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GUARDING AGAINST MACHINE HAZARDS

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**SUMMARY:**

Successful guarding strategies requires knowledge of machine functions, the physical and psychological characteristics of man, and the their interactions. Machine hazards are identified along with recognized guarding methods. Material is included that could be used to teach this subject (case study, problem set, glossary).

**KEYWORDS:**

Safety, Human Factors, Guard

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## GUARDING AGAINST MACHINE HAZARDS

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### INTRODUCTION

Safety considerations have not always preceded or coincided with the development of machinery. It was a "user beware" environment during the industrial revolution. Workers' Compensation laws enacted in the early 1900s had the objectives to:

- (1) Reduce accidents through employer incentives, and
- (2) Accident analysis

Creation of Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) continued to promote safety with the objectives of: (1) A safe working environment; (2) Safe tools; (3) Knowledge of hazards; (4) Competent fellow employees and manager; and (5) Safety rules (Huston 1987).

Increased social awareness of the "true" cost of accidents motivates increased safety in the workplace. Though it is unrealistic to think that all risk can be eliminated in the workplace, efforts must continue to find the proper balance between safety in the workplace, the economic costs and maintaining the functionality of the machine.

Knowledge of the physical and psychological characteristics of man, the operating characteristics of the machine and the man-machine interface is necessary if we are going to guard against machine hazards. The design process of a machine in a general case can be represented as shown in Figure 1. The designer must have a clear understanding of the project's objectives, decide what tasks will be assigned to the human (operator), and what tasks will be assigned to the machine.

Recognition and comprehension of human and machine abilities is critical in task assignment. Table 1 highlights some of those abilities. In general, it can be said "Men are flexible but cannot be depended upon to perform in a consistent manner, whereas machines can be depended upon to perform consistently, but have no flexibility whatsoever" [Jordan].

The interface between man and machine may be a simple exchange of information, of material, control, or a combination of these. Man may have several roles as he interacts with the machine. He could be the operator in a single one-time operation, or he may be using the machine in a repetitive task.

He could also be a bystander, just observing the machine operation, or maybe involved with the service and maintenance of the machinery.

#### Why Guarding Strategies Fail

No matter how much effort goes into the design of safe machinery, accidents continue to occur. An understanding of why these accidents occur can help identify weaknesses in guarding strategies. Consider the following situations:

- 1) An equipment operator gets paid on a piece rate. Management decides that a new guard is necessary to reduce the possibility of accidents. The guard slows down the throughput of the system. The piece rate is not raised to compensate for the lower output. What is the operator's attitude towards the guard?
- 2) A farmer has only 100 acres of wheat left to harvest. A storm is moving in that threatens to destroy the unharvested crop. He has been working many long hard days to get the crop harvested. Any delays means a loss of money. How does the farmer respond to a malfunction of a harvester? Will the power be shut off before attempting to correct the malfunction? Will guards and warning labels be heeded?
- 3) The equipment operator knows that the power should be shut off before trying to work on a PTO powered implement. The seat of the tractor is wired with an interlock device to shut off the PTO power when the operator gets off the tractor seat. The operator uses the safety device as an on-off switch instead of the standard PTO on-off switch provided by the equipment manufacturer. What is the operator's attitude towards the interlock switch? How might this help/hurt him when he works with a tractor without this interlock device?
- 4) The equipment operator is also the maintenance person. Daily servicing of the equipment requires the removal of several guards and their reinstallation which requires 30 minutes of additional time. What is the person's feelings towards these guards?

As you study this material, keep in mind these situations. Determine what guarding strategies are being implemented and what additional strategies need to be followed in order to have successful machine guarding.

## HAZARD IDENTIFICATION AND RISK ASSESSMENT

Risk may be defined by the following equation:

$$\text{Risk} = \text{Hazard} \times \text{Probability}$$

A hazard is the outcome of an unsafe act (i.e. if you touch a spinning saw blade, you will get cut). The probability of you touching the blade encompasses both the physical situation (closeness of hand to the blade, amount of protrusion of the blade above the table, sharpness of the blade) and the psychological situation (fatigue, stress, boredom, etc.). The closer you place your hand to a spinning table saw blade, the higher the probability of being cut. By placing a physical barrier between your hand and the blade, the probability of being cut is lowered, therefore the overall risk is lowered.

