# RELIABILITY OF PRESENCE SENSING DEVICES

Final Report

Boeing Aerospace Company
Houston Operations

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Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Division of Safety Research
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# ABSTRACT

This report defines the functions and limitations of presence sensing devices; develops a model for the performance of hazard analyses on industrial equipment; and specifically applies the developed model to identify hazards in the use of presence sensing devices as guards to mechanical power presses.

The identified hazards are divided into (1) causes which exist without presence sensing device failure and (2) those which exist only when failure of presence sensing devices has occurred. The hazards which exist without device failure are analyzed. Each factor in the equation used for safety distance calculation is analyzed and its variability determined. Practical limits are established for each factor when calculating safety distance on mechanical power press applications.

Generic failure modes of presence sensing devices which may cause injury are identified, as well as specific failure modes of each device. The manufacturing and assembly proficiency of the devices analyzed are assessed. Research conducted on presence sensing device evaluation tests is described and the developed test methods are explained. Presence sensing devices marketed in the U.S., western European countries, Japan, and Australia are identified. A comparison is made between U.S. and European safety regulations. Presence sensing device performance criteria in general, and in particular for mechanical power press applications, are included with justification.

ACKNOWLEDGEMENTS

We thank those manufacturers of presense sensing devices who voluntarily supplied their equipment on consignment and provided valuable assistance in defining application possibilities and limitations. Their cooperation made it possible to develop this document. This document is based on the cooperation of manufacturers of commercially available presence sensing devices who supplied information on their products.

The presence sensing device manufacturers who participated in the study showed a keen awareness of the benefits that would be derived by the publication of a comprehensive document on safety requirements for presence sensing devices and a genuine desire to demonstrate that their design included safety features well beyond those required by current safety regulations.

# INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is responsible for conducting research on occupational safety and health hazards and developing criteria in support of standards. One area of concern to NIOSH is the relatively high severity rate associated with injuries involving the operation of mechanical power presses.

A study was conducted for NIOSH which assessed the relative hazard levels of metal and woodworking machines. The study established the mechanical power press to rank first in terms of research needs for machine guards. The report describing this ranking system has been published as a NIOSH document entitled "Machine Guarding - Assessment of Need," DHEW Publication Number (NIOSH) 75-173.

Analysis of existing press safeguarding systems and experiences in other countries led NIOSH to the conclusion that further research is needed on presence sensing devices where used as guards in mechanical power presses.

Presence sensing devices are used to deactivate the clutch control and apply the brake of the press when a hand, other body part or object interrupts the sensing field. The device forms one part of a total safeguarding system. The other parts of the system include a control circuit, the press clutch, and brake.

In some countries, presence sensing devices are used both as a guarding and a tripping mechanism. In this country, presence sensing devices are used only as a safeguarding mechanism. Regardless of the usage, reliability of the total system needs to be high.

This document contains the study results of NIOSH Contract Number 210-78-0124, "Reliability of Presence Sensing Devices." The study was conducted to determine the adequacy of presence sensing devices in protecting workers when used as guarding devices. The purpose of the study was to: (1) Analyze the reliability needed for effective press safeguarding with presence sensing devices; (2) recommend performance criteria for presence sensing devices; and (3) determine appropriate tests for evaluating presence sensing devices.

Specifically, this contract studied the application of presence sensing devices in mechanical power presses by the performance of four distinct tasks. These tasks were:

1. Survey the U.S. and foreign markets to identify commercially available presence sensing devices.

2. Conduct failure modes and effects analyses on selected devices.

3. Develop presence sensing device performance criteria.

4. Evaluate testing methods used in industry for assessing the characteristics of presence sensing devices.

## DEFINITION OF THE PROBLEM

This study was undertaken to elucidate some of the NIOSH concerns on the use of presence sensing devices. These concerns were manifested by: Accident reports in which the failure of presence sensing devices allegedly caused the injuries; claims that some of the devices currently marketed in the U.S. are not adequate; lack of clear guidance in the current OSHA standards for employers to assess the safety adequacy of presence sensing device applications; claims that presence sensing devices improved productivity; differences of opinion among users of presence sensing devices, manufacturers of these devices, and manufacturers of interfacing equipment (press manufacturers) concerning causes of injuries, maintenance, and reliability; and discussions on the safety regulations in use in Europe and the adoption of the European regulations in the U.S., specifically the use of presence sensing devices as tripping mechanisms in power press applications.

The study elucidates some of these concerns. The study effort was directed toward presence sensing devices and their contribution to the safety of the system where these devices are used.

## DEFINITION OF PRESENCE SENSING DEVICE FUNCTIONS AND LIMITATIONS

A presence sensing device is an apparatus designed, constructed, and arranged to create a sensing field which detects the presence of an object when the object is within the boundaries of the sensing field. The objective of these devices is to produce a change of state of the output element of the device when the sensing field is disturbed by the presence of an object (including a person) within its field.

The output of these devices is either "ON" or "OFF." The output is normally a low-voltage signal (12 volts) that actuates a relay. The relay or relays are arranged either in series or parallel circuits, depending on the intended function of the device and the electrical circuitry of the interfacing equipment. A presence sensing device may be classified as an instrument that either has or does not have an output; i.e., a simple switch, or a valve which can be fully opened or fully closed, but cannot be half open. It does not have a proportional output. The sensing fields generated by these devices are three dimensional. The sensing fields can be generated in several ways; however, commercially available presence sensing devices are of three types which generate:

1. A sensing field in the visible light spectrum (600- to 800-nanometer wavelengths).

2. A sensing field in the infrared spectrum (900- to 1200-nanometer wavelengths).

3. A sensing field in the radio frequency spectrum (750- to 1700-meter wavelengths).

Sensing fields generated by devices which have wavelengths of 600 to 1200 nanometers (visible and infrared devices) are definable. The height and length of these fields coincide with the physical location of the wave generator and its receivers. The thickness is very small as compared to the height and length.

Sensing fields generated by devices which have wavelengths of 750 to 1700 meters (radio frequency devices) are not readily definable. The height, length, and thickness do not coincide with the physical dimensions of the antenna, and the generated volume is several times larger than the volume defined by the antenna.

### LIMITATIONS OF PRESENCE SENSING DEVICES

The fact that an object must be within the boundaries of the sensing field to be detected limits the use of these devices to applications where the object enters or interrupts the sensing field. For these devices to be effective, therefore, there must be no other way that an object may enter the protected area, except through the sensing field.

## LIMITATIONS OF VISIBLE AND INFRARED DEVICES

Visible and infrared devices generate a very thin volume which, for practical purposes, may be considered a plane. If an object passes through the plane, the device will detect the object as long as it is within the plane. Once the object has passed through the plane, however, it is no longer detected. This limitation restricts the use of these devices to applications in which the object cannot fully cross the sensing plane or there is no danger on the other side of the sensing plane.

## LIMITATIONS OF RADIO FREQUENCY DEVICES

Radio frequency devices generate a volume several times larger than the volume defined by the physical configuration of the antenna, thus the detection zone of these devices is very large. An object may therefore be detected several meters away from the antenna and continue to be detected as long as it remains within the volume. This characteristic, and the fact that the volume generated is not readily definable, limits the use of radio frequency devices. For instance, an object may be moving in a course which will not enter the protected zone, but it crosses the sensing field generated by the radio frequency device. The device will detect the object and generate a signal. The signal is considered in error and thus it becomes a false signal. If there is no way to differentiate a false signal from a true signal, false signals are considered nuisances and the effectiveness of the device is questioned.

Another limitation of radio frequency devices is that electrically nonconductive objects are not detected. Further, electrically conductive materials which are not grounded may not be detected. This latter limitation was the subject of a special study which determined that the sensing capability of radio frequency presence sensing devices is susceptible to change resulting from changes in the quantity of conducting areas in the electromagnetic field, the physical characteritics of people (operators), the quality of the electrical path between the object and person and ground, and the conditions existent at the time of presence sensing device adjustments. These limitations restrict the use of radio frequency devices to applications where the environment within the generated sensing field is fairly static.

## DEFINITION OF PRESENCE SENSING DEVICE

### BASIC FAILURE MODES

The objective of presence sensing devices is to generate a signal when an object penetrates the generated field. Presence sensing devices can have three basic failures:

(1) Fail to signal when the field is penetrated.

(2) Fail to sense the presence of an object when the field is penetrated.

(3) Signal when no object penetrates the field.

Any of these failure modes may cause injury depending on the application. To assess the significance of these failures when presence sensing devices are used with industrial equipment, a model was developed which generalized their use as guarding devices.

# DEFINITION OF THE GENERAL SYSTEM WHEREIN PRESENCE SENSING DEVICES ARE USED AS GUARDING DEVICES

## GENERAL SYSTEM

To create a product, an energy source and a method to transmit the energy to the point of operation are necessary. There is also a need to simultaneously deliver the material to the point of operation so that the material can be transformed into the required product. The material delivery system, in turn, requires its own energy source and energy transmission system. The application of this general industrial system to machine operation cycles is shown in Figure 1, Machine Operation Cycle. In this model, the prime mover represents the energy source. The prime mover could be an electric motor, a gasoline engine, a steam turbine, or any other method of transforming energy into motion.

The energy transmission system is either by direct coupling or intermittent coupling. If the system has intermittent coupling, it can require an energy dissipation system (brakes), or it can dissipate the energy by gravitational and internal friction.

The material delivery system can be totally automatic or, as shown in Figure 1, performed manually by an operator.

The point of operation is the point at which energy is applied to the material to create a product.

The last step in the model industrial cycle is the retrieval of the final product from the point of operation. This can be done automatically or manually. In this representation, it is shown to be done manually.

The dotted lines in the figure represent the command given by the controls to operate the system. The solid lines represent the signals required by the control system to perform its function. The heavier dotted lines represent fault detection.

The system in Figure 1 is defined as follows:

1. The prime mover of the machine or equipment being guarded.
2. The interface of the prime mover and the machine mechanical actuation mechanism.
3. The operator or the equipment that feeds the work to the machine.
4. The mechanical actuator performing the work.

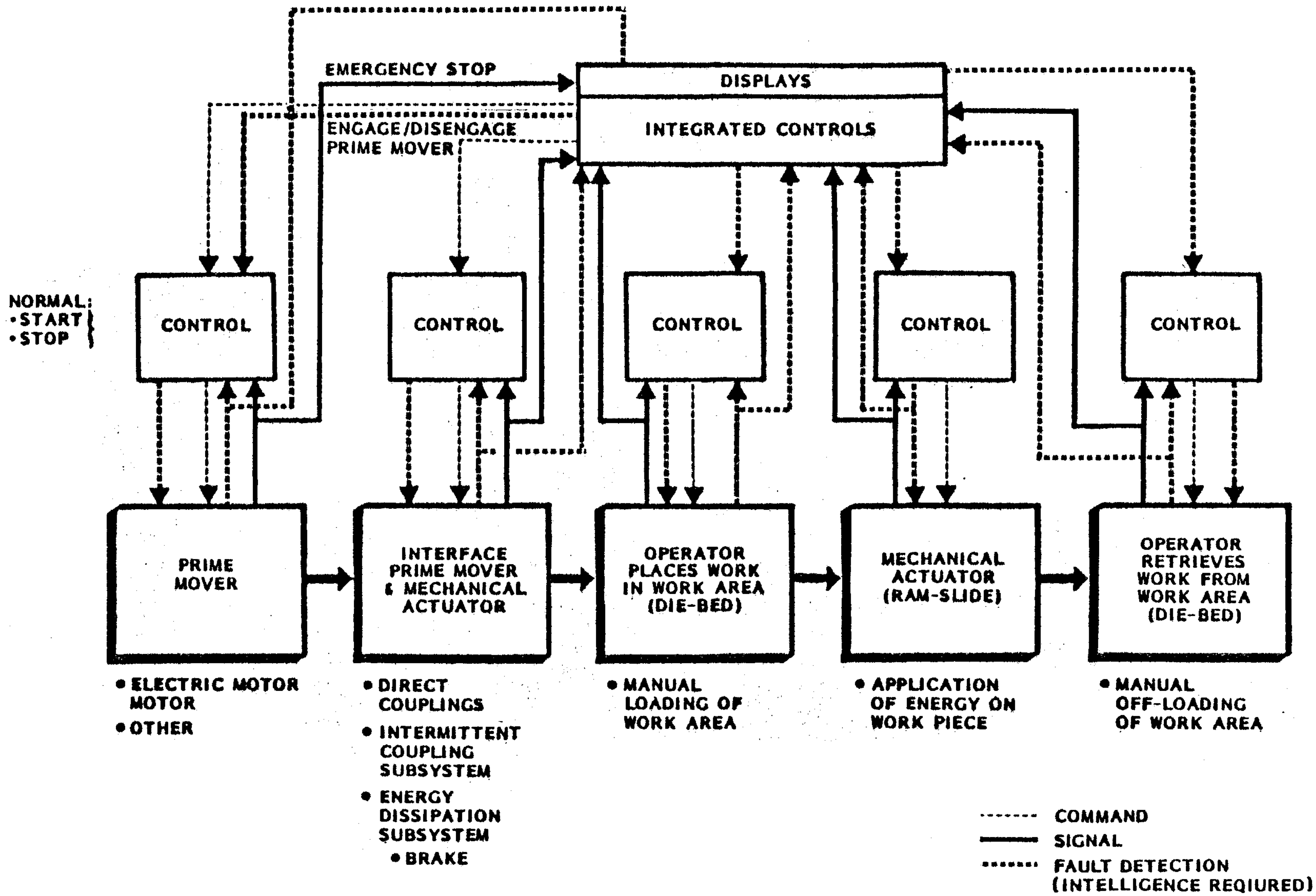



FIGURE 1 MACHINE OPERATION CYCLE

5. The operator or the equipment that retrieves the work from the work area.

Each of these five interrelated subsystems works together in a defined sequence of events.

The normal sequence of events for each subsystem during startup, operation, and shutdown is:

1. Apply power (electrical, hydraulic, pneumatic, etc.) to the prime mover. To perform this function, it is necessary to develop, design, and assemble a control system that will start and stop the prime mover.

2. Engage and disengage the prime mover (rotation or translation) to the mechanical actuator. This function requires its own control system.

3. Feed the material that is to be worked on into the work area. On fully automatic machines, the feed mechanism needs its own control system. On machines which do not have a feed mechanism, the work is supplied manually by an operator. The operator, however, still requires a "control system" that will indicate the time when the workpiece can be fed into the machine safely.

4. The command to perform the work is given upon placing the work on or in the work area. Again, this requires a control system.

5. Retrieve the material from the work area. This condition is similar to the activity of feeding or placing the material in or on the work area described in 3. above. A control system is required to command the retrieval of work or provide an indication to the operator that the work can or cannot be retrieved.

Upon completion of this action, the system is cleared and a signal or indication is displayed showing that a new workpiece can be introduced into the system.

In addition to the normal operating mode of the machine, there are other activities that are performed with the machine. These activities are:

1. Setup. This activity consists of preparing the machine to do a particular task. This activity can be very simple or very complex, depending on the type of machine and the work to be performed. To perform this function, the machine may be required to simulate the normal operating cycle (startup, operation, and shutdown) incrementally so that adjustments can be made.

2. Service. This activity consists of performing minor work on the machine or control systems. Usually, this is done with power off, but may require a power-on condition for testing the adequacy of the service actions.

3. Repair. This activity consists of inspecting the condition of the machine and control systems and repairing or replacing worn or faulty

components. Usually, repair activities are divided into routine or major. Routine repair is done with the machine temporarily out of service. Major repair is usually performed in a special shop or, if done "in situ," the machine is out of service for the duration of the major repair activity.

The brief description of machine system, operating cycle, and different operating conditions is required to develop a safety analysis of machines, in general, and of mechanical power presses and presence sensing devices, specifically.

Presence sensing devices, in combination with press controls, may perform the following functions:

1. Prevent out-of-sequence introduction of objects into the work area.

2. Prevent in-sequence, but premature, operation of the machine; i.e., before system is ready to accept the object.

3. Allow for in-sequence and timely introduction of objects into the work area.

4. Allow for the machine to start the cycle in sequence (prepare to trip).

5. Start the machine cycle (trip).

The system representing machine cycle operation is complete except that the cycle must be started, operated, and stopped. If the machine is fully automatic, the operator or an external signal must command the cycle to start. This study concentrates on those machines which are not totally automated, and operator intervention is needed.

The function of the operator in semiautomatic machines is twofold. First, he monitors the overall operation of the machine to determine whether the machine is operating correctly. Second, he performs the duty of feeding the material to the point of operation.

To monitor the system, he should know how to diagnose adequate machine operation. In most manufacturing activities, this function is reserved for a foreman or supervisor because it requires a level of skill greater than the skill required to feed material to the point of operation. This study concentrates on the activities performed by the operator when feeding material; however, it is necessary to understand thoroughly the machine internal design characteristics in order to identify existing hazards, assess their likelihood of occurrence, and formulate corrective actions in the form of performance criteria.

## OPERATIONAL ANALYSIS OF INDUSTRIAL EQUIPMENT USING PRESENCE SENSING DEVICES

To start, operate, and stop the machine, the operator must follow a certain sequence of operations. Generally, these operations are:

1. Start function.

   a. Apply power to the prime mover. This activity is usually performed by a pushbutton control.

   b. Apply power to the machine control. Again, this is usually accomplished by pushing a button or turning a switch.

   c. Start the machine. This is usually done by actuation of one, two, or more pushbuttons or switches in a preset sequence.

2. Prestart operation. To accomplish this function, the operator must have:

   a. The material to be fed into the operation.

   b. The machine set up to perform the work.

   These activities are related to this study inasmuch as they describe the general scenario for the actual operation of the machine.

3. Machine operation. The operator is required to:

   a. Pick up the material.

   b. Transport the material to the point of operation.

   c. Place the material on or in the point of operation by placing part of or his whole body in the danger area (point of operation) or use a tool to place the material.

   d. Retrieve his body, part of his body, or tool from the danger area (point of operation).

   e. Actuate the machine. This command is accomplished by foot pedals, pushbutton, switch, lever, or any other means. (In Germany and Sweden, this function can be performed by the presence sensing device. In the U.S., England, and France, it is forbidden to actuate the machine by this mode.)

   f. Wait until the work is completed.

   g. Grasp the material at the point of operation by placing part of or his whole body in the danger zone or use a tool to grasp the finished part.

   h. Transport the finished product to an appropriate location for storage or as input material for another operation in the manufacturing process.

   i. Pick up the material and repeat the cycle described above.

The operating cycle described indicates that a presence sensing device is commanding the operation of the machine when the operator interrupts the sensing field of the device at a point in space somewhere between the operations described in steps 3.b. and 3.c., and between 3.c. and 3.d. The presence sensing device again commands the machine between 3.f. and 3.g. and between 3.g. and 3.h.

4. Stop operation (same as start operation).

5. Stop function (same as start function).

In addition, the presence sensing device can command the machine at any time in the cycle (steps 2. through 4.) if the device sensing field is interrupted by any object.

## HAZARD ANALYSES AND FAILURE MODES AND EFFECTS ANALYSES

The system described in the previous paragraphs, as well as the description of the presence sensing device function, is needed to identify hazards. The objective of the hazard analysis is to identify the way(s) that a power press operator can be injured and with this knowledge prevent injury. Injury can be caused by human error, malfunction of the presence sensing device, or deliberate avoidance of the device. The fault tree method was selected for hazard identification because it was necessary to define the systems that need to be developed.

The objective of the Failure Modes and Effects Analyses (FMEA's) is to provide insight into the adequacy of the hardware (design) and to identify hardware deficiencies which could trigger an event and cause injury to the operator.

### HAZARD AND FAILURE MODES AND EFFECTS ANALYSES GROUND RULES

The safety and reliability ground rules are the criteria used by safety analysts to determine the adequacy of the system being analyzed. These criteria are established before the analysis is begun. The criteria noted below are given in order of priority.

The system is analyzed to determine whether it meets the fail-safe criteria. If the criteria for fail-safe are not met, the system is analyzed to determine if single failure points may cause injury. If single failure points exist which may cause injury, the design should be changed to eliminate the single failure point.

The use of redundancy is third in the priority list. It should only be considered if the single failure point cannot be eliminated. When considering redundancy as a method of accepting a potential hazard, it should be remembered that failure of the redundant system will cause injury. The only hedge against injury is that two parts performing identical functions must fail. Part selection, as well as design and shelf life, becomes critical. To determine whether the selected parts will function properly, the analyst should consider the environment in which the system is to operate and the design limits of the system. The designer of the system specifies those parameters.

Electronic equipment for industrial use is usually manufactured to withstand the most adverse environment to be encountered. The values chosen in this study represent: (1) Temperature and relative humidity extremes encountered during transportation; (2) vibration values taken at press frames by Anatrol Corporation, Cincinnati, Ohio, and the Swedish safety requirements; and (3) effect of oil and hydraulic fluid spills on electronic parts.

Equipment manufacturers' brochures provide some information on the design limits of their products. Presence sensing device manufacturers are no exception. Design limits set by the manufacturers reflect the design philosophy used in this study. No attempt was made to assume design limits.

The safety and reliability ground rules used in this study are:

1. Safety logic.

   Fail-safe - The ability to sustain a failure or a human error and retain the capability to successfully terminate an operation without injury to personnel. This definition of fail-safe is broader than that which appears in OSHA Standard 1910.217.

2. Reliability.

   a. No single failure points that may cause injury.

   b. Redundancy of critical subsystems.

   c. Part selection: Electrical, electronic, electromechanical, and mechanical part selection to match the environment and derated.

   d. Design life of device: Five years. (This ground rule should be made to conform to user downtime requirements and current manufacturer's estimated design life.)

   e. Shelf life of parts and components: Ten years. (Same as above.)

   Exclusions:

   Structural items (not considered): Stress analysis to verify safety factors.

3. Design Considerations.

   a. Environmental.

      (1) Temperature: $-20^{o}C$ to $+50^{o}C$.

      (2) Relative humidity: 99 percent.

      (3) Vibration: 45 g. for 1 ms. per stroke when the device is mounted on the press frame.

      (4) Contamination: Analysis of environment indicates that hydraulic fluid spills may represent worst condition.

b. Design limits.*

(1) Power.

(2) Power transient.

(3) Material compatibility.

(4) Drift (stability).

(5) Sensitivity.

(6) Repeatability.

(7) Electromagnetic interference.

*Note: Manufacturers established parameters. Designers are the only ones who can define these values.

HAZARD ANALYSIS

The fault tree (Figure 2) shows the events that need to exist for injuries to operators caused by the machine to occur. The first five pages of the fault tree deal with the machine in general (necessary steps in fault tree logic). The inspection of the fault tree indicates the areas which were developed for this study. All other possible causes of injury to personnel were not studied (outside the scope of this contract).

The analysis of the fault tree determined that injury can occur without system failure as well as with system failure.

Causes of injury with and without system failure are listed below.

1. Without system failure:

   a. An object arrives at the point of danger before the danger is eliminated.

   b. An object enters the danger zone through paths outside the guard perimeter.

   c. An object is between the guard and danger point.

   d. An object is too small to be detected.

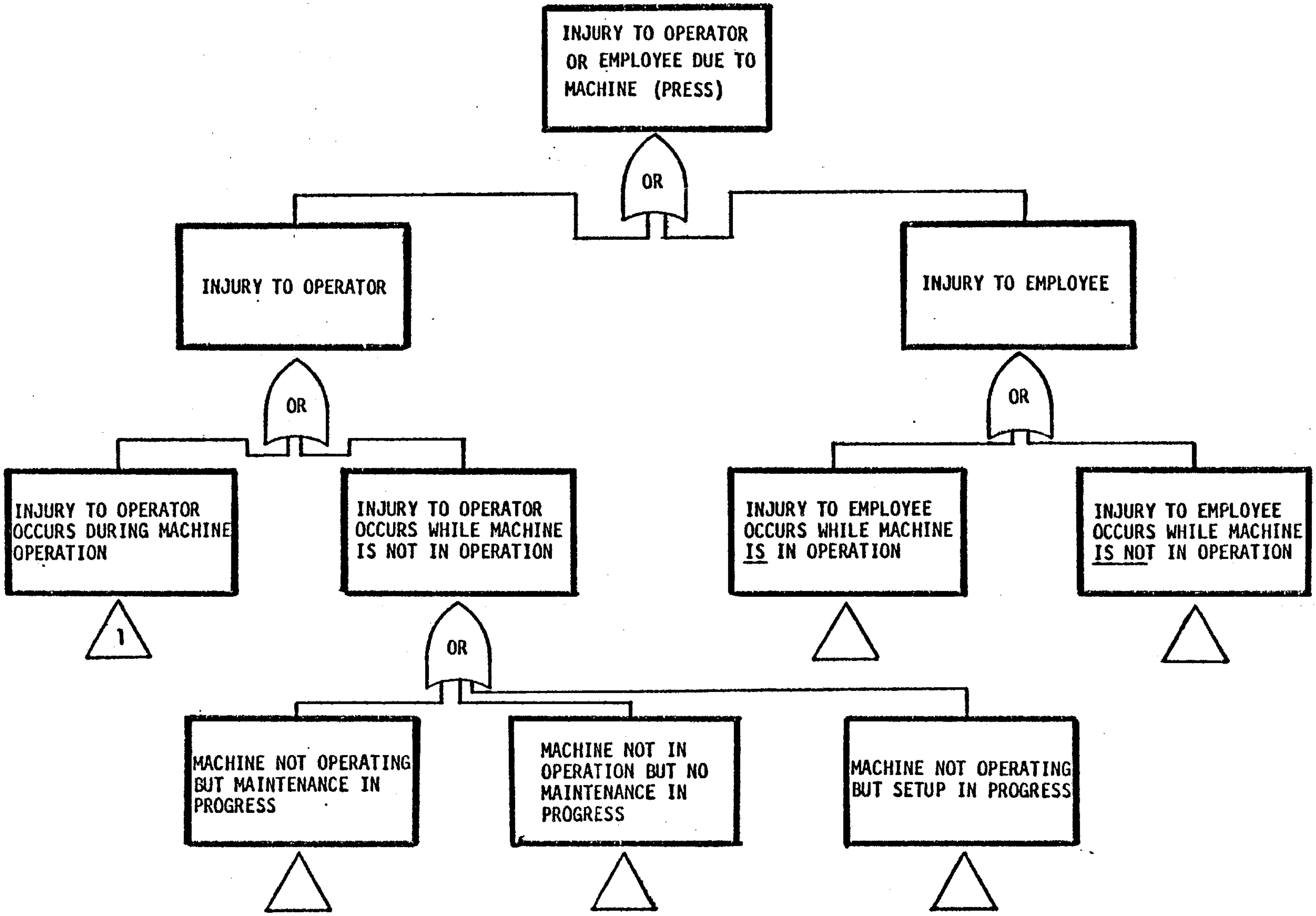
   e. An object is transparent to the sensing field.

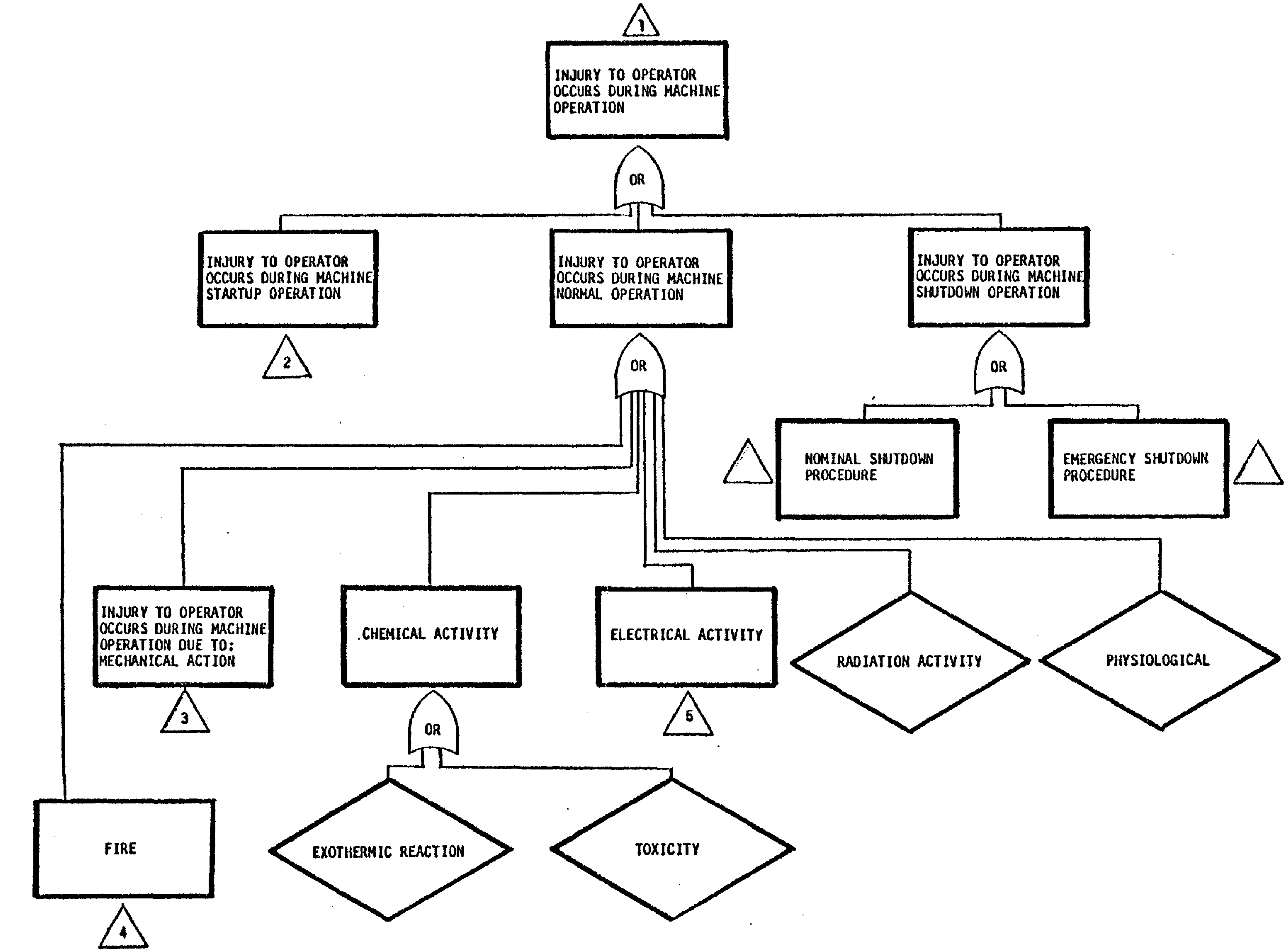
   f. The input signal is simulated.

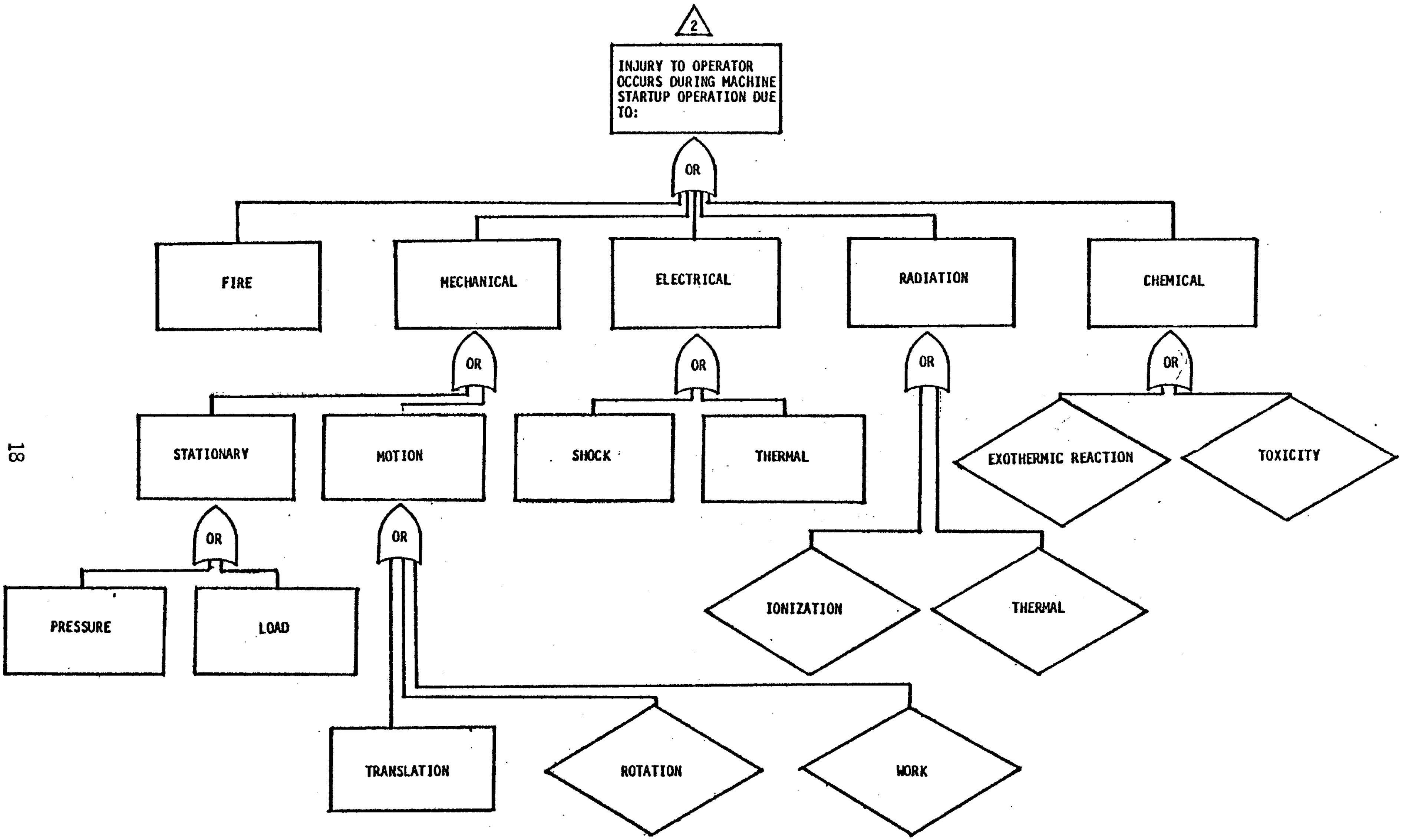
   g. An object reflects the signal.

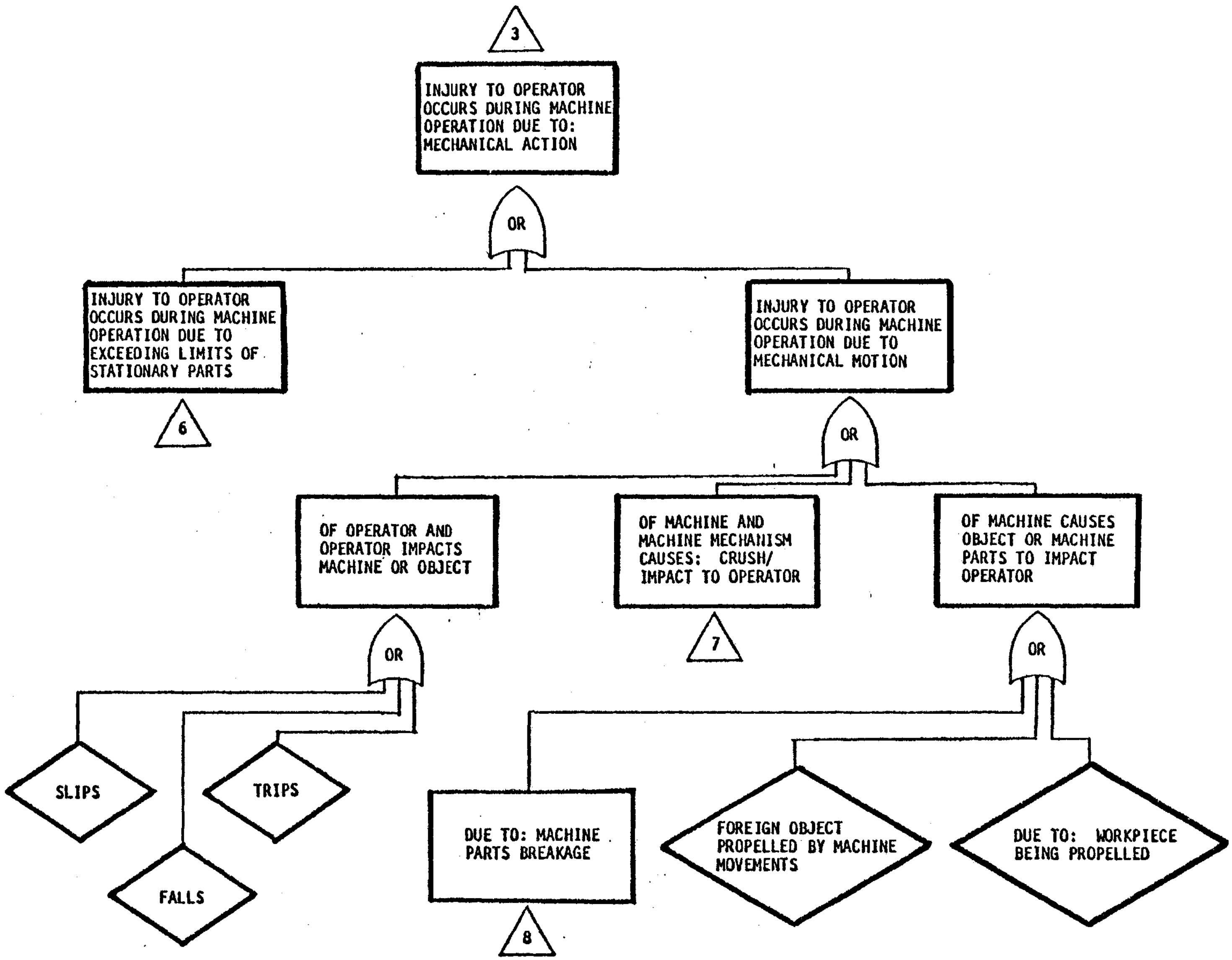
Figure 2

FAULT TREE - MECHANICAL POWER PRESS (ECCENTRIC)

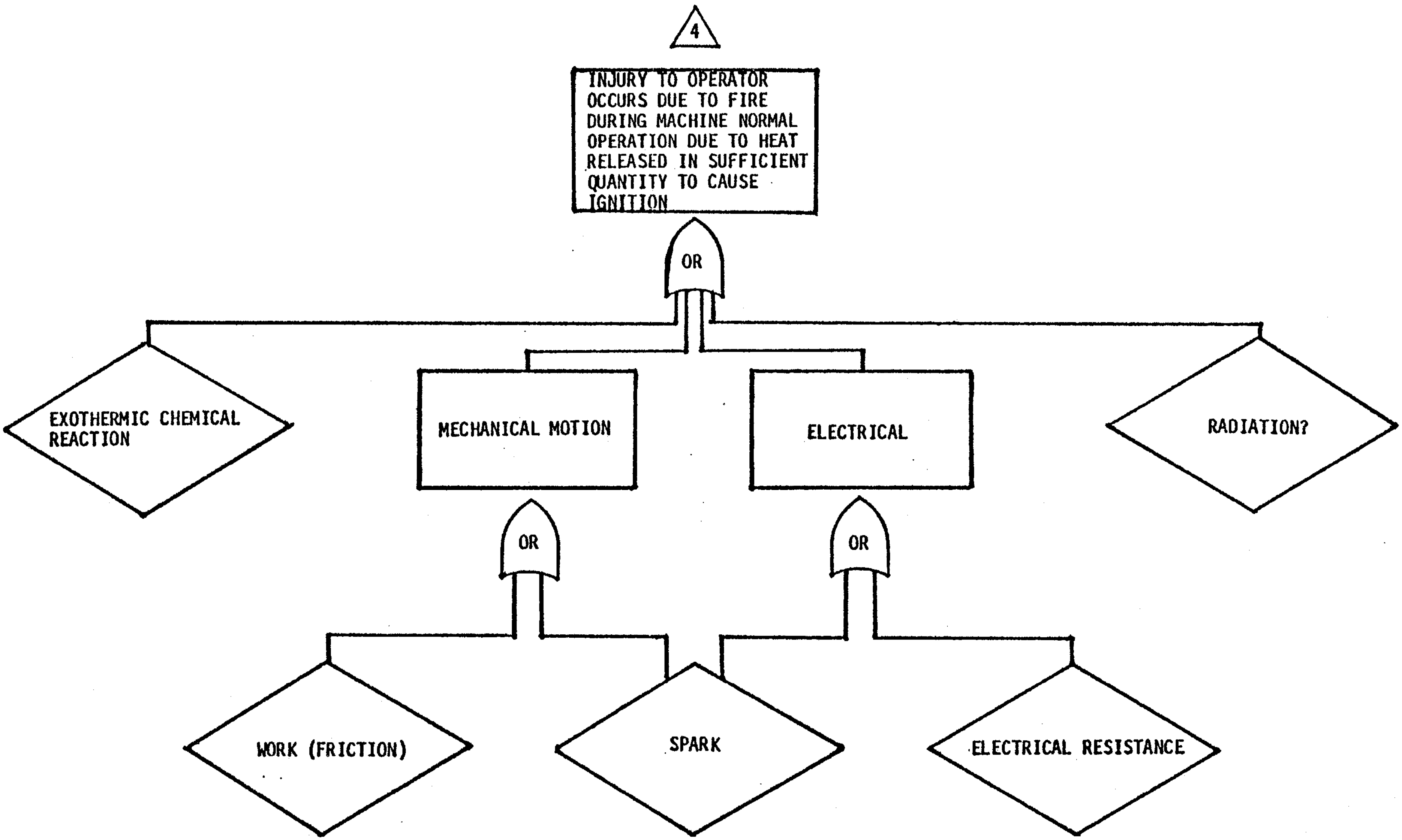


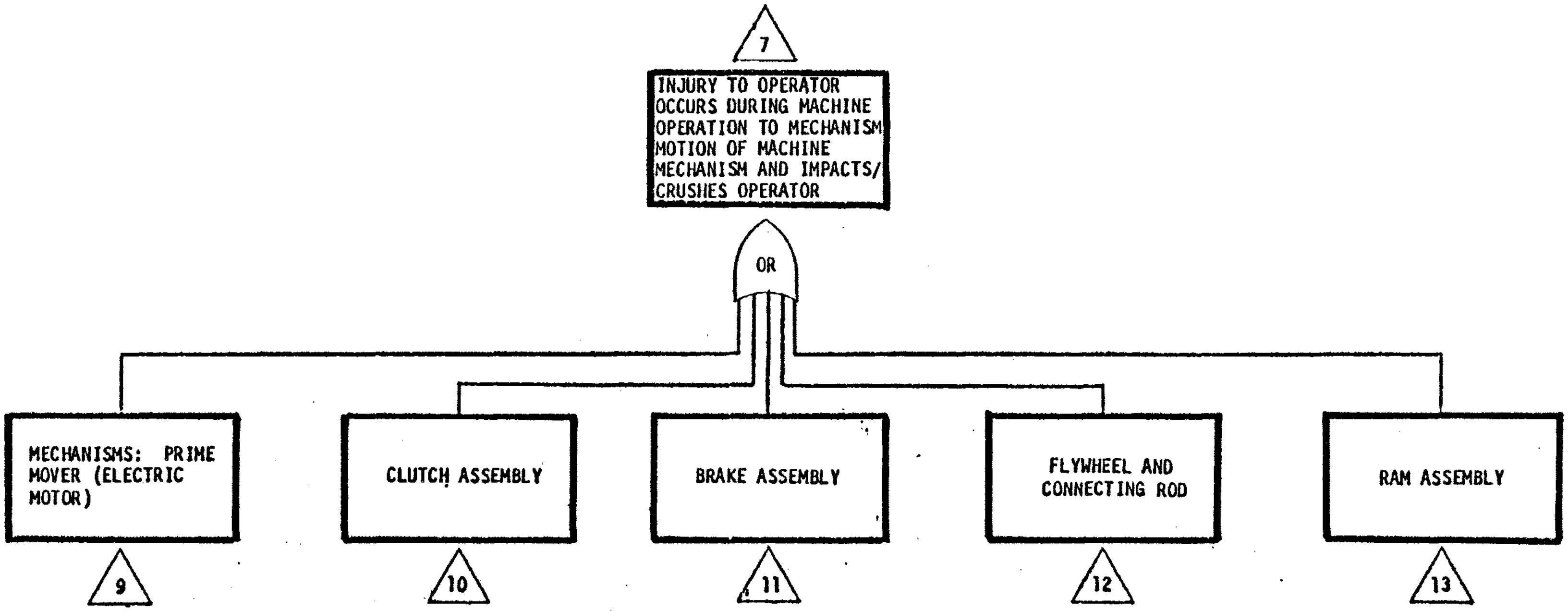

1
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION
OR
INJURY TO OPERATOR OCCURS DURING MACHINE STARTUP OPERATION
2
INJURY TO OPERATOR OCCURS DURING MACHINE NORMAL OPERATION
OR
INJURY TO OPERATOR OCCURS DURING MACHINE SHUTDOWN OPERATION
OR
NOMINAL SHUTDOWN PROCEDURE
EMERGENCY SHUTDOWN PROCEDURE
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION DUE TO: MECHANICAL ACTION
3
CHEMICAL ACTIVITY
OR
ELECTRICAL ACTIVITY
5
RADIATION ACTIVITY
PHYSIOLOGICAL
FIRE
4
EXOTHERMIC REACTION
TOXICITY


2
INJURY TO OPERATOR OCCURS DURING MACHINE STARTUP OPERATION DUE TO:
OR
FIRE
MECHANICAL
ELECTRICAL
RADIATION
CHEMICAL
OR
OR
OR
OR
STATIONARY
MOTION
SHOCK
THERMAL
EXOTHERMIC REACTION
TOXICITY
OR
OR
PRESSURE
LOAD
IONIZATION
THERMAL
TRANSLATION
ROTATION
WORK

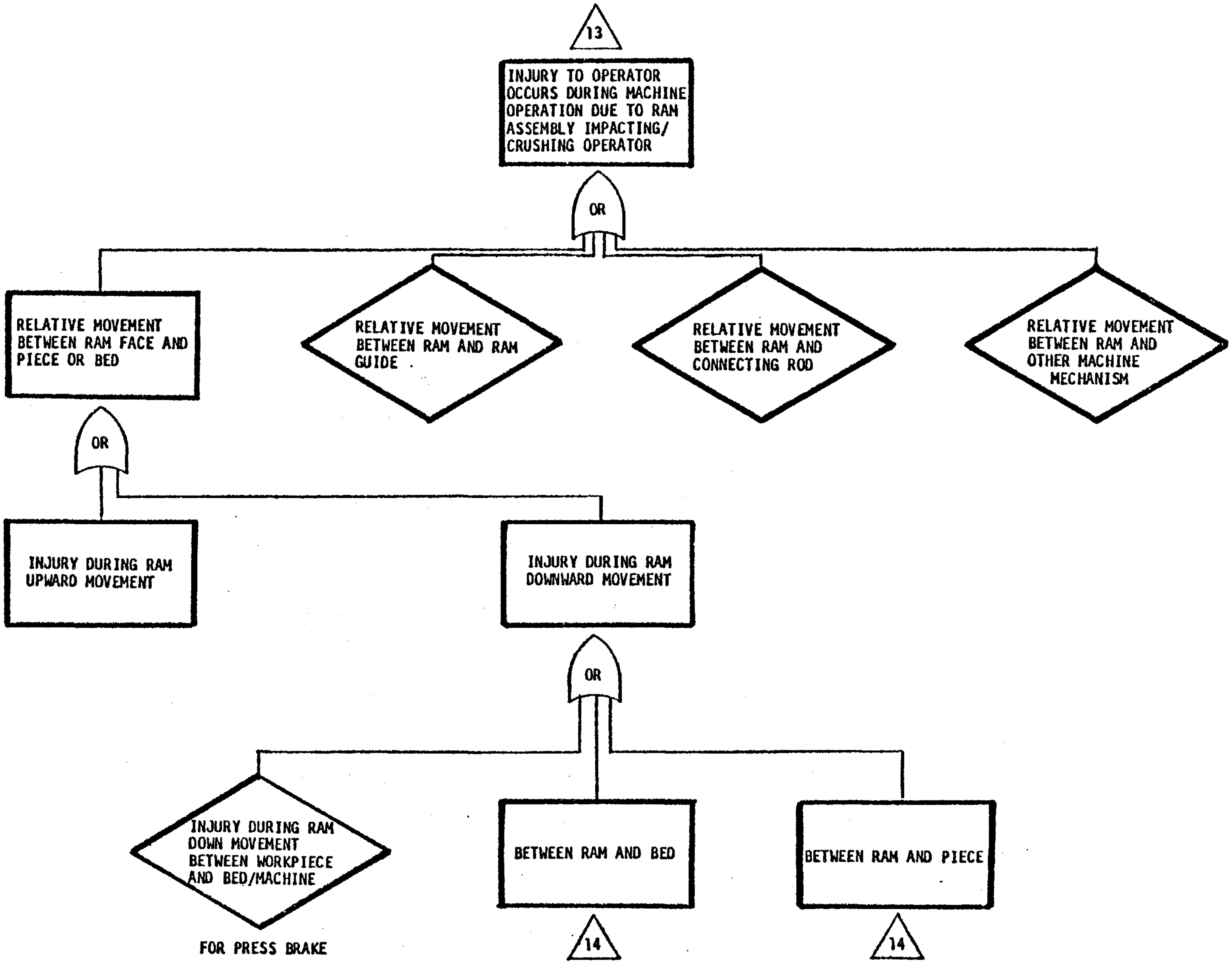


3
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION DUE TO: MECHANICAL ACTION
OR
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION DUE TO EXCEEDING LIMITS OF STATIONARY PARTS
6
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION DUE TO MECHANICAL MOTION
OR
OF OPERATOR AND OPERATOR IMPACTS MACHINE OR OBJECT
OF MACHINE AND MACHINE MECHANISM CAUSES: CRUSH/ IMPACT TO OPERATOR
7
OF MACHINE CAUSES OBJECT OR MACHINE PARTS TO IMPACT OPERATOR
OR
OR
SLIPS
TRIPS
FALLS
DUE TO: MACHINE PARTS BREAKAGE
8
FOREIGN OBJECT PROPELLED BY MACHINE MOVEMENTS
DUE TO: WORKPIECE BEING PROPELLED


4
INJURY TO OPERATOR OCCURS DUE TO FIRE DURING MACHINE NORMAL OPERATION DUE TO HEAT RELEASED IN SUFFICIENT QUANTITY TO CAUSE IGNITION
OR
EXOTHERMIC CHEMICAL REACTION
MECHANICAL MOTION
ELECTRICAL
RADIATION?
OR
OR
WORK (FRICTION)
SPARK
ELECTRICAL RESISTANCE



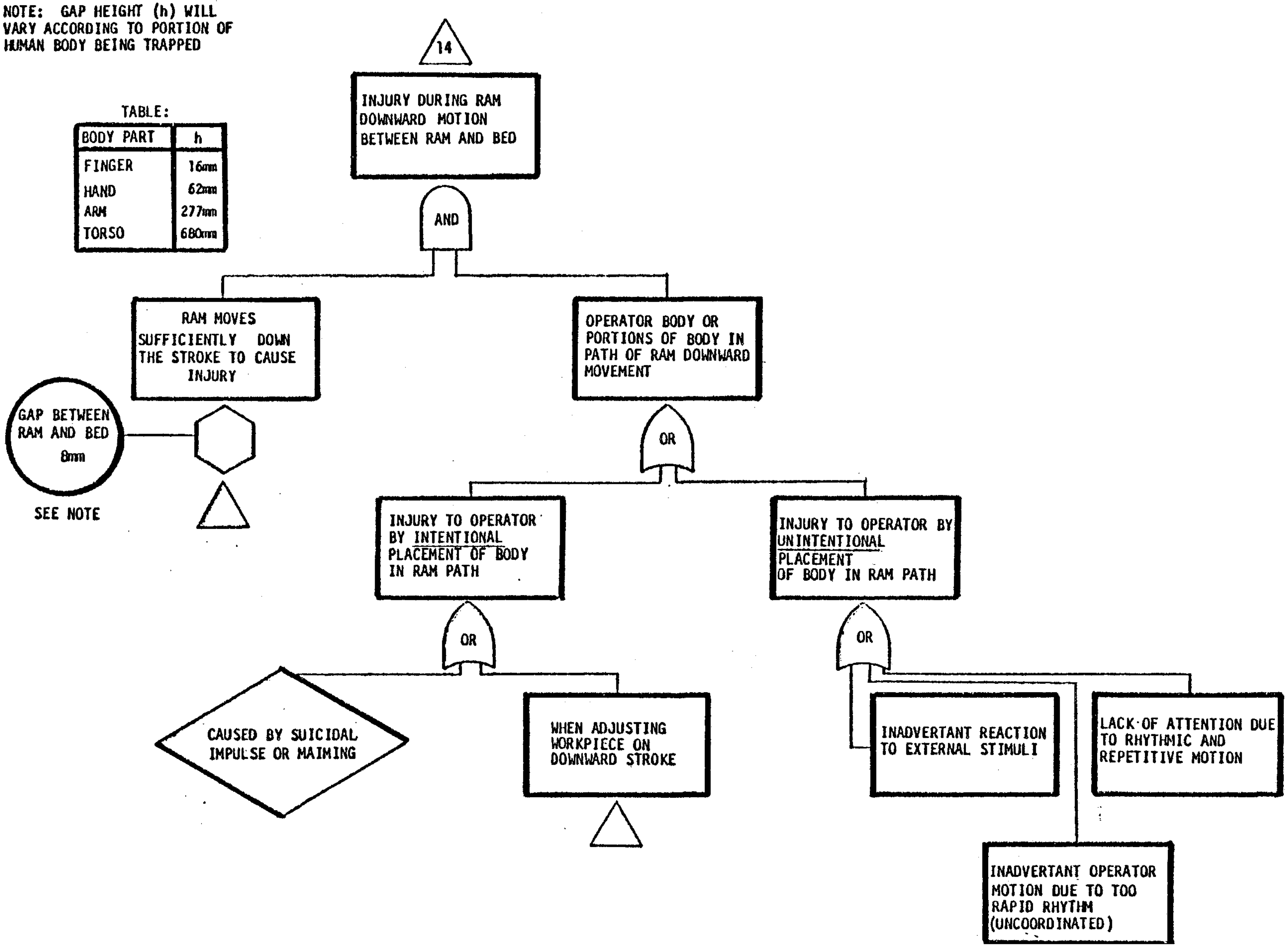
7
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION TO MECHANISM MOTION OF MACHINE MECHANISM AND IMPACTS/ CRUSHES OPERATOR
OR
MECHANISMS: PRIME MOVER (ELECTRIC MOTOR)
CLUTCH ASSEMBLY
BRAKE ASSEMBLY
FLYWHEEL AND CONNECTING ROD
RAM ASSEMBLY
9
10
11
12
13


13
INJURY TO OPERATOR OCCURS DURING MACHINE OPERATION DUE TO RAM ASSEMBLY IMPACTING/ CRUSHING OPERATOR
OR
RELATIVE MOVEMENT BETWEEN RAM FACE AND PIECE OR BED
RELATIVE MOVEMENT BETWEEN RAM AND RAM GUIDE
RELATIVE MOVEMENT BETWEEN RAM AND CONNECTING ROD
RELATIVE MOVEMENT BETWEEN RAM AND OTHER MACHINE MECHANISM
OR
INJURY DURING RAM UPWARD MOVEMENT
INJURY DURING RAM DOWNWARD MOVEMENT
OR
INJURY DURING RAM DOWN MOVEMENT BETWEEN WORKPIECE AND BED/MACHINE
FOR PRESS BRAKE
BETWEEN RAM AND BED
14
BETWEEN RAM AND PIECE
14

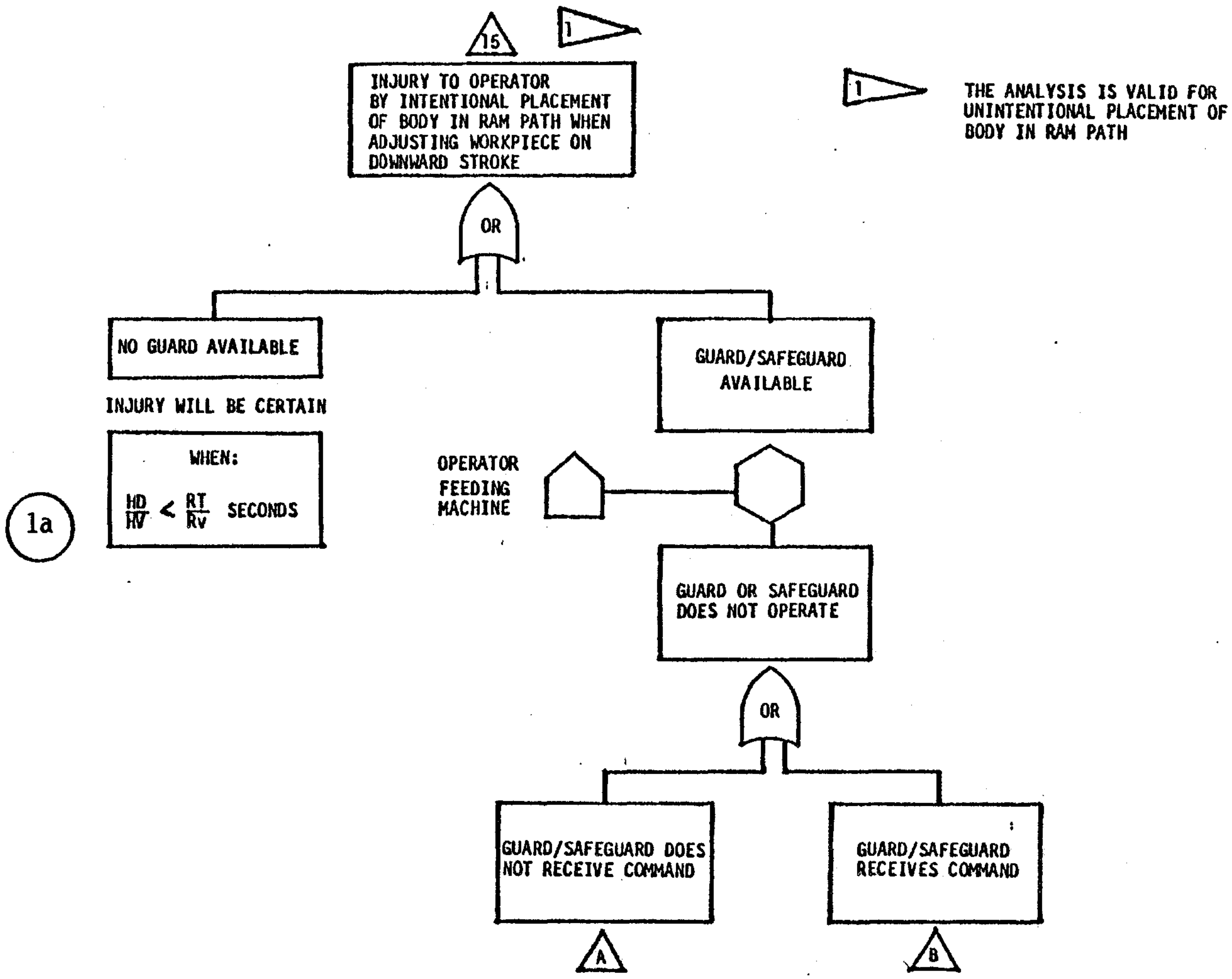
NOTE: GAP HEIGHT (h) WILL VARY ACCORDING TO PORTION OF HUMAN BODY BEING TRAPPED

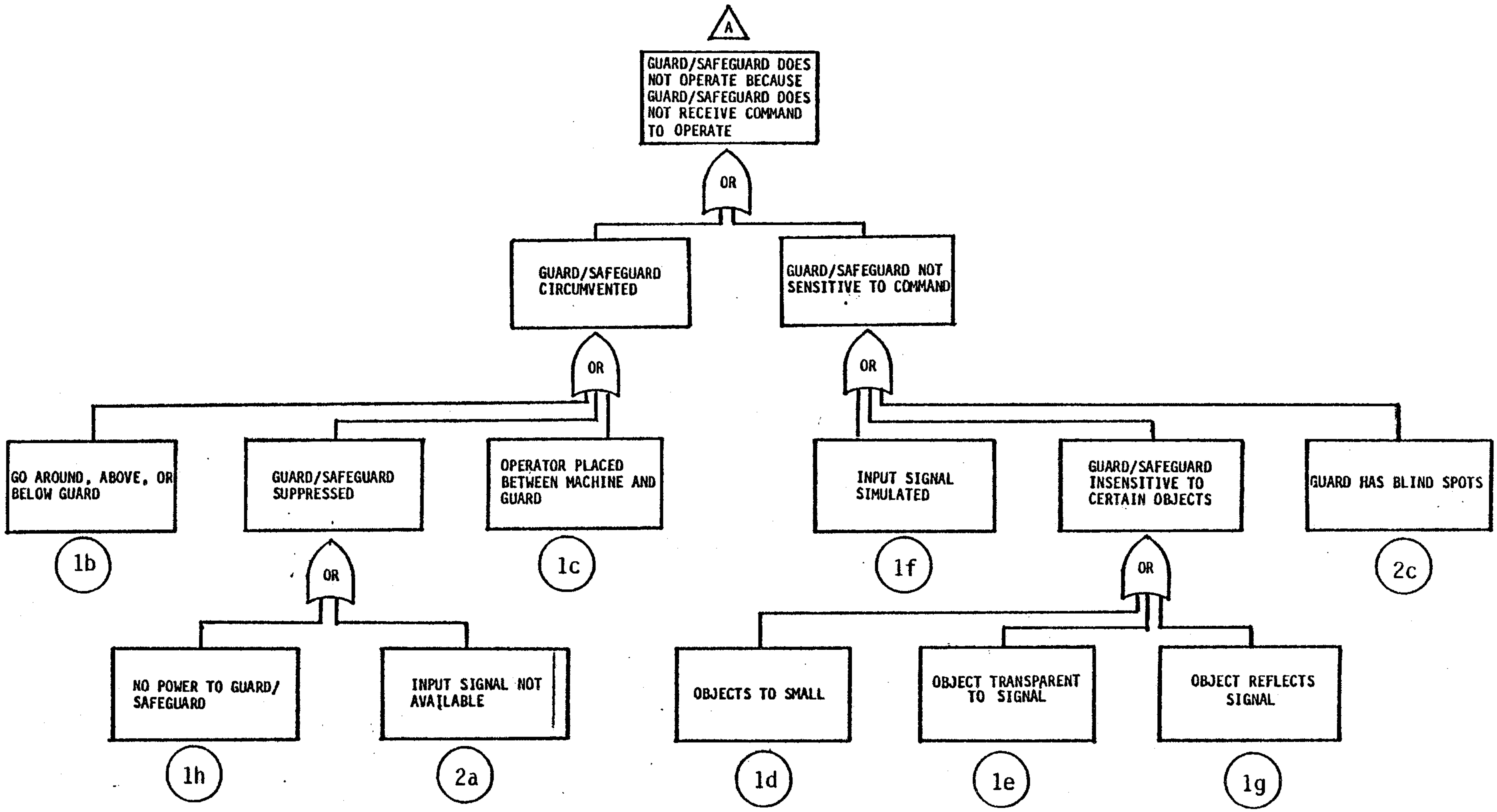
TABLE:

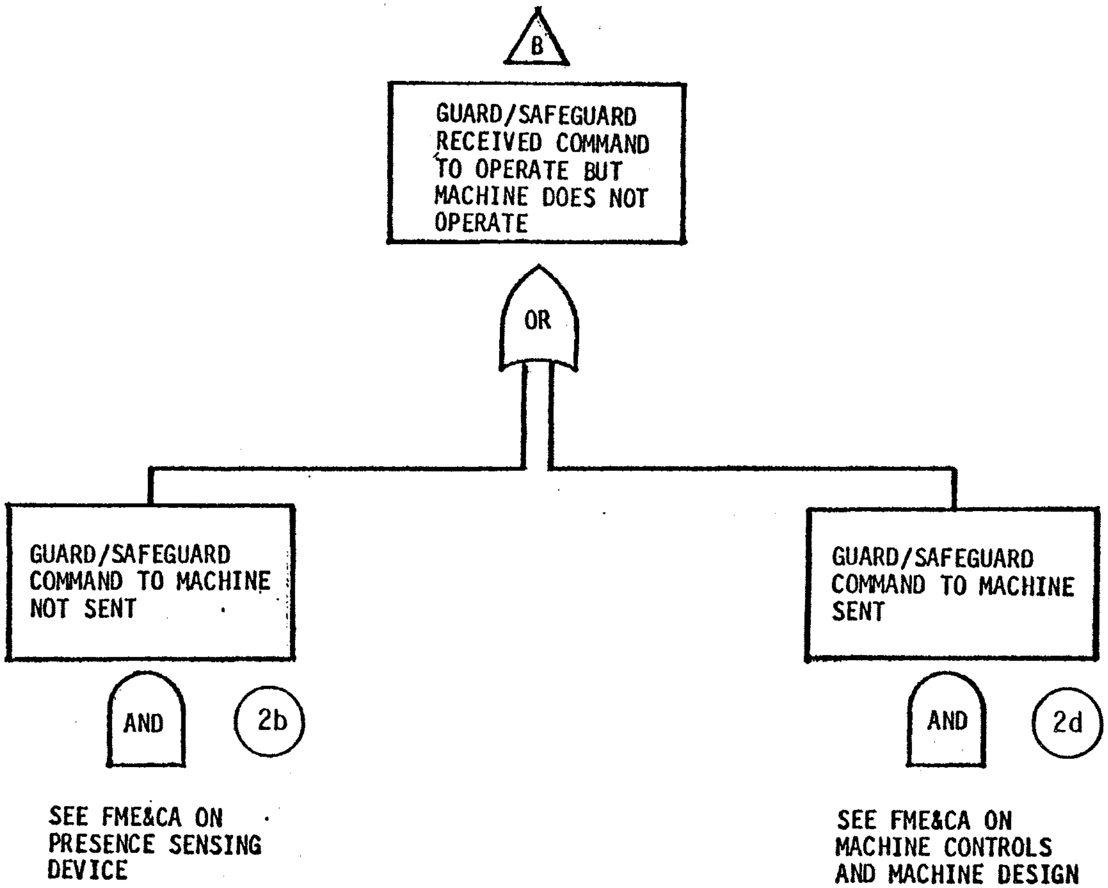
| BODY PART | h |
|---|---|
| FINGER | 16mm |
| HAND | 62mm |
| ARM | 277mm |
| TORSO | 680mm |

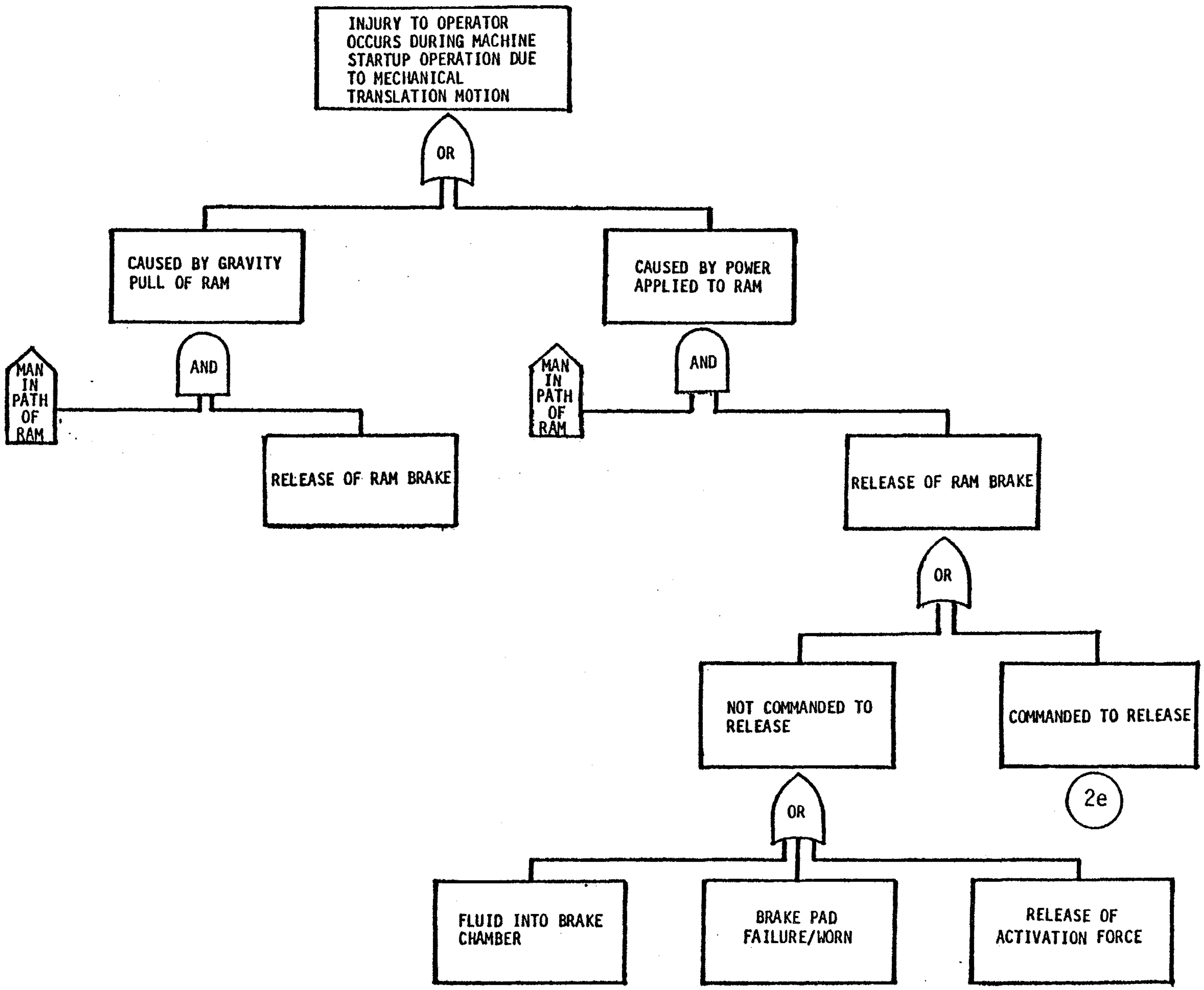


HAND VELOCITY = 2.5 m/SECOND (Hv)
RAM VELOCITY = Rw (Rv)
RAM ACCELERATION = Rw$^2$ (Ra)
HD = HAND TRAVEL DISTANCE
RT = RAM TRAVEL DISTANCE




A
GUARD/SAFEGUARD DOES NOT OPERATE BECAUSE GUARD/SAFEGUARD DOES NOT RECEIVE COMMAND TO OPERATE
OR
GUARD/SAFEGUARD CIRCUMVENTED
GUARD/SAFEGUARD NOT SENSITIVE TO COMMAND
OR
OR
GO AROUND, ABOVE, OR BELOW GUARD
1b
GUARD/SAFEGUARD SUPPRESSED
OR
OPERATOR PLACED BETWEEN MACHINE AND GUARD
1c
INPUT SIGNAL SIMULATED
1f
GUARD/SAFEGUARD INSENSITIVE TO CERTAIN OBJECTS
OR
GUARD HAS BLIND SPOTS
2c
NO POWER TO GUARD/ SAFEGUARD
1h
INPUT SIGNAL NOT AVAILABLE
2a
OBJECTS TO SMALL
1d
OBJECT TRANSPARENT TO SIGNAL
1e
OBJECT REFLECTS SIGNAL
1g


B
GUARD/SAFEGUARD RECEIVED COMMAND TO OPERATE BUT MACHINE DOES NOT OPERATE
OR
GUARD/SAFEGUARD COMMAND TO MACHINE NOT SENT
AND
2b
SEE FME&CA ON PRESENCE SENSING DEVICE
GUARD/SAFEGUARD COMMAND TO MACHINE SENT
AND
2d
SEE FME&CA ON MACHINE CONTROLS AND MACHINE DESIGN


INJURY TO OPERATOR OCCURS DURING MACHINE STARTUP OPERATION DUE TO MECHANICAL TRANSLATION MOTION
OR
CAUSED BY GRAVITY PULL OF RAM
CAUSED BY POWER APPLIED TO RAM
AND
MAN IN PATH OF RAM
RELEASE OF RAM BRAKE
AND
MAN IN PATH OF RAM
RELEASE OF RAM BRAKE
OR
NOT COMMANDED TO RELEASE
COMMANDED TO RELEASE
2e
OR
FLUID INTO BRAKE CHAMBER
BRAKE PAD FAILURE/WORN
RELEASE OF ACTIVATION FORCE

    h. No power is available to the guard.

2. With system failure:

    a. The input signal to the guard is not available.

    b. The safeguard command is not sent to the machine.

    c. The guard has blind spots.

    d. The safeguard command is sent to the machine out of sequence.

    e. The safeguard command is sent to the machine but is not received by the machine.

## HAZARD ASSESSMENT

The sensing field generated by presence sensing devices is a volume. This volume must be defined in order to determine when the object enters and exits the sensing field. The volume generated by visible and infrared is very thin because the generated energy is focused and little dispersion occurs. Measurements taken to define its thickness established thickness values of approximately 3 mm (.125 inch). Practically, this thickness can be neglected and the volume generated by visible light and infrared devices can be considered a plane.

From the above, it can be seen that if an object can enter and exit the sensing plane before the object arrives at the point of danger, injury may occur because (1) no guarding function is provided by the presence sensing device, and (2) the power stroke of the machine can be activated. These two conditions are identified in the fault tree as conditions (1) and (3). This can occur in applications where (1) the equipment is large enough for the operator to be able to walk into the danger point, or (2) the sensing plane is sufficiently removed from the point of danger, or (3) if the object penetrating the sensing field arrives at the danger point before the danger is eliminated.

These are credible injury causes controllable by proper application. Hazard control measures are discussed in detail later in this document.

Item 1.b. requires deliberate operator action to circumvent the system.

Item 1.d. may cause injury, but is not credible. The rationale for assessing it as not credible is discussed later in this document.

Item 1.e. may cause injury and is credible only on radio frequency devices. The rationale for its credibility is discussed under "Limitations of Radio Frequency Devices." Studies conducted on these devices to substantiate the credibility of the hazard are included in Appendix K.

Item 1.f. may cause injury, but is not credible because the signals generated by some devices are pulse coded, and those devices which are not pulse coded will send a command recognizing uneven distribution of light, which in effect is equal to sensing field interruption.

There is a theoretical possibility for the condition in item 1.g. to exist if the object introduced into the sensing field were to exhibit the same characteristics as the reflecting surface. Consequently, it is not considered credible because the reflecting surfaces analyzed have an intricate design pattern which cannot be reproduced by random objects.

Item 1.h. may cause injury and is credible. This condition cannot be attributed to the presence sensing device.

Items 2.a. through 2.d. are caused by failed parts in the presence sensing device.

These are credible failure modes in each of the devices analyzed. The failure modes and effects analysis identified output relay failure as generic to all devices.

Of the 13 possible causes for injury, 12 can be eliminated or adequately controlled by (1) proper installation of presence sensing devices; (2) elimination of single failure points in the design of presence sensing devices; and (3) selection of devices to match the application requirements.

Machine control failures, item 2.e., is a credible failure mode which cannot be eliminated or controlled by presence sensing devices.

## HAZARD CONTROLS

To control injuries caused by item 1.a; i.e., "an object arrives at the point of danger before the danger is eliminated," requires that the relationship be established between object speed and travel distance, and machine moving part speed and travel distance.

The operational analysis of presence sensing device applications indicates that injury can be averted when the time needed by the object to travel the distance defined by the sensing plane of the presence sensing device and the danger point is greater than the time needed to stop the moving part of the machine that will cause injury. This statement is demonstrated in the following paragraphs.

The fault tree established that for no guard available, injury will be certain when the following equation is satisfied:

$$\frac{S_d}{H_V} < \frac{R_d}{R_V} \qquad (1)$$

Where $S_d$ = Object (hand) travel distance = safety distance.
$H_V$ = Object (hand) velocity.
$R_d$ = Machine (ram) travel distance.
$R_V$ = Machine (ram) velocity.

When a presence sensing device is used as a guard, a signal will be sent by the presence sensing device to the machine control system commanding the moving part of the machine to stop. The signal is generated when the object interrupts the sensing field. Thus, the object travel distance is fixed by the presence sensing plane and the danger point.

The fixed distance is called "safety distance" $S_d$. The machine travel distance $R_d$ is a function of the time it takes the signal generated by the presence sensing device to activate the machine control system which, in turn, activates the machine brake system, which needs additional time to dissipate the energy of the moving part of the machine.

The above indicates that the performance of each of these subsystems directly affects the stopping time of the power press. These subsystems, which interface serially, are:

1. Presence sensing device.
2. Electric control of press.
3. Brake.
4. Brake energy source.

The total time required to stop a power press, therefore, is equal to the summation of the time required to complete the activation of each subsystem.

From the above, it was established that:

Total required time for press stoppage is:

$$T_{ps} = T_{psd} + T_{pc} + T_{pb}\ T_{de}$$

Where: $T_{ps}$ = Press stopping time.

$T_{psd}$ = Response time of presence sensing device.

$T_{pc}$ = Response time of press controls.

$T_{pb}$ = Response time of press brake.

$T_{de}$ = Response time of dissipation of energy by brake.

The general equation (1) becomes

$$V, \frac{S_d}{H_V} = T_{ps} \quad \text{or} \quad S_d = H_V \times T_{ps} \quad (2)$$

Equation (2) has two other factors which are not constant. These factors are object speed and safety distance.

Object speed is equal to operator hand speed in mechanical power press application, and safety distance is the distance between the sensing plane of the device and the point of danger.

Human Hand Reach and Speed

The scope of this contract did not provide for the determination of human speed of movements, nor the determination of anthropological characteristics. Consequently, no studies were conducted to make such determinations. However, because of the criticality of such determinations, a search was conducted to establish the hand reach envelope of a human from the sitting and standing positions, and hand speed. No data were found defining hand reach envelope from the standing position.

Data were found defining hand reach envelope from a sitting position. These data are presented in Figure 3 and were obtained from the Air Force Manual AFSC-DH1-3. This reach represents a normalized hand reach envelope for a 95 percentile of male U.S. Air Force personnel. The figure indicates that comfortable human reach from the sitting position is approximately .380 m (15 inches) to .585 m (27 inches).

Studies conducted in Germany in 1936 on human hand speed related to industrial operations established that a human hand speed of 1.6 meters per second was attained when the operator was transporting large objects, and that a human hand speed of 2.5 meters per second was attained when the operator transported small objects. No copies of this study were obtained from Government safety officials of Germany, Sweden, France, or England; however, Swedish and German safety regulations covering the use of presence sensing devices clearly differentiate between these two human hand speeds. Current research being conducted in England and France has demonstrated that the human hand can reach speeds of 4.1 to 4.5 meters per second. The research findings from these two countries are to be published. These maximum hand speeds were obtained when the test subject was standing at an approximate angle of 45 degrees with respect to the presence sensing device plane. (Photographs of the British test setup were taken and are available.)

Table I shows that when the safety distance is calculated using 1.6 meters per second on a power press with a stopping time of .200 second (assumed to be the average stopping time for mechanical power presses) injury will occur if the operator hand speed is greater than 2.3 meters per second.

SUB-NOTE 2.1(1) Plot of Optimum Manual Space for Seated Operator

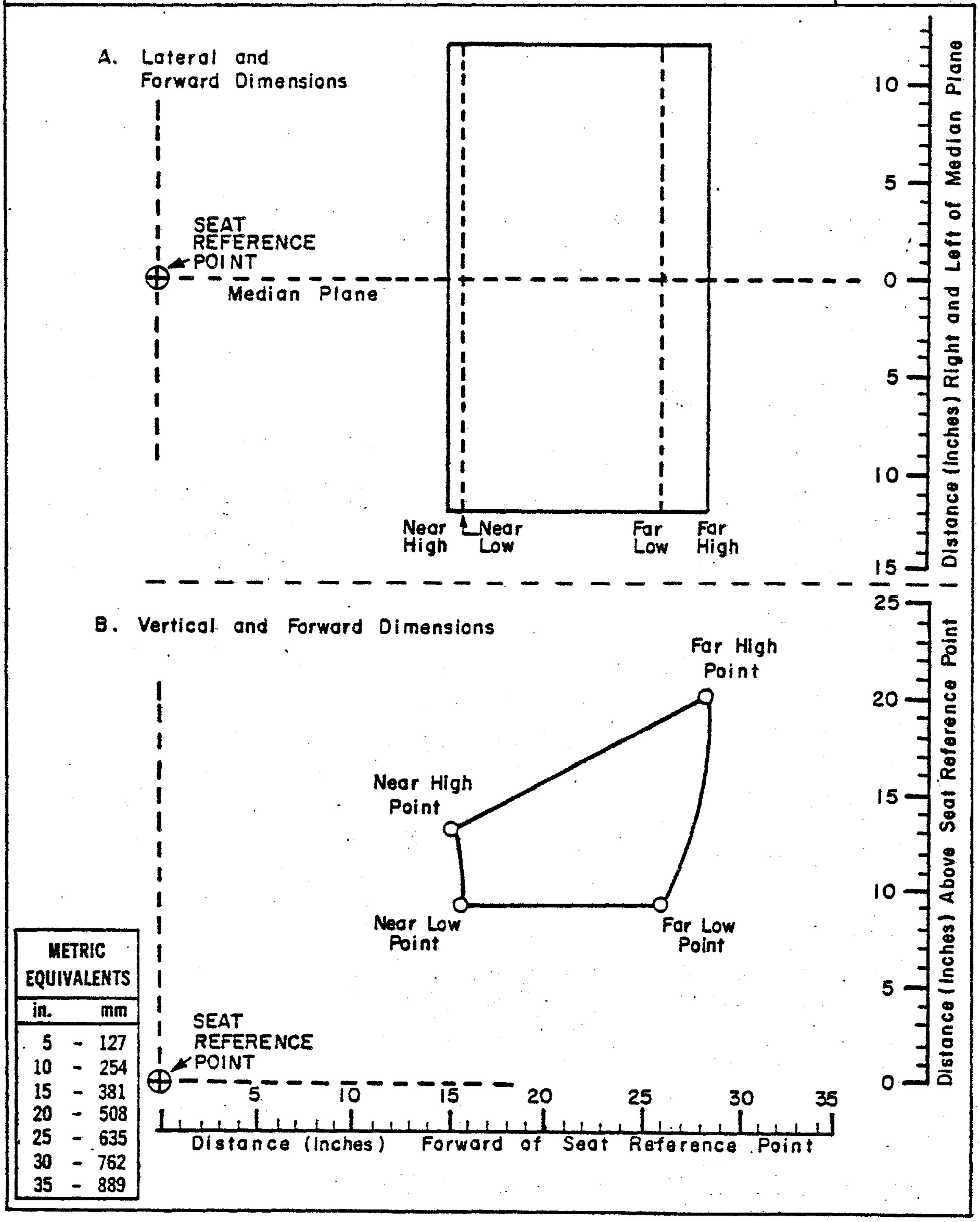



Figure 3

HAND REACH ENVELOPE FROM A SITTING POSITION

TABLE I
Total Time Available for Various Hand Speeds

| Hand Speed | Safety Distance | Total Time |
|---|---|---|
| 1.6 m/sec. | .460 m. | .288 sec. |
| 2.0 m/sec. | .460 m. | .231 sec. |
| 2.2 m/sec. | .460 m. | .210 sec. |
| 2.3 m/sec. | .460 m. | .200 sec. |
| 2.4 m/sec. | .460 m. | .193 sec. |
| 2.5 m/sec. | .460 m. | .1845 sec. |
| 2.6 m/sec. | .460 m. | .1775 sec. |
| 2.8 m/sec. | .460 m. | .165 sec. |
| 3.0 m/sec. | .460 m. | .154 sec. |
| 3.5 m/sec. | .460 m. | .132 sec. |
| 4.0 m/sec. | .460 m. | .115 sec. |
| 4.5 m/sec. | .460 m. | .1025 sec. |

This analysis establishes a limitation on the use of presence sensing devices in relation to the speed of human hand or arm movement, speed of machine, and the application of presence sensing devices to press-like equipment. It becomes apparent that presence sensing devices can be used safely if the equipment has sufficient braking capacity to stop the dangerous motion of the equipment before any part of the human body can reach the machine's danger zone. This basic safety consideration limits the type of equipment which could tolerate a presence sensing device. The limit is defined by equating the speed with which a human can interrupt the intangible safety barrier and the time it takes the braking system of the machine to stop the dangerous motion.

An anthropometric limitation is immediately perceived; i.e., the length of the human arm reach. Thus, the barrier cannot be placed beyond a certain distance because it would hinder operations. This human limitation taxes the braking system of the machine because the brake must be able to stop the moving part faster than the hand speed.

These findings, and the fact that Swedish and German regulations clearly indicate the use of two hand speeds, seriously question the adequacy of the OSHA safety regulation establishing 1.6 meters per second as the hand speed constant for presence sensing device applications.

This analysis indicates that in the U.S., injury may be sustained by an employee trying to beat the machine because the hand speed used in the OSHA standards is too slow.

Machine Stopping Time Determination

It was established that:

Total required time for press stoppage is:

$$T_{ps} = T_{psd} + T_{pc} + T_{pb}\ T_{de}$$

Where: $T_{ps}$ = Press stopping time.

$T_{psd}$ = Response time of presence sensing device.

$T_{pc}$ = Response time of press controls.

$T_{pb}$ = Response time of press brake.

$T_{de}$ = Response time of dissipation of energy by brake.

Tests conducted during this study yielded $T_{psd}$ response times varying from 9 milliseconds to 60 milliseconds. Of the 11 presence sensing devices tested, 1 had a response time of 60 milliseconds; 1 of 9 milliseconds. The response times of the remaining nine devices were concentrated between 17 and 22 milliseconds. In order to standardize the response time of presence sensing devices, the value of 20 milliseconds was used as a representative value of presence sensing device response time. The response time tests were conducted using the methods described later in this report.

Even though the contract did not require the analysis of machine control circuitry, it was decided that some determination of the response time values of press controls, press brake, and dissipation of energy by the brake was needed. Machine controls are manufactured by specialty companies. These controls use solid state electronic components and parts, electromechanical relays, or a combination of both. Regardless of the speed of response of solid state electronic circuitry, however, the interface between the control circuitry and the prime mover power supply is usually an electromechanical relay. Electromechanical relay response time varies between 5 milliseconds to approximately 30 milliseconds, depending on the size and current rating of the relays. Typical relays used in machine control systems have a response time of 12 to 16 milliseconds. We have assumed, therefore, a machine control response time of 20 milliseconds based on tests conducted in France and current U.S. manufacturers' literature on relay response times.

The determination of the response time of press brakes and the time required to dissipate the energy by the brake was not undertaken; however, an analysis of pneumatic partial revolution power press brakes was made. Partial revolution power press brakes are applied by constant mechanical spring pressure acting against the nonbraking surface of the brake movable plates. To operate the press, therefore, compressed air (usually between 45 to 60 pounds per square inch) is required to release the brake. (The press brake operates in a way opposite to the way automobile brakes operate.) To apply the brake, it is necessary to release the entrapped air in the space or volume so that the air pressure counteracts the brake springs. It can be deduced that operating at air pressures higher than that specified by the manufacturer will cause the press brake to respond slower than specified. This is because there is more air (higher pressure) entrapped and, therefore, it will take longer to exhaust the air to the atmosphere through a fixed restrictor. This analysis was verified by tests performed in England. From this analysis, it becomes apparent that response time of brake control and time required to dissipate the energy of brakes should be taken at a preset pneumatic pressure. Changes in response time due to abnormally high pneumatic pressures of 70 to 110 psi may change the brake response time substantially. Tests conducted in England show that this change could be as great as 20 percent; therefore, mechanical power press stopping time is dependent on the air presure applied to the brake. It should be required that power press stopping time be measured at pneumatic pressure values presently recommended by press manufacturers.

Analysis of power press control systems found no justification for requiring that power press stopping time measurement be made at approximately the $90^{o}$ position of the crankshaft. This statement is made on the basis of the following:

The combination of crankshaft and connecting rod, transforming rotary motion into linear motion, transforms the constant rotary velocity of the crankshaft into a linear velocity that changes in a sinusoidal manner. The linear velocity changes are directly dependent on the ratio of crankshaft offset and the length of the connecting rod. Since the length of the connecting rod usually is significantly longer than the crankshaft offset, the velocity changes of the slide movement are very small. The slide reaches its maximum velocity at approximately one-fourth of the total downward travel and its minimum velocity at approximately three-fourths of the downward travel. Because the changes in velocity are very small and the accuracy with which stopping time of movement measurement can be made, measuring stopping time at approximately $90^{o}$ of crankshaft rotation does not significantly improve the results of measuring the response time of the dissipation of energy by the press brake at any point in the downward stroke.

Determination of Safe Distance

The analysis has assumed that the distance from the presence sensing device sensing plane and the danger point is constant. The description of the presence sensing device function and limitations established that the sensing field created by a presence sensing device is a volume and that intrusions into the volume produce a change of state in the output signal of the presence sensing device. Visible and infrared devices generate a volume with a thickness of approximately 3 mm (.125 inch). The volume generated by radio frequency devices has an indeterminate thickness.

Visible and Infrared Devices Sensing Plane Determination

This report contains simple tests developed for determining presense sensing device sensing planes for visible and infrared types of devices. Additional tests were conducted to define the effects on the location of the sensing field plane as a function of the distance between light emitter and light receiver. The limiting factor in this set of tests was the angular relation between the light emitter and receiver combination, rather than the diffusion of the light beam. (This comment refers only to visible and infrared light sources.)

It becomes increasingly difficult to align transmitter and receiver as the distance between them is increased. As the distance is increased, a small vibration causes the device to shut down the press. Two of the devices tested use a reflective surface instead of a receiver where the emitter and receiver are placed in the same housing. In these two devices, the results of the test were the same. The sensitivity to angular changes varied between ± 2 to ± 7-1/2 degrees from the centerline with a 1.22-meter (48-inch) spacing between transmitter and receiver.

Receiver-emitter devices use an array of transmitters spaced 19 mm (3/4 inch) apart and 38 mm (1-1/2 inches) apart, as measured from centerline to centerline of each transmitter. This type of presence sensing device exhibits the characteristic that objects 25 mm in diameter and 38 mm in diameter can penetrate the light curtain undetected if the rod is precisely introduced at the mid-distance between the two transmitters. The 25 mm and 38 mm measurements apply to the 19-mm and 38-mm transmitter spacings, respectively. If these values are translated into finger/hand penetration, hand detection will occur at approximately 76 mm (3 inches) past the sensing field plane. The approximate value of 76 mm is given because employees with small hands will penetrate further than employees with large hands.

Other devices exhibit different optical characteristics. For instance, presence sensing devices which generate a sweeping light will not detect objects up to 76 mm in diameter which pass through the detection zone at exactly a $45^{o}$ angle with respect to the detection zone plane.

Radio Frequency or Capacitance Devices Sensing Field Determination

No method was found to determine the sensing field plane of radio frequency devices which would remain constant with changes in operational environment.

Radio frequency devices exhibit the following limitations:

1. The energy volume generated by the antenna is not precisely defined. Its shape and size are not known.

2. The radio frequency signal can be disturbed by external energy sources and changes in capacity-resistance to ground.

The practical effect of these two limitations is that the sensitivity of the device will change with changes in capacitance-resistance ground; thus, the safety distance will change. These changes will be evidenced in two ways:

1. The device becomes too sensitive; thus, it stops the machine without apparent cause.

2. The device becomes too insensitive; thus, it reduces the safety distance or creates a "blind spot."

These devices generate a sensing field of wavelengths varying from 1700 to 750 meters and frequencies of 175 to 400 KHz.

Tests conducted in Houston and Seattle electromagnetic interference (EMI) facilities determined that the measurable sensing field extends to approximately 5 meters from the antenna of the device. The 5-meter distance reflects the resolution and sensitivity of the instrument with which field strength measurements were made (one microvolt change = $1X10^{-6}$ volts). Therefore, the actual sensing field volume boundaries could not be defined.

Further tests were conducted in the Seattle laboratories to evaluate device detection capabilities with respect to changes in capacity-resistance to ground. The complete report on these tests can be found in Appendix K, "Evaluation of Radio Frequency Presence Sensing Devices."

The study of radio frequency presence sensing devices has shown that the sensing plane (the detection capability) of radio frequency presence sensing devices is susceptible to change resulting from (1) changes in the quantity of conducting mass in the electromagnetic field; (2) the physical characteristics of the press operator; (3) the quality of the electrical path between the operator and ground; and (4) the conditions existent at the time of presence sensing device adjustment. These factors cannot be adequately controlled for extended periods of time in the plant environment. Therefore, it is recommended that:

1. Radio frequency presence sensing devices not be used to protect the press operator when performing "hands-in-die" operations or any other operation that requires exposure of portions of the operator's body to injury resulting from the downward movement of the press ram.

2. Radio frequency presence sensing devices be considered to provide adequate protection for operations in which automatic feed of stock material is used or for perimeter guards.

The above recommendations are made as the result of the study conducted on radio frequency presence sensing devices from which the following conclusions were determined:

1. Radio frequency presence sensing devices are capable of providing adequate protection around the perimeter of power presses and adequate protection of operators in processes using automatic feed of stock material.

2. The sensitivity of radio frequency presence sensing devices is usually set too low to provide sufficient protection for operators in secondary press operations or "hands-in-die" operations.

3. The lack of standardized methods for adjusting and maintaining radio frequency presence sensing devices permits degradation of sensing capability because of variations in operational configurations.

4. The lack of established guidelines for the installation of radio frequency presence sensing devices results in widely varying installation schemes which may reduce the guarding effectiveness of the device.

5. Inattention to "housekeeping" (the accumulation of hydraulic oil and/or oil absorbent material) around power presses increases the likelihood of slips and/or falls and decreases the guarding effectiveness of the radio frequency presence sensing devices.

6. Hazardous conditions inherent in the use of power presses cannot be eliminated by the installation of radio frequency presence sensing devices; however, exposure of the press operator to these hazardous conditions may be reduced.

7. The distance an object can penetrate the electromagnetic field of a radio frequency presence sensing device before the device responds increases as the resistance between the intruding object and ground increases.

8. The detection capability of the presence sensing device may be degraded by the use of excessive lengths of antenna.

9. The introduction of conducting material into the electromagnetic field after adjustment of the presence sensing device can enhance the detection capability. Removal of conducting material after adjustment of the device degrades its detection capability.

10. The installation of shielding around the presence sensing device antenna or the installation of the antenna too near the press degrades the detection capability of the device.

11. Objects entering the electromagnetic field of the presence sensing device at speeds of 1.6 meters per second and 2.5 meters per second are detected at approximately the same penetration distance. This implies that the device is slower to respond to slow-moving objects.

12. The ability of the presence sensing device to detect an operator's hand is degraded by the isolation of the operator's electrical ground through the use of rubber mats or other nonconducting materials.

13. The requirements of individual press operations vary to the extent that a standardized method for adjusting and maintaining the adjustment of radio frequency presence sensing devices is not possible.

14. Factors which affect the capability of radio frequency presence sensing devices vary from plant to plant and from operation to operation. This prohibits the establishment of universal guidelines for installing the devices.

15. Factors affecting the detection capability of radio frequency presence sensing devices may vary sufficiently over the duration of individual jobs to alter the degree of protection provided by the device.

FMEA FINDINGS

FMEA's were performed on each of the devices supplied to the Boeing Aerospace Company on consignment by presence sensing device manufacturers.

The FMEA's on presence sensing devices can be found in Appendices B through J. The FMEA and criticality determination apply only to the system described because a failure of the presence sensing device without knowledge of its function within the system has no meaning.

Presence sensing device output relays are single failure points which may cause injury to personnel. The critical failure is closed relay contact, either caused by mechanical malfunction or current loading. The basic cause for hazard 2.b.; i.e., "the guard or the safeguard command is not sent to the machine," is welding of contacts.

Mechanical failures of relays are likely to happen if relays are used beyond their expected mechanical life. Most mechanical relays are rated for $10^6$ cycles. Electrical failures are likely to happen if relays are used beyond their rated current loading capacity. Expected electrical life of relay contacts varies from $10^5$ to $10^6$ depending on the type of load.

The load factor variations can be illustrated in the following table extracted from "Electrical Requirements for Utilizing Equipment Used on Commercial Transport Airplanes," Boeing Commercial Airplane Company (D6-44588).

| Type of Load | Derating Factor |
|---|---|
| Capacitive | 1.33 |
| Resistive | 1.33 |
| Inductive | 2.50 |
| Motor | 5.00 |
| Lamp | 10.00 |

It is recommended, however, that a derating factor of at least 10.0 be used to size presence sensing device output relay contacts because this will tend to reduce relay contact welding failures.

Other single failure points which may cause injury (described as hazards 2.a., 2.c., and 2.d.) are peculiar to each design and are not generic to the interface between presence sensing device and machine control system. Further discussion of these failure modes may infringe on information which the manufacturers may consider proprietary. The FMEA's conducted on presence sensing devices indicate that manufacturers should perform FMEA's on their devices to provide assurance that no single failure points exist. Some devices exhibited single failure points which could be eliminated by improved design.

Determination of Systems Which Need Reliability Standards

The FMEA's performed on the devices analyzed indicate that presence sensing device manufacturers use the latest engineering technology.

The reliability of presence sensing devices is closely related to the manufacturing and assembly proficiency. Our study showed that manufacturing and assembly proficiency could be improved, as shown in Table II - Manufacturing and Assembly Proficiency. It is recommended, therefore, that manufacturers improve their manufacturing and assembly techniques, particularly soldering and serviceability.

Selection of high-reliability parts as a means of improving reliability is not recommended. Parts selected should be derated. Derating factors should be selected according to part usage, duty cycle, and environment.

Sample calculations of expected failure rates of presence sensing devices were calculated using the method described in MIL-HBDK-217C, 9 April 1979, "Reliability Prediction of Electronic Equipment." These calculations indicate that expected failure rates for the presence sensing devices analyzed vary from 400 to 800 failures per $10^6$ hours of operation. No attempt was made to correlate these findings with actual failures.

Manufacturers may be able to correlate the calculated failure rates with actual failures and use the numerical approach as an index to judge design simplicity. Another use of these numerical calculations may be in establishing warranties, maintenance schedules, and manufacturing spare parts for logistic considerations. The use of quantitative values should be judicious, as these calculations are approximations, at best.

## HAZARD AND FMEA CONCLUSIONS

These analyses identified 13 possible causes of injury to personnel when a presence sensing device is used as a guard. Of these 13 possible causes, 8 will be the causes of injuries occurring without presence sensing device system failure. Three of these eight causes require deliberate operator action to circumvent the device, and three may be attributed to ignorance of the devices limitations.

One cause, external to the presence sensing device system, is power failure. Power failure will normally stop the total system. The total system (power press and its associated control system) should fail in a safe condition. If this condition is not met, the possible injury cannot be attributed to the presence sensing device.

The maximum distance that the sensing plane of a presence sensing device can be safely located is dependent on the thickness of the sensing field volume, anthropological limitation of human arm reach, and the object speed.

One of the five failure effects can be attributed to output relays. Critical failure mode of closed relay contact caused by mechanical malfunction or current loading is generic to presence sensing devices. Other failure modes identified in the FMEA are peculiar to each device analyzed. These identified single failure points should be eliminated from the design.

## EVALUATION OF CURRENT METHODS FOR TESTING PRESENCE SENSING DEVICES

During a trip to England, France, Germany, and Sweden in January 1979, inquiries were made on the availability of presence sensing device standard tests. No standard test protocols were found in these European countries.

In Sweden, however, presence sensing devices are "type tested" by semi-governmental organizations. These tests are similar to, although not as rigorous as, qualification tests required by the Department of Defense for military purposes. The Swedish Government requires that each presence sensing device manufacturer submit, as a minimum, a failure modes and effects analysis on the devices.

The test protocols used by Swedish testing agencies to test presence sensing devices were not documented. Similar conditions were encountered in Germany, France, and England. It is to be noted here, however, that Government safety personnel of these four European countries were well aware of each other's activities and findings concerning presence sensing devices and other safety research.

In February 1979, a meeting was held with several power press manufacturers to obtain from them information related to the interface between power press controls and presence sensing devices. The information provided by these power press manufacturers indicated that generally the control circuitry was a purchased item. The controls were manufactured and assembled by independent companies, and the user had a choice of control systems. This practice, however, is not followed by all power press manufacturers.

Further attempts were made to obtain values of the normal stopping time of a power press. Power press manufacturers indicated that a blanket statement concerning power press stopping time could not be made because stopping time of the slide motion of a power press varies. Small, fast power presses may need four to five revolutions to come to a stop. Usually these fast power presses are fully automatic. For the purpose of this study, however, an average stopping time of 200 milliseconds may be found in newer machines and stopping times of 500 milliseconds or greater may be found in older machines.

The main difference between older and newer power presses is based on the control systems used to stop the machine, rather than the actual date of the power press manufacture. Old machines can be retrofitted with newer control systems, but the press manufacturers suggested that attaching new control systems, which include the brake systems, may create greater problems because the brake systems may stress the power press structure beyond its shock resistance capability.

Inquiries were made concerning standard tests that power press manufacturers may have developed to demonstrate the adequacy of the control system as it interfaces with presence sensing devices. No such tests were available.

In March 1979, a meeting was held with presence sensing device manufacturers to inform them of the scope of the contract and solicit from them any standard tests they conduct in their own plants to verify the adequacy of their product. No such tests were made available. The lack of documented test methods for evaluating presence sensing devices indicated the need for developing test methods for this purpose. A simple electronic laboratory was established for the specific purpose of evaluating presence sensing device performance and development of test protocols, even though these test activities were not fully scoped in the contract. The developed tests are included in this report.

## PRESENCE SENSING DEVICE MANUFACTURE AND ASSEMBLY

The 11 presence sensing devices submitted for analysis were inspected to determine quality of manufacturing and assembly. The devices were disassembled as needed to inspect for soldering quality, shock protection, serviceability, packaging, completeness of instructions, clarity of instructions, ease of maintenance, and ease of installation.

The proficiency of manufacturing and assembly techniques were graded by experienced quality inspectors from 1 to 10, 10 being excellent, 1 poor. The grading is shown in Table II. From this table it can be seen that soldering quality could be improved, as well as ease of servicing. It is important to note that the failure modes and effects analysis (FMEA) does not include failure considerations due to poor workmanship. However, poor workmanship, especially soldering quality, is a significant factor in the fault free function of any electronic devices.

Improvement in this area should reflect the manufacturer's warranty on the product and industry experience with the product. In this regard, users should remember that equipment failure causes downtime with the attendant loss of productivity. Therefore, the users should establish allowable downtime based on plant productivity goals and its effect on manufacturing costs. In order to achieve the user's productivity goals, the device manufacturer should provide the user with failure rates derived from FMEA's, parts selections, maintenance analyses, and recommended maintenance schedule.

### CRITERIA USED TO RATE MANUFACTURING AND ASSEMBLY CHARACTERISTICS

Soldering Quality. Are there burned components, bad foil runs on the printed circuit boards? Are the leads on the various components badly crimped, stressed, or otherwise abused? Are there bad solder joints? Are there bad wire runs, lack of insulation?

Shock Protection. The relative ability of the device to survive and give reliable service while being subjected to shocks normally associated with the device while attached to a machine press. This would include (1) how well individual components are attached to the printed circuit board, (2) how well the printed circuit boards are mounted and how they resist working out of the jacks into which they are plugged, and (3) how well the relays are mounted; do they have spring or other retainer clips?

Serviceability. The ease of getting the device back into operation with a minimum of downtime. Criteria would include: (1) Is the device built in a modular manner (can individual modules be plugged in and out)? (2) Can items be accessed with minimum trouble? (3) Can high failure rate items be changed easily (i.e., the relays)?

Packaging. How well will the case stand up to industrial abuse, and how good is the security? Is the case easily popped open either accidentally or by unauthorized personnel?

Completeness of Instructions. Are the instructions complete enough to be of help in the maintenance and service of the device? Are there adequate safety warnings?

Clarity of Instructions. Are the instructions easily understood? Are they accompanied by clear illustrations? Are there ambiguities in the instructions?

Ease of Maintenance. Once installed, is the device easy to keep working properly? How do external physical conditions affect the device's operation (i.e., ambient light and temperature or for radio frequency devices, metal masses and stray radio frequency radiation, etc.)? Can the device withstand large voltage power line transients? Are there any cables exposed that might cause a problem? How often does the device need cleaning?

Ease of Installation. Is the device easily installed? Is all mounting hardware supplied? Are any modifications (drilling and tapping, etc.) needed to prepare the device for installation? Is any special wiring needed?

Table II

MANUFACTURING AND ASSEMBLY PROFICIENCY

| Manufac-turer | Soldering Quality | Shock Protection | Serviceability | Packaging | Completeness of Instructions | Clarity of Instructions | Ease of Maintenance | Ease of Installation |
|---|---|---|---|---|---|---|---|---|
| 1 | 9 | 8 | 3 | 10 | 9 | 9 | 9 | 4 |
| 2 | 4 | | 4 | 5 | 2 | 4 | 7 | |
| 3 | 8 | 6 | 8 | 7 | 9 | 9 | 8 | 4 |
| 4 | 9 | 8 | 4 | 10 | 9 | 9 | 9 | 4 |
| 5 | 7 | | 7 | 8 | 2 | 4 | 7 | |
| 6 | 4 | 6 | 5 | 5 | 8 | 8 | 8 | 5 |
| 7 | 7 | | 5 | 8 | 2 | 4 | 7 | |
| 8 | 8 | 9 | 3 | 10 | 8 | 8 | 8 | 5 |
| 9 | 5 | 6 | 10 | 6 | 8 | 8 | 9 | 5 |

1 = Poor

5 = Good

10 = Excellent

## MARKET SURVEY

Commercially available presence sensing devices are manufactured by 33 companies (15 in the U.S., 1 in Canada, 5 in the United Kingdom, 8 in France, and 4 in West Germany). Of the 13 U.S. manufacturers who responded to the survey, 4 use visible light, 7 use infrared, and 3 use radio frequency/capacitance principles to form the safety barrier. (One manufacturer markets infrared and radio frequency devices.) The four companies from France that responded use infrared, as do the Canadian, the British, and four West German manufacturers.

U.S. presence sensing device manufacturers have sold an estimated 21,000 units in the U.S. It is estimated that 85 percent (18,000) of these units are in use on all types of machines. This represents 3.4 percent of the total market of approximately 544,000 pieces of equipment (mechanical power presses and other machinery with similar operating principles) which could use presence sensing devices as safeguards. The total market employs from 280,000 to 300,000 workers.

Manufacturers were approached to determine if they would provide their equipment on consignment. Of the 15 U.S. manufacturers, 10 agreed to furnish their equipment on consignment, as did Sick Elektronik of Germany. The decision to use devices cooperatively consigned was budgetary. Selection of products for study was not random, since manufacturers were contacted and asked to voluntarily participate in the study.

### DOMESTIC MANUFACTURERS

The survey identified 15 commercially available presence sensing devices in the U.S. for safeguarding mechanical power presses. Of the 15 manufacturers, 13 responded to inquiries. Of the 13, 4 use visible light for the "invisible barrier," 7 use infrared, and 3 use radio frequency/capacitance principles. Two did not respond to inquiries. Eight manufacturers supplied eleven devices for analysis.

A summary of the responses from the U.S. manufacturers follows:

Bachman Industries, Inc. - Visible Light

This company supplied a sales brochure and a list of customers, but did not provide a device or technical information.

Cincinnati, Inc. - Infrared

This company manufacturers hydraulic presses and supplies a presence sensing device as an option. The company will not sell the presence sensing device

(Waveguard) independently and did not supply a device. Complete logic-diagrams of the device and press controls, operating manual, and modifications that must be made on presses in order to install the Waveguard instrument were provided.

Data Instruments, Inc. - Infrared

This company supplied sales and price literature, complete circuit diagrams, and a parts list. A list of U.S. manufacturers who are using their devices and two devices for analysis were also provided.

Dolan-Jenner Industries, Inc. - Infrared

This company supplied sales and pricing information, as well as circuit diagrams and a device for analysis.

Electronic Control Corporation - Visible Light

This company supplied a price list, a sales catalog, circuit diagrams, and operating instructions, but did not supply a device. The device may not be suitable for marketing in the U.S. Electronic Control Corporation sales literature states that the device is susceptible to excessive ambient light, a false light signal that prevents the device from stopping the press.

Gordon Engineering Corporation - Radio Frequency/Capacitance

This company supplied a sales catalog and price list, a failure modes and effects analysis, circuit diagrams, and information concerning United Kingdom and French Government offices dealing with press operations and presence sensing devices. The company also provided a device.

Guardimation, Inc. - Infrared and Radio Frequency/Capacitance

The chief executive officer of this company, Mr. O. R. Twyman, visited our Houston office in response to a letter of inquiry and provided infrared and radio frequency/capacitance devices.

Micromenex - Infrared

This company provided a sales catalog, installation instructions, and a price list. No additional information or device was provided.

I.S.B. - Infrared

This company supplies the unit to Micromenex. A device was supplied; however, wiring diagrams or schematics were not provided.

Scientific Technology, Inc. - Visible Light, Infrared

This company supplied a sales catalog and price list, but no diagrams or device.

Sick Optik Elektronik, Inc. - Visible Light, Infrared

This company supplied circuit diagrams and logic for two models of its device; German, Swedish, and French publications on presence sensing devices; addresses and contacts with German and Swedish authorities; and typical electrical drawings of press controls and interfaces. The U.S. sales manager provided insight into the application of presence sensing devices and supplied two models of the devices, one visible light and one infrared.

Link Electric and Safety Control Company - Visible Light

This company provided a sales brochure, complete drawings and diagrams, and a device. The vice president in charge of engineering provided detailed information on circuit design philosophy and a demonstration of device capabilities.

Weldotron Corporation - Radio Frequency/Capacitance

This company supplied diagrams, wiring diagrams, and a device.

Electro Dynamics and Telecom Sales

No response.

Quancor, Inc.

No response.

FOREIGN MANUFACTURERS

British, French, West German, and Swedish Government authorities regulating and controlling industrial safety were conducted. A trip to Europe was made to contact European safety personnel who are engaged in research activities on presence sensing device applications and human reactions. Their research results were valuable in conducting hazard analyses and failure modes and effects analyses, as well as in formulating the approach to the development of the safety performance criteria.

The Swedish Government advised that only one manufacturer (Erwin Sick Company) is "accredited" to sell presence sensing devices in Sweden, and the West German officials stated that there are four manufacturers in West Germany. They were:

1. Fa. Erwin Sick, Optik-Elektronik.
2. Fa. Fiebler Electronik.
3. Fa. Endl Grubtl and Co.
4. Fa. Krohne.

No further inquiries to West German manufacturers were made because Sick Optik-Elektronik, U.S.A., provided the information on their device.

French manufacturers Cometa, Industel, Krohne, and Jay Electronics produce infrared devices.

Lightguards, Ltd., manufactures presence sensing devices in England. The unit is not for sale in the U.S. because of liability problems.

One Canadian manufacturer sells his device in the U.S. through distributors, one of which is Micromenex.

The market survey did not disclose any presence sensing device manufacturers in Japan. The only presence sensing device in Australia appears to be Erwin Sick Company of West Germany.

Inquiries were made in other Western European countries, but there was no indication that presence sensing devices are manufactured in those countries.

## ESTIMATE OF PRESENCE SENSING DEVICE POPULATION IN THE U.S., GERMANY, AND SWEDEN

The use of presence sensing devices in the U.S. was determined from manufacturers' estimated sales and application figures.

Information on the population, use, and regulation of presence sensing devices in Germany and Sweden was developed during the trip to Europe.

Swedish officials estimated that approximately 50 percent of the mechanical power presses (estimated to be 10,000) in operation in Sweden use presence sensing devices.

German, French, and U.K. safety officials could not provide data on presence sensing device usage, except by statements such as:

Germany - "Use of presence sensing devices is quite common."

England - "Use of presence sensing devices is not known, but it is not as prevalent as it may seem."

France - "Absolutely no idea of how many presence sensing devices are in use."

The specific regulations of interest were those establishing criteria and design operating and maintenance requirements on metal-working presses (mechanical power presses, hydraulic presses, pneumatic presses, and press brakes).

The countries were visited in the order mentioned above during a period of time starting on January 15, 1979, through January 26, 1979.

The Government offices visited were:

England: Health and Safety Executive<br>Safety in Mine Research Establishment (SMRE)<br>Red Hill<br>Sheffield 537HO

France: Institute de Recherche et de<br>Securite' (INRS)<br>Avenue de Bourgogne<br>54500 Vandoeure

West Germany: Fachausschuss "Eisenund Metall III"<br>Zentralstelle fur Unfallverhuntung and<br>Geweblichen Berufsgenosseuschaften, eu<br>Bougarstrasse 3<br>4000 Dusseldorf

Sweden: The National Board of Occupation Safety and Health<br>Arbetarskyddsstyrelsen (ASS)<br>Fack, S-100-26<br>Stockholm 34

Swedish Institute of Production Engineering Branch<br>Institute for Verkstadstekrisk Forskruing (IVF)<br>Molndalsvagen 85<br>41285 Goteborg, Sweden