stacked. The worker attempted to clear a jam in the cuber. He stood on a frame member and leaned into the cuber to rearrange the blocks with a hooked metal rod. As the machine cycled, the victim's head became caught between the moving arm and a large stationary bolt securing a frame member.

It may be necessary to create an opening in a barrier guard, for example, for stock feed, finished part removal, conveyors, hydraulic lines, electrical conduit, or piping. The opening should be located a certain distance so that the operator cannot reach through the opening to the danger area (Figure 9.6). The distance depends on the

**Table 9.8** Maximum guard openings versus distance from hazard (ANSI B11.1).

| Opening | Minimum distance |
|---|---|
| 0–6 mm (0–0.240 in) | 13 mm (0.5 in) |
| 6.1–11 mm (0.250–0.375 in) | 64 mm (2.5 in) |
| 11.1–16 mm (0.376–0.625 in) | 89 mm (3.5 in) |
| 16.1–32 mm (0.626–1.250 in) | 166 mm (6.5 in) |
| 32.1–49 mm (1.251–1.875 in) | 455 mm (17.5 in) |
| 49.1–132 mm (1.876–5.000 in) | 915 mm (36.0 in) |
| >132 mm (>5.0 in) | Not permitted |

**Table 9.9** Safe distances for hand and arm reach through a guard (Ridley and Pearce, 2006, based on EN294) and types of opening.

| Body part | Opening, $e$ (mm) | Slot (mm) | Square (mm) | Round (mm) |
|---|---|---|---|---|
| Finger tips | $e < 4$ | <2 | <2 | <2 |
| | $4 < e < 6$ | >10 | >5 | >5 |
| Finger to knuckle or hand | $6 < e < 8$ | >20 | >15 | >5 |
| | $8 < e < 10$ | >80 | >25 | >20 |
| | $10 < e < 12$ | >100 | >80 | >80 |
| | $12 < e < 20$ | >120 | >120 | >120 |
| | $20 < e < 30$ | >850 | >120 | >120 |
| Arm up to shoulder | $30 < e < 40$ | >850 | >200 | >120 |
| | $40 < e < 120$ | >850 | >850 | >850 |

size of the opening and the body part. Table 9.8 gives guard opening distances from ANSI B11.1. For example, a 1 in (25.4 mm) opening in a guard should be no closer to the danger area than 6 1/2 in. Table 9.9 shows opening distances from Ridley and Pearce (2006). Using Table 9.9, a 1 in square opening should be 120 mm (4.724 in) from the danger area.

Self-adjusting guards cover the dangerous parts of the machine, retract as the material is worked on, and then automatically return to the original position when the work is finished. Self-adjusting guards can be found on miter saws and hand-held circular saws.

Safeguarding devices prevent or stop machine operation when the operator enters a danger zone. These devices include light curtains, capacitance fields systems, perimeter light beams, pressure-sensitive edge devices, and safety mats. Figure 9.7 shows light beams mounted at each end of a rewinder machine to protect the operator from web-generated nip points. The machine will not start unless the beams are aligned. The machine will stop if the beam is interrupted. A light beam system with a brake to stop the machine rotation would have prevented a fatality in the following instance (CA/FACE, 2006):

**Figure 9.7** Light beams can be used to protect the operator from moving parts.

> A 45-year-old machine operator died when he became caught in the threads being wound on to the unguarded spool of a warping machine. A warper machine draws nylon thread from 600 spools of thread mounted on a rack called a ''creed'' behind the machine. The threads are wound around a large drum using various speeds and tension, and then cut into sections. The ends of those threads are then fed on to a smaller removable spool mounted on the front of the machine. When the smaller removable spool was full, it was replaced with an empty spool. The operator's job was to control the speed and tension on the threads being wrapped around the spool and to replace the spool when full. The operator was reaching towards the thread and take-up spool when he became caught in the threads being wound on to the spool. He activated the emergency stop, but was completely wrapped in thread before the machine stopped.

Hold-to-run and two-hand controls require the operator's hands to be clear of moving parts to activate the machine. Hold-to-run controls require the operator to maintain pressure on a control switch to activate the machine. Releasing the switch stops the machine. A two-hand control requires that two buttons be activated simultaneously to activate the machine. The two buttons should be well separated so that the operator cannot activate them with one hand or a hand and an elbow. Figure 9.8 shows a two-hand control fitted to a printing machine that prevents activation of the machine until the operator's hands are clear of moving parts. Pullbacks are cables that are attached to the operator's hands which pull the operator's hands out of the danger area when the machine is cycled. Holdback restraints prevent an operator from reaching into a dangerous area.

Grab wires can be used on long machines, such as conveyors, when other methods of safeguarding may not be practical. The grab wires should run the full

**Figure 9.8** A two-hand control prevents activation of the machine until the operator's hands are clear of the danger area.

**Figure 9.9** A safety bar on a truss machine. Unlike the safety bar shown in the photograph, a safety bar should be of rigid construction and have redundant limit switches.

length of the machines and be within easy reach of anybody who might be caught in moving parts. Movement of the wire should open a switch and stop the machine.

Pressure-sensitive body bars, trip rods, and foot treadles are safety devices designed to stop a machine if the bar, rod, or treadle is displaced. These devices should be of rigid construction and have redundant limit switches. Figure 9.9 shows a safety bar on a truss machine. The gantry shown in the photograph moves on wheels that roll along on side rails. It is powered by a 10 hp motor and is controlled by a joystick from the operator's platform. The gantry passes over the tables and presses the wooden trusses together. The design intent of the safety bar is to provide a means for a worker to stop the gantry from moving if the operator activates the machine while a worker is still in the table area. This particular safety bar was not of rigid construction. It was designed with a horizontal bar attached to a pivot arm at each end with screw collars. There was only one limit switch that

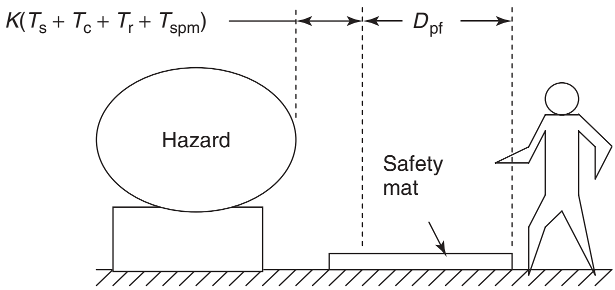


**Figure 9.10** Nomenclature for calculating safe distance.

was mounted on one of the pivot arms. Machine vibration loosened up the screw collars, creating ''play'' in the safety bar. When the worker pushed on one end of the safety bar to stop the machine, the limit switch that was located on the pivot arm at the opposite end did not activate. The moving gantry crushed the worker's leg.

Guarding by location assumes that a dangerous part of a machine does not need a barrier guard or other safeguarding device because it is located in an area that is normally not accessed by the operator. Rotating shafts located underneath machines and hazards high enough above the plant floor that they would require at least a step-ladder to reach are sometimes left unguarded for this reason. This safeguarding strategy is dangerous (Gallagher, 1990). Although the hazard may not normally be within reach, an operator may come in contact with a dangerous part of a machine when cleaning, sweeping, removing waste, or climbing up high to do maintenance. When this occurs, management makes the claim that the operator's actions were not foreseeable. The operator is then criticized for acting irrationally, carelessly, or violating company policy.

Situations where guarding by location is contemplated in lieu of a barrier guard or other safety device should be seriously evaluated.

Awareness barriers allow access to a dangerous part of a machine, but contact the operator in such a way that they are made aware that they are close to the danger point. Awareness barriers are used on machines such as metal shears which require the operator to feed or hold the metal close to the nip point. Awareness barriers do not prevent an operator from reaching into the dangerous area of a machine and should therefore only be used as a last resort.

Safeguards such as interlocked barrier guards, two-hand controls, two-hand trip devices, single control devices, electro-optical presence sensing, safety mats, and safety edge devices should be located at such a distance from the hazard that the hazardous motion is stopped before the operator reaches the hazard. The equation for calculating the safe distance (see Figure 9.10) is (ANSI, 2009a, B11.1)

$$D_s = K\left(T_s + T_c + T_r + T_{spm}\right) + D_{pf} \tag{9.1}$$

where

$D_s$ = safe distance

$K$ = the maximum speed at which an individual can approach the hazard

$T_s$ = stopping time
$T_c$ = reaction time of control system
$T_r$ = reaction time of device
$T_{spm}$ = stopping performance monitor to account for gradual increase in stopping time caused by degradation
$D_{pf}$ = depth penetration factor.

The factor $K$ is the maximum speed at which an individual can approach the hazard. For example, a common value for horizontal motion of the hand and arm is 1.6 m s$^{-1}$ (63 in s$^{-1}$). The factor $T_s$ is the time it takes the hazardous motion to stop. This depends on the type of machine. Some machines cannot be stopped during a machine cycle. Control systems have a delay from the time an input is received to the time a command is initiated ($T_c$). Safeguarding devices have a delay from the time they sense a presence. This is accounted for by $T_r$. The factor $T_{spm}$ accounts for factors such as increase in stopping time due to degradation or the variation in stopping time during different portions of a machine cycle. A device may not sense an operator exactly at the sensing plane or the edge of the device. For example, electro-optical devices do not detect operator presence until there is an amount of penetration into the sensing field. An operator can step over the edge of a safety mat before stepping down. The depth penetration factor $D_{pf}$ accounts for this. $D_{pf}$ = 1200 mm (48 in) for a safety mat.

## 9.8 Machine Controls

Machines can have one or more operating modes, such as automatic, manual, normal, and bypass. Mode selection by itself should not initiate machine operation and inadvertent mode selection should not cause a hazardous condition. A lock-out device preventing automatic operation should be provided when it is necessary to override machine safeguards temporarily.

The controls should have one or more of the following capabilities for use when safeguards are suspended for maintenance and troubleshooting operations that require power to the machine:

- A hold-to run or jog control device.
- A portable control station (pendant) with an emergency stop button. The machine should only be capable of being controlled using the portable station.
- A means to limit the speed or power of the machine motion.
- A means to limit the range of the machine motion.

The controls should have a means to lock out the power when the machine must be stopped for maintenance, repair, or troubleshooting.

Controls should be designed to prevent inadvertent actuation. This can be accomplished by one of the following:

- Recess controls so that they do not protrude above the control panel.

**Figure 9.11** A pull-to-engage toggle switch reduces the likelihood of inadvertent activation.

**Figure 9.12** A shielded foot pedal control with a toe-kick will reduce the likelihood of inadvertent activation of a machine.

- Place a raised barrier around the control.
- Locate controls so they are unlikely to be hit accidentally.
- Use protective covers or guards.
- Lock controls in position.
- Require sequential application of a force in at least two directions.

For example, a pull-to-engage toggle switch (Figure 9.11) reduces the likelihood of inadvertent activation because the user must pull the toggle out and then up to engage the switch. A shielded foot pedal control with a toe-kick will reduce the likelihood of inadvertent activation of a machine (Figure 9.12).

Flashing lights can be used to attract attention, require immediate action, indicate a discrepancy between the command and actual machine states, or indicate a change

**Figure 9.13** A flashing beacon light can be used to alert an operator whether a machine is in automatic or manual mode. The light should be located close to the machine where the operator can see it while attending the machine.

in process. Figure 9.13 shows a flashing beacon light that was used to alert an operator whether a machine is in automatic or manual mode. The light should be located close to the machine where the operator can see it when working on the machine. The light shown in Figure 9.13 was located behind where the operator would be standing. The operator received a serious crushing injury while clearing a jam when the machine, which was still in automatic mode, cycled. He did not recognize that the machine was in automatic mode because the beacon light was located behind him.

There should always be an emergency stop button(s). The emergency stop button(s) provide(s) a means of last resort and should be placed within reach of the operator around the machine at each operator control station and other areas where an emergency stop may be required. The emergency stop button should override all other controls and stop the machine. Releasing the emergency stop should require resetting the machine controls before the machine will start. The emergency stop button should be the large mushroom head type and colored red. The background immediately around the emergency stop buttons or actuators should be colored yellow.

The emergency stop button should protrude out from the surface of the panel. Figure 9.14 shows a control panel with an emergency stop button.

A safeguard control system must be reliable. This will often require that a control system and emergency stop provide a self-checking, independence output. The input from the safety device is fed to a safety control module which performs a self-checking operation to ensure safety reliable output to the system.

Consider the probability of ‘‘2.’’ Using two safety devices to protect against the same hazard greatly increases the system reliability. The failure rate of a crucial safeguard limit switch is P1. Adding a second (redundant) identical limit switch will reduce the system failure rate to P1 × P1, which will usually be several orders of magnitude less than P1.

Controls should fail in a ‘‘fail-safe’’ mode, that is, a failure of a control system stops the machine and prevents restart until the fault is cleared.

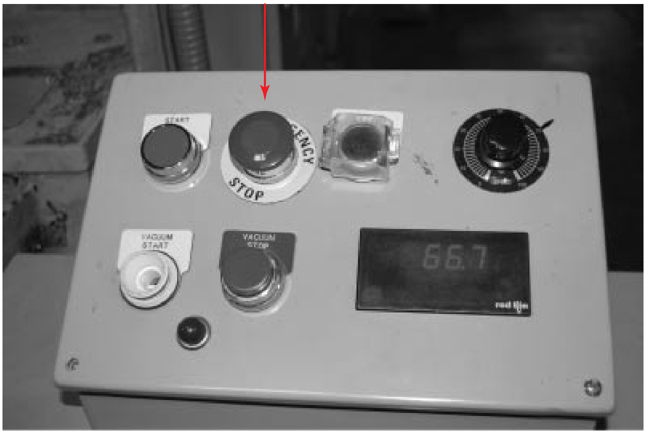


**Figure 9.14** An emergency stop button should be located on every control panel. The button should be a red "mushroom" type with a yellow background (arrow).

## 9.9 Responsibilities of the Machine Builder

The responsibilities of the machine builder include (Gallagher, 1991; Ridley and Pearce, 2006):

- Carry out a design risk assessment.
- Incorporate state-of-the-art safeguarding methods to eliminate the hazard or reduce the risk to an acceptable level.
- Comply with all applicable safety standards and legislature regulations.
- Consider that standards and regulations are generally only minimum requirements. It may be necessary to go beyond standard requirements to ensure safety.
- Ensure that all components have a high degree of reliability.
- Obtain feedback from users of similar or identical equipment to identify hazards and/or improve the safety of their machines.
- Ensure compatibility of controls if the machine will be interfaced with other machines in a production line.
- Provide safety bulletins to end users and/or upgrade kits as newer, safer technology becomes available or if new hazards are uncovered.
- Monitor field usage.

The responsibilities of the machine supplier or machine re-seller include:

- Ensure that the machine meets the relevant safety standards and regulations.
- Check for missing guards or safety devices and replace as necessary.
- Upgrade safeguards as required by standards or regulations.
- Ensure that the machine has an instruction manual.
- Make sure that the warnings are in place and are clearly visible.

There are multi-purpose machines where guarding is left up to the end user. In these machines, a guard that is installed by the manufacturer might limit the utility of the machine or pose a hazard.

## 9.10 Mechanical Power Presses

A mechanical power press is a machine that is used to punch, form, or shear metal. A tool or upper die is mounted on a ram. The ram moves downwards towards a stationary bed which contains the lower die. The desired finish piece is formed when the upper and lower dies are pressed together (point of operation). When the downstroke is complete, the ram moves up and the finished piece is removed either manually or automatically. A new work piece is fed into the die and the process repeats. Power presses can be mechanical, hydraulic, or pneumatic. Amputations at the point of operation are most common with mechanical power presses (OSHA, 2007, 3170-02R).

The safeguarding methods for power presses depend on the mode of operation. Full revolution clutch machines will complete one full cycle (one downstroke and one upstroke) before it can be disengaged to stop the machine. Presence sensing devices will not work on these machines. The operator must be protected during the entire press operating cycle. Appropriately installed barrier guards, pullbacks, restraints, or two-hand trip devices may be considered for these machines.

Part revolution clutches can be disengaged at any point during the cycle before it completes the downstroke. Properly installed presence sensing devices can be used on these machines. Hydraulic presses are similar to part revolution clutches in their operation.

Injuries with power presses usually occur from guards with larger than the maximum allowed opening or two-hand controls that are located within the safety distance of the machine.

Operators will instinctively reach into the point of operation to adjust a misaligned piece or clear a jam (OSHA, 2007). Injuries can also occur if the operator is riding the foot pedal control. Equipment failures can also cause injuries. For example, if a mechanical linkage fails, a control relay fails, or air pressure to the clutch/brake is lost. Safety practices for power presses can be found in ANSI B11.1 Safety Requirements for Mechanical Power Presses.

## 9.11 Power Press Brakes

Power press brakes use vertical motion to form metal. Frequent causes of injuries with power press brakes include foot controls being inadvertently activated while the operator's hand is in the point of operation, a body part caught between the work piece and the press brake frame while the bend is being made, or a co-worker activating a single operator control while the operator aligns the work piece (OSHA, 2007, 3170-02R).Safeguarding methods for power press brakes include safe distance guarding, safety holding devices, back gauges to hold the work piece, hand feeding tools, and protected foot pedals with a toe-kick or other mechanism that must be depressed before the pedal is activated. ANSI B11.3 Safety Requirements for Power Press Brakes provides information on these machines.

## 9.12
## Conveyors

Conveyors are used in almost every industry such as wholesale, retail, manufacturing, and construction. Conveyors have different and unique features depending on the purpose. Injuries with conveyors result from hands or fingers becoming caught in gears, sprockets, belts, pulleys, shafts, and other moving parts. Very serious amputation injuries have occurred, for example, if a worker is underneath a conveyor adjusting it or cleaning it with a rag and an arm is pulled in, amputating the arm. Conveyors need to have guards to protect the operators from moving mechanical parts. Emergency stop cables extending the full length of the conveyor should be considered. ASME B20.1 Safety Standard for Conveyors and Related Equipment provides safety requirements and guidelines for conveyors.

## 9.13
## Roll-Forming and Roll-Bending Machines

Roll-forming machines contain a series of rolls that bend a continuous strip of metal into a predetermined shape. They can also perform other processes such as piercing holes, slots, notches, stamping, and stretch-bending. Roll-bending machines are similar. They usually have three rolls arranged in a pyramid shape that produce a bend across the width of the metal. Most injuries with roll-forming and roll-bending machines occur at in-running nip points. Safeguarding methods include a barrier guard at the in-feed and out-feed section of the machine. The sides of the rollers should also be guarded to prevent clothing and body parts from being drawn into nip points. All rotating parts and power transmission apparatus should be guarded. ANSI B11.12 Safety Requirements for Roll-Forming and Roll-Bending Machines provides details on the safeguarding of these machines.

## 9.14
## Shearing Machines

Shears perform a number of functions, such as squaring, cropping, and cutting. Shears may be mechanically, hydraulically, pneumatically, or manually powered. In the basic shearing operation, stock is fed between two blades. A hold-down

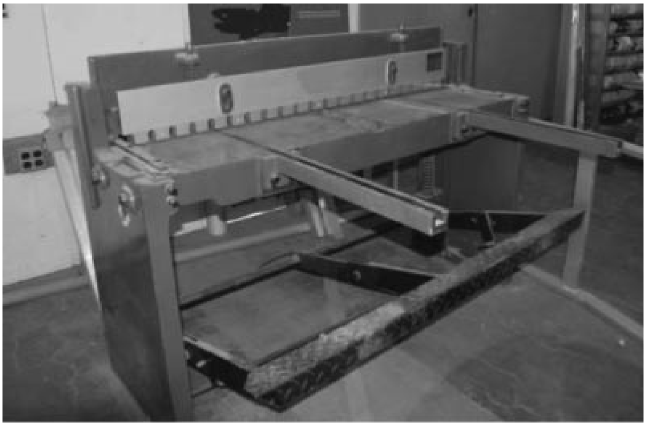

**Figure 9.15** Finger guards provide operator protection for this manual foot shear.

mechanism may be activated to apply pressure to the stock to keep it from moving. The top blade moves past the lower blade followed by an upstroke to complete the cycle. Amputations occur when the foot control is inadvertently activated while the operator's hands are in the point of operation. A tripping device located on the back of the mouth of the shear operates the shear, thus increasing productivity, but does not prevent the operator from reaching into the point of operation. Amputations can occur with both manual and powered shears.

Shears have a wide range of applications so that safeguarding methods must be determined for the specific use. Safeguarding options for shears include a fixed or adjustable guard that prevents operator contact with the point of operation and also the pinch point of the hold-down. Figure 9.15 shows finger guards on a manual foot shear. Properly arranged two-hand controls will keep the operator's hands out of the point of operation when the machine is activated. Additional information on shears can be found in ANSI B11.4 Safety Requirements for Shears.

## 9.15 Laser Machining

A class of machine tools uses lasers to provide enough energy to melt or evaporate the work piece.

The safeguarding of laser machines is complicated by the fact that there are laser radiation hazards, laser effluent hazards, and many other hazards associated with the wide variety of operations. Mechanical damage or a machine malfunction to the beam delivery system can cause the laser to be aimed at an operator or the viewing window.

There are electrical hazards due to the high voltages and electrical currents. Many industrial lasers use beams that are not in the visible spectrum, making it difficult to safeguard a hazard that cannot be seen.

A space (nominal hazard zone) should be established in which the direct, reflected, or scattered radiation during operation exceeds the maximum permissible exposure levels. Safety mats or light curtains can be used to prevent entry into the nominal hazard zone. In addition, additional protective measures may be required which will depend on the direction of the beam propagation with regard to the workpiece, the type of machining operation, the shape and composition of the workpiece, and the workpiece support. Other radiation hazards include direct or reflected laser beams, heat generated by ionizing radiation, and radiation produced by flash lamps and discharge tubes. There may also be a need to remove effluent from the machine. Other hazards include toxic gases produced by the laser process, ignition of explosive vapors, secondary light radiation from beam to materials plasmas, and high-temperature surfaces on processed materials or equipment (ANSI, 2006).

## 9.16 Robots

Industrial robots are programmable, automatically controlled manipulators. They perform a variety of tasks such as moving material, parts, and tools, or specialized tasks such as welding, painting, and spraying. Robots are useful for unsafe, hazardous, or repetitive tasks. Most robot systems are programmed by "teach" programming. With this type of programming, the programmer uses a portable control device to move the robot through the steps at slow speed.

The robot learns by storing the feedback from its position sensors. Special safety precautions need to be taken during the teaching mode. For example, the teaching programmer should have single control of the robot through a pendant. Programming should only be done under slow speed conditions. Only one programmer is permitted in the safeguarded area during teach programming.

Robot systems have unique characteristics from other machines. Robots can move very quickly over a large space. They may or may not repeat the same patterns, depending on the program. Robots may appear safe when they are stopped in a dormant part of the program, but then move very suddenly without warning. The speed of the robot can vary depending on the load. The following case study (NIOSH, 2001) illustrates the importance of safeguarding to prevent operator entry during automatic operation.

> A 29-year-old male died from injuries sustained when he was struck on the head by a cycling single-side gantry robot. The victim had recently performed a mold change on a 1500 ton horizontal injection-molding machine. He was apparently looking for tools that he may have left within the machine during the set-up operation. The victim climbed on top of the purge guard and leaned over the top of the stationary platen machine to see if the tools had been left within the mold area. His head was between the robot's home

position and the robot's support frame on the stationary platen. The robot cycled, and the victim's head was struck from the side and crushed between the robot and the robot's support frame.

Hazards associated with robot systems include contact accidents from unpredicted movements and system malfunctions. A worker's body or a body part can be crushed or trapped between the moving parts of the robot and other equipment or fixed objects such as a building support column. There may be a mechanical failure resulting in a release of the part or object in the robot's grip. There can be software errors which might cause unpredictable movement or speed.

Safeguarding robot systems includes fixed and interlocked barrier guards that prevent access to dangerous areas. Interlocks or other detection devices should stop the robot motion and prevent restart without a deliberate action from outside the safeguarded area. Safety light curtains, radiofrequency/capacitance devices, and safety mats can also be used to safeguard robots. There should be ample clearance between the moving parts of the robot and any fixed objects. Every operator control station, including pendants, should have a manually initiated emergency stop device capable of overriding all robot controls and stopping the motion of the robot (ANSI, 2009b).

## 9.17 Conclusion

Machinery hazards exist in every industry. Properly designed machine safeguards can eliminate injuries and fatalities, reduce long-term costs, and increase productivity. Systematically evaluate all operations when designing machines, including operator error, human behavior, assembly, maintenance, repair, wear and tear, use and misuse. Determine the hazard(s) and assess the risk associated with each hazard. Follow the *design hierarchy* to eliminate the hazard and/or reduce the risk associated with each hazard to an acceptable level. Do not assume that operators will always do the right thing, and strive to design machines that are ''human error proof'' as much as possible.

## References

ANSI (American National Standards Institute) (2000a) B151.5. *Manufacture, Care and Use of Plastic Film and Sheet Winding Machinery*, ANSI, Washington, DC.

ANSI (American National Standards Institute) (2000b) B11.TR3. *Risk Assessment and Risk Reduction – A Guide to Estimate, Evaluate and Reduce Risks Associated with Machine Tools*, Association for Manufacturing Technology, McClean, VA.

ANSI (American National Standards Institute) (2006) B11.21. *Safety Requirements for Machine Tools Using a Laser for Processing Materials*, Association for Manufacturing Technology, McClean, VA.

ANSI (American National Standards Institute) (2009a) B11.1. *Safety Requirements for Mechanical Power Presses*, ANSI, Washington, DC.

ANSI (American National Standards Institute) (2009b) R15.06. *Safety Requirements* *for Industrial Robots and Robot Systems*, Robotic Industries Association, Ann Arbor, MI.

CA/FACE (California FatalityAssessment and Control Evaluation) Program (2006) A machine operator died when caught in the threads being wound onto the take-up spool of a warping machine. California FACE Report # 06CA006, *http://www.cdph.ca.gov/programs/ohb-face/Documents/06CA006.pdf* (last accessed 16 October 2011).

Cohen, H. and Cohen, D. (1991) *Prof. Saf.* (10), 32–36.

Gallagher, V. (1990) *Prof. Saf.*, (9), 34–39.

Gallagher, V. (1991) *Prof. Saf.*, (12), 22–26.

Hagan, P. (2009) *Accident Prevention Manual for Business & Industry: Engineering & Technology*, 13th edn, National Safety Council, Itasca, IL.

Hammer, W. (1972) *Handbook of System and Product Safety*, Prentice-Hall, Englewood Cliffs, NJ.

MacDonald, D. (2004) *Practical Machinery Safety*, Elsevier, Amsterdam.

Mroszczyk, J.W. (2010) Take your pick: error proof humans or your organization's environment. in Proceedings of the ASSE Rethink Safety: a New View of Human Error and Workplace Safety Symposium, San Antonio, 2010.

NIOSH (National Institute for Occupational Safety and Health) (1994) Preventing Scalping and Other Severe Injuries from Farm Machinery, DHHS/NIOSH Publication No. 94-105, NIOSH, Cincinnati, OH.

NIOSH (National Institute for Occupational Safety and Health) (2000) A 33-year-old textile worker dies after being pinned by a bobbin lift/dump. NIOSH FACE Report 2000-24, *http://www.cdc.gov/niosh/face/in-house/full200024.html* (last accessed 13 September 2011).

NIOSH (National Institute for Occupational Safety and Health) (2001) Mold setter's head struck by a cycling single-side gantry robot. NIOSH FACE Investigation Report # 01MI002, *http://www.cdc.gov/niosh/FACE/stateface/mi/01mi002.html* (last accessed 4 October 2011).

NIOSH (National Institute for Occupational Safety and Health) (2002) Machine operator killed in masonry block palletizing machine. NIOSH FACE Investigation Report # 01-NJ-092, *http://www.nj.gov/health/surv/documents/01nj092.pdf* (last accessed 15 October 2011).

NIOSH (National Institute for Occupational Safety and Health) (2009) Print machine operator is strangled when his shirt is caught on a rotating knob. NIOSH FACE Investigation Report # 09CA006, *http://www.cdc.gov/niosh/face/stateface/ca/09ca006.html* (last accessed 16 October 2011).

NSC (National Safety Council) (1946) *Accident Prevention Manual for Industrial Operations*, National Safety Council, Chicago, IL.

Ridley, J. and Pearce, D. (2006) *Safety with Machinery*, Elsevier, Amsterdam.

Stern, A. and Keller, R. (1991) *Prof. Saf.*, (5), 37–43.

OSHA (US Occupational Safety and Health Administration) (2007) *Safeguarding Equipment and Protecting Employees from Amputations*, OSHA 3170-02R, US Department of Labor, Occupational Safety and Health Administration, Washington, DC.

Van Cott, H. and Kincade, R. (eds) (1972) *Human Engineering Guide to Equipment Design*, McGraw-Hill, New York.

Woodson, W.E., Tillman, B., and Tillman, P. (1992) *Human Factors Design Handbook*, 2nd edn, McGraw-Hill, New York.

## Further Reading

Blundell, J. (1983) *Machine Guarding Accidents*, Hanrow Press, Columbia, MD.

Christensen, W. and Manuele, F. (1999) *Safety Through Design*, National Safety Council, Itasca, IL.

European Commission (2010) Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on Machinery, and amending Directive 95/16/EC (recast), *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:284:0001:0047:EN:PDF* (last accessed 14 September 2011).

Haight, J.M. (2003) *Prof. Saf.*, (12), 18–24.

Kitchens, C. (1980) *Prof. Saf.*, (3), 27–30.

Marshall, G. (1999) *Safety Engineering*, 3rd edn, American Society of Safety Engineers, Des Plaines, IL.

Mroszczyk, J.W. (2008) in *The Safety Professionals Handbook*, 1st edn (ed. J.M. Haight), American Society of Safety Engineers, Des Plaines, IL, pp. 129–169.

NFPA (National Fire Protection Association) (2012) NFPA 79. *Electrical Standard for Industrial Machinery*, NFPA, Quincy, MA.

NIOSH (National Institute for Occupational Safety and Health) (1975) Machine Guarding – Assessment of Need, DHHS/NIOSH Publication No. 75-173, NIOSH, Cincinnati, OH.

NSC (National Safety Council) (1993) *Safeguarding Concepts Illustrated*, 6th edn, National Safety Council, Chicago, IL.

OSHA (US Occupational Safety and Health Administration) (1980) *Concepts and Techniques of Machine Safeguarding*, OSHA 3067, US Department of Labor, Occupational Safety and Health Administration, Washington, DC.

Peterson, D. (2003) *Prof. Saf.*, (12), 25–32.

Schultz, G. (2000) *Conveyor Safety*, American Society of Safety Engineers, Des Plaines, IL.

US Department of Defense (2000) MIL-STD-882D. *Standard Practice for System Safety*, Department of Defense, Washington, DC.