The ability of the user to correctly assess the hazard and the probability of that hazard happening influences the behavior of the user. Unfortunately man's ability to make these assessments is low. Some common fallacies we are prone to are (Baron, et al. 1988):

1. Short-sightedness. We overweigh the immediate present.
2. Impulsiveness. We sometimes make choices with insufficient thought, or no thought at all.
3. Neglect of probability. Some assume that improbable events won't happen, but of course, they do.
4. "My-side" bias. We defend our beliefs as if we were self-hired lawyers to convince ourselves that we were right all along.
5. Single-mindedness. We sometimes make decisions as though we have only a single goal, while ignoring other relevant goals.

Hazards associated with the work place are:

- |               |               |            |
|---------------|---------------|------------|
| 1. Mechanical | 4. Chemical   | 7. Noise   |
| 2. Thermal    | 5. Electrical | 8. Fatigue |
| 3. Fire       | 6. Radiation  | 9. Stress  |

Many of these hazards are explicit (such as mechanical and fire) while others are implicit (noise and stress) and are much more difficult to protect against. A large part of safety efforts have gone into mechanical hazards for the simple reason that this represents the largest area of occupational accidents. Nearly one-third of OSHA general industry citations address this subject (Asfahl 1984).

## MECHANICAL HAZARDS

A machine can be defined as "any contrivance for the conversion and direction of motion; an apparatus for doing some kind of work, i.e. an engine, the vehicle" (Allee 1975). Machinery involves moving parts to transmit power and do work. There exists the possibility of this energy being transmitted to people. There are four basic mechanical hazards associated with machinery. They are:

1. Rotating, reciprocating and traverse motions.
2. In-running nip points.
3. Cutting actions.
4. Punching, shearing and bending actions.

These hazards are associated with "transmission of power" within the machine and the "Point of Operation" associated with the output (action) of the machine. Mechanical guarding parts associated with transmission of power, shafts, belts, gears, etc., are easiest to design and implement. Point of operation guarding is much more difficult, due to the need to inspect and/or place material into or remove material from the operation area (Figure 2).

Shafts, augers and belts are examples of rotating, reciprocating, and transverse motions. The principle hazard is clothing on a body part becoming entangled in a protrusion from a shaft, pulley sheave or a sliding mechanism. An example of this would be a bolt protruding through the coupling on a PTO shaft or a lug on a chain conveyor, Fig. 3.

In-running nip points occur where two rotating objects come together -- pressure rollers, where the chain meets with a sprocket, a belt meets a pulley or the rack and gear. This type of danger will cause a crushing action between the two objects, Fig. 4.

Cutting actions are part of the point of operation of the following shop tools: saws, drills, lathes, milling machines, and grinding machines. Field equipment such as mowers, (flail, sicklebar, and blade) and harvesters also have cutting surfaces. These types of equipment have cutting hazards that could cause possible amputation if contact was made (Figure 5).

The fourth hazard area involves punching, shearing and bending actions. Equipment using these types of actions are commonly used in manufacturing (sheet metal and plate steel formations). Hay baling equipment (rectangular bales) have shearing action due to the plunger in the bale compression area. This hazard is associated with the point of operation, Fig. 6.

## HAZARD REDUCTION OF MACHINERY

Putting a guard around a sloppily designed piece of equipment is like putting a band aid on a festering wound. Sooner or later you have to open it up and do major surgery. The best solution is to design it correctly in the first place. A design process goal should be to eliminate, if possible, hazards to the user, bystander and service-maintenance personnel. During the design phase of a machine, methods of power transmission and the placement of moving parts within the machine must be looked at with an eye towards safety. Not all hazards can be designed out a machine. This is particularly true of point and operation hazards. Where good design processes can not eliminate a hazard, guarding is the next best strategy.

### CLASSIFICATION OF GUARDS

The methods of guarding may be grouped under four main classifications (OSHA 1973):

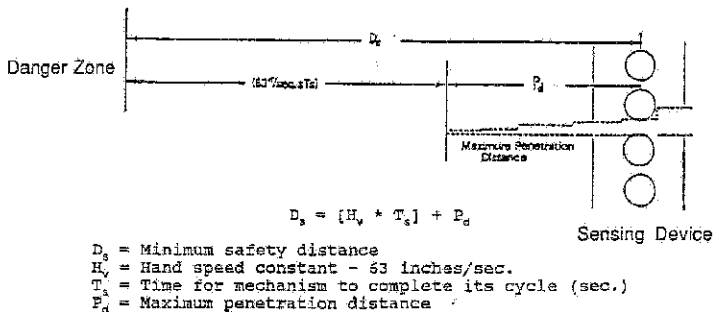
1. Enclosure Guards
  - a. Fixed enclosures
  - b. Adjustable enclosures
2. Interlocking Guards
  - a. Enclosure or gate guard with electrical or mechanical interlock.
  - b. Barrier with electrical or mechanical interlock activating a brake.
  - c. Electronic or other type field or beam connected with operating and stopping mechanism.
3. Automatic Guards
  - a. Moving barrier connected to operating mechanism of machine (push-away).
  - b. Removal device connected to operator, and operating mechanism of machine (pull-away).
  - c. Limitation of stroke.
  - d. Automatic pressure release devices.
4. Remote Control, Placement, Feeding, Ejecting
  - a. Two-hand tripping devices (also multiple operation).
  - b. Automatic or semiautomatic feed.
  - c. Special jigs or holding devices.
  - d. Special handtools and dies.
  - e. Special ejecting devices.

## A. Enclosure Guards

Enclosure guards provide the greatest degree of protection. The hazard is completely contained within the guard. The guard may have adjustable openings to allow for the introduction of material into the machine. The adjustable opening should be fixed once the correct size opening is established. Standards are developed to limit the size opening so the user can not place his hands through gap and reach the danger zone (Figure 7). Guards should be strong enough to prevent a 270 lb. individual from deforming the guard and coming into contact with the guarded mechanism (ASAE 1988). Guards that may potentially be used as a stepping surface must be strong enough for this use, Figure 7A.

## B. Interlocking Guards

A second type of guarding is called interlocking. This is the coupling of an electrical or mechanical barrier to a braking device or power control panel of the machine. If the guard is removed, the interlock will not allow the machine to operate. This has been used on equipment where the operator's seat is wired with a switch. If the operator gets up from his seat, the equipment shuts off. Newer electronic presence detection systems are now available, Figure 8. The sensor may use body heat or capacitance to detect the presence of the operator. The distance from the danger zone to the presence detector is a function of the speed of operator's hand, the time required to stop the hazardous mechanism, and the penetration distance into the detector before detection. The following shows their relationship:



Interlocking type guards should be designed to guarantee a "fail safe" condition in case the interlocking device fails.

### C. Automatic Guards

Automatic type guards involve barriers that are connected to the operating mechanism and "push away" the person from the danger zone (this type of guarding is no longer recommended for mechanical power presses) or are connected to both the operating mechanism and the operator and "pull away" parts of the body that could become entangled in the machinery. These are common with machinery that entail operations around the point of operation, Figure 9. Automatic guarding includes automatic pressure release devices and limitation of stroke designs in the mechanisms.

### D. Remote Control, Placement, Feeding, Ejecting

Though these are not technically guards, they serve the same function by reducing the risk of an accident. A common application of remote control is two handed tripping devices, Figure 10. The operator must trip two separate switches simultaneously in order to activate the mechanism. The switches are located at a distance so the operator cannot reach into the danger zone after tripping the switches. This distance is based on the following equation:

$$D_s = H_v \times T_s$$

where  $D_s$  = minimum safety distance, inches ( $D_s$  minimum = 12 inches)  
 $H_v$  = hand speed constant, 63"/sec.  
 $T_s$  = time for mechanism to complete its cycle (sec.)

A common method to defeat two-handed tripping devices is to lock one of the switches in an "on" state, allowing the operator to use one hand to engage the mechanism. Two-handed tripping devices should be designed so the safety feature cannot be defeated.

The use of automatic or semi-automatic feed mechanisms can keep the operator away from the point of action; these can be difficult to design if the task continuously changes. Also jigs and special holding devices can provide aids in this area. Associated with these are special hand tools, dyes and injecting devices that prevent the operator from needing to reach into the hazard area, Figure 11.

Guarding by location is useful in work places where most employees do not need access to a certain machine. By limiting access to a machine you have essentially guarded it from people who have no need to be in contact with it. Of importance to service-maintenance personnel is guarding by lockout. Guarding by lockout prevents others applying power to or restarting a piece of equipment while maintenance and repair are being done.



This is typically done through locking the electrical power switch for the equipment in an "open" condition.

#### METHODS OF WARNING

In connection with guarding, adequate warning must be given to the operator about the dangers associated with the equipment. Regulations govern the type of warning signs and proper labeling necessary so an individual approaching a hazard area can properly identify the hazard and make a correct decision on the relative risk and probability of danger [Ryan 1987]. Audio warnings may also be used in conjunction with sensing type guards to alert the individual that he has entered into a potentially hazardous area or to warn that a hazardous event is about to occur. Flashing and colored lights can be used to visually indicate to the operator the danger zone and degree of danger. Different colors may be used to signify the relative level of danger to the individual -- green meaning the situation is safe; yellow - use caution; and red -- danger imminent, injury or accident could happen.

#### SUMMARY

To be successful guarding against machine hazards requires thought and foresight. Knowledge of the machine functions, the physical and psychological characteristics of man, and the interaction of these two is necessary for optimal guarding strategies. Machine designers must first minimize hazards in their designs. When hazards cannot be removed, then physical guarding of the hazard is necessary. Guards may range from total enclosure guard to operating aids that minimize the risk while working in a hazard area. This must be accompanied by adequate warning signs, labels, and/or the use of auditory and visual warning systems.

#### GLOSSARY TERMS

Guard - a protective device designed and fitted to minimize the possibility of inadvertent contact with machinery hazards as well as to restrict access to other hazardous areas.

Shield - a guard that alone, or with other parts of the machine, provides protection from the sides covered.

Enclosure - a guard that alone, or with other parts of the machine, provides protection on all sides.

Barrier - a guard, such as a rail, fence, frame, or the like.

Interlock - a guarding method where the guard is coupled to a brake or power unit of the machine to stop the machine action when the physical guard is broken.

Lockout - a method to prevent power being supplied to a machine while under repair or maintenance.

Point of operation - the location on the machine where the work or output is done.

#### PROBLEMS

1. The corn harvester is responsible for X number of injuries each year due to the operator trying to unplug the harvester. The danger lies in the operator not disengaging power to the harvester. What types of guarding mechanisms could be employed to reduce this type of accident?
2. PTO shafts are commonly used to transmit power from a tractor to an implement. Though physical guarding has been suggested and standards have been developed for this type of guarding, many accidents still occur due to improper guard maintenance and guard removal. What other types of methods to guard against PTO entanglement can you think of?

#### CASE STUDY: The Table Saw

Physical guards have become standard with the modern table saw. Unfortunately these guards are frequently removed because they either limit the function of the saw in reality, or are perceived to. As a consequence, numerous table saw injuries are reported each year.

A brain storming session was held with faculty and students to come up with different alternatives for guarding of the table saw. The list of alternatives included the following suggestions: (1) Redesign of the saw, i.e., use a different type of saw; (2) use of special jigs to hold the material and feed the material through the saw, (3) special protective equipment, gloves for the operator to prevent cutting injury of accidental contact with the blade, (4) auditory warning system to alert the operator if he came close to the blade, and (5) a visual warning system consisting of a method to illuminate the hazard area adjacent to the blade with a highly defined beam of red light.

Each of these suggestions were then critically examined. Redesign was felt to be impractical because of the function the saw provided. There is also a large base of table saws in use, and we wanted to protect users of these saws as well. Automatic holding and feeding jigs could potentially be used in a commercial establishment, but for many of the home saws the cost would be prohibitive. The use of a protective glove was rejected

because gloves could become entangled in the saw blade causing greater injury.

Use of proximity sensors to detect the closeness of the hand to the saw blade was examined, but a method of providing accurate feedback to the user was unclear. The visual warning system showed potential and was chosen as a research area. An intense light was used to delineate where the critical hazard area was around the sawblade. This method located the hazard area to the operator and gave visual feedback as to his proximity to the blade. The size of the lighted area was adjustable to provide a cushion (comfort zone) between the operator and the point of operation. A red light source was set up above a table saw and used to outline the area of the blade (1 inch on each side of the blade and 1 inch in front and behind the protruded blade). The table saw with the "light guard" installed was tested by several individuals. Positive comments were expressed toward this method, helping them to identify the danger zone around a saw blade (Fig. 12).

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Table 1. Comparison of tasks better adapted to humans and to machines.

Humans are generally better in their abilities to:

- Sense very low levels of certain kinds of stimuli, visual, auditory, tactile;
- Detect stimuli against high-noise level background;
- Draw upon varied experience in making decisions; act in emergencies;
- Reason inductively, generalize;
- Develop new solutions.

Machines generally are better in their abilities to:

- Sense stimuli that are outside man's normal range of sensitivity;
- Maintain performance over long periods of time;
- Maintain efficient operations over distractions.

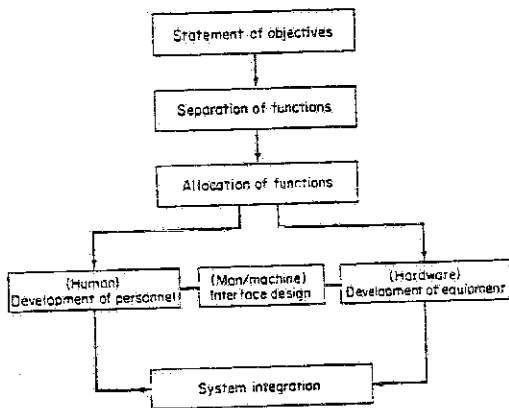


Figure 1. Representation of certain human-factors-related functions involved in systems design. [From Applied ergonomics handbook, 15, Fig. 15.5 p. 156]

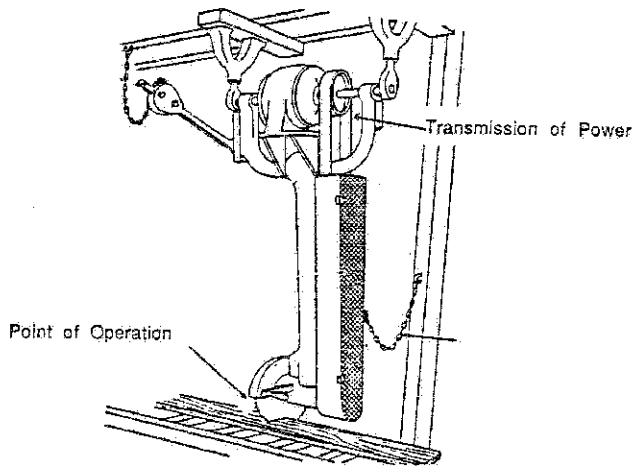


Figure 2. Hazard areas associated with machinery . (OSHA)



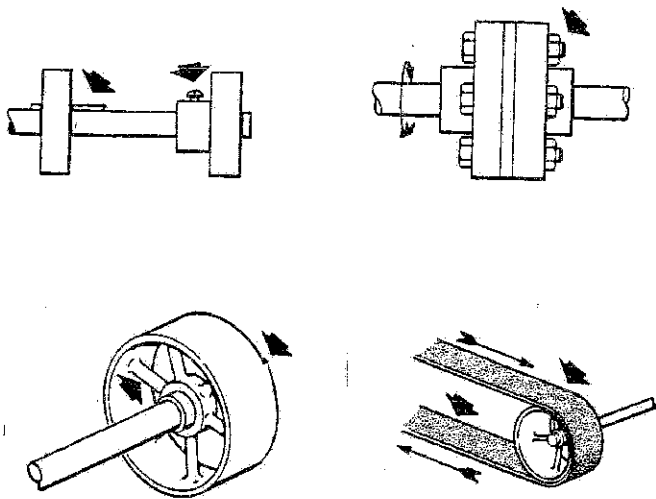


Figure 3. Hazards from rotating, reciprocating and transverse motions. (OSHA)

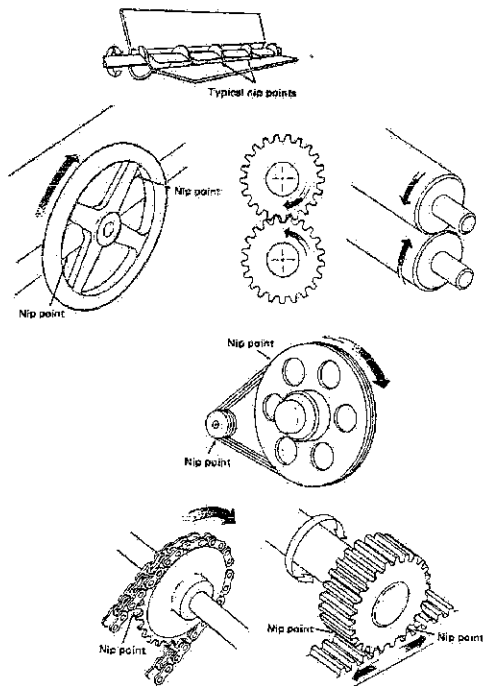


Figure 4. Hazards from in-running nip points. (OSHA)

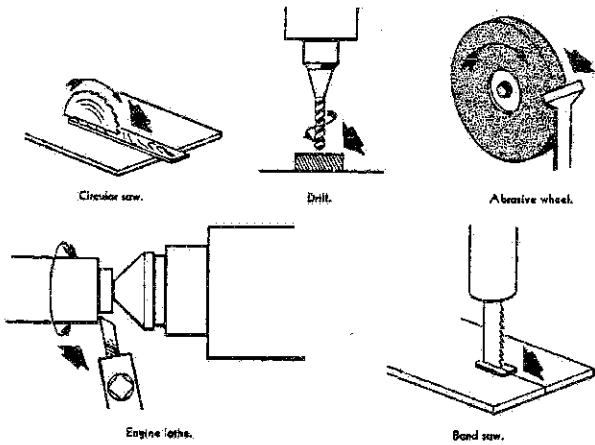


Figure 5. Hazards from cutting actions. (OSHA)

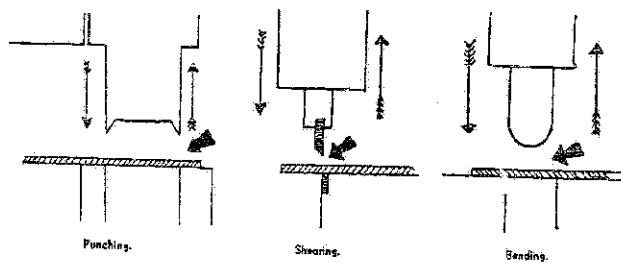


Figure 6. Hazards from punching, shearing, and bending operations. (OSHA)

OSHA'S SPECIFICATION FOR  
 MAXIMUM PERMISSIBLE GUARD OPENING SIZE  
 VERSUS DISTANCE FROM THE POINT OF  
 OPERATION

| Distance of opening<br>from point of opera-<br>tion hazard (in.) | Maximum width of<br>opening<br>(in.) |
|--|--------------------------------------|
| 0-1 1/2  | 1/8                                  |
| 1 1/2-2 1/2  | 3/16                                 |
| 2 1/2-3 1/2  | 1/4                                  |
| 3 1/2-4 1/2  | 5/16                                 |
| 4 1/2-5 1/2  | 3/8                                  |
| 5 1/2-6 1/2  | 1/2                                  |
| 6 1/2-7 1/2  | 5/8                                  |
| 7 1/2-12 1/2   | 1 1/8                                |
| 12 1/2-15 1/2  | 1 1/4                                |
| 15 1/2-17 1/2  | 1 1/2                                |
| 17 1/2-31 1/2  | 2 1/4                                |

Source: OSHA Standard 1910.217, Table O-10.

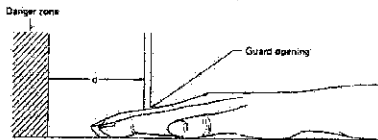


Figure 7. Maximum permissible opening size as a function of distance to hazard zone. (OSHA)

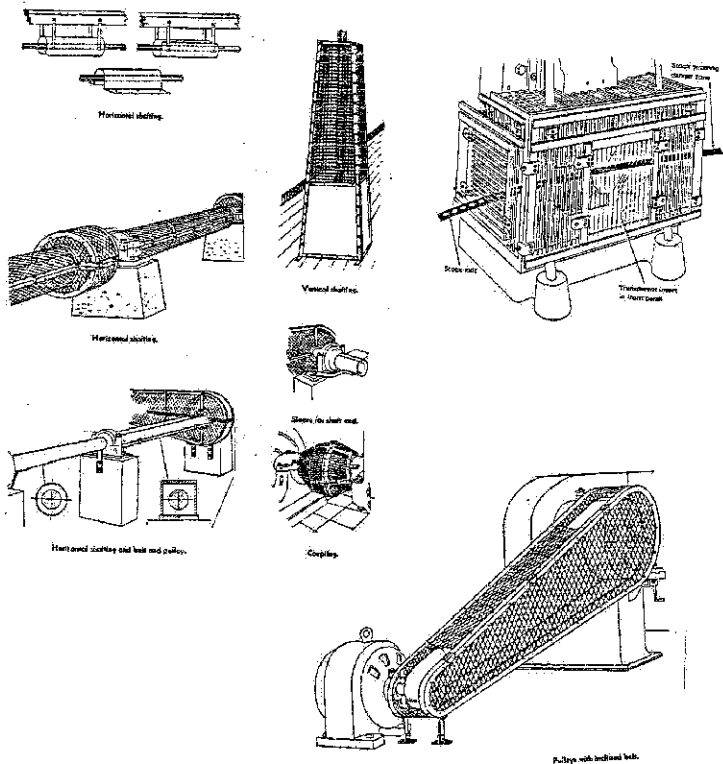


Figure 7A. Examples of enclosed guards. (OSHA)

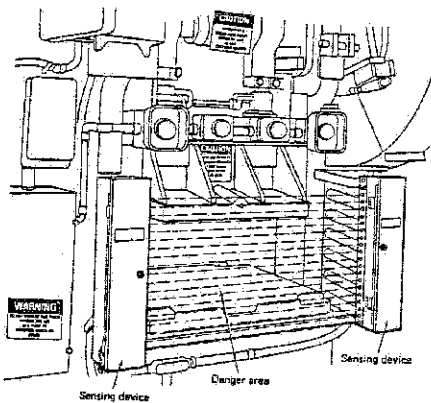
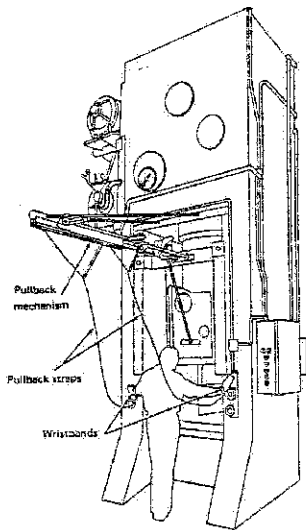
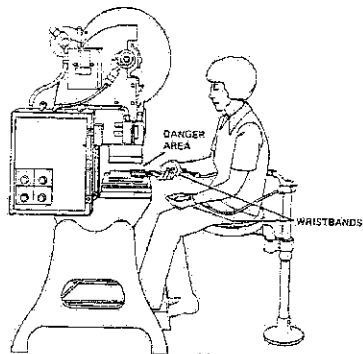


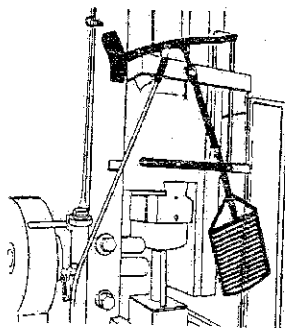
Figure 8. Examples of interlock devices. (OSHA)



Pull Away



Hold Back



Push Away

Figure 9. Examples of automatic guards. (OSHA)



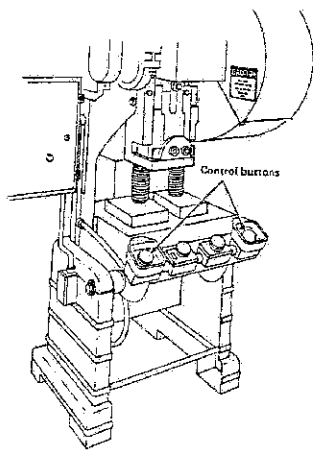


Figure 10. Example of a two-handed tripping device. (OSHA)

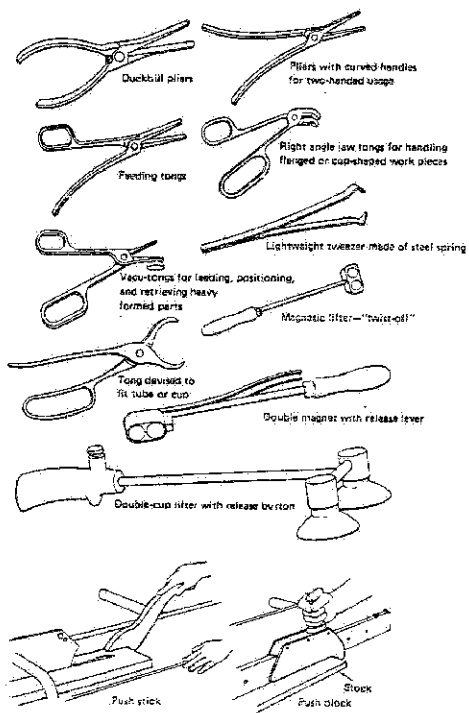


Figure 11. Hand-feeding tools help but do not replace the function of a point of operation guard. (OSHA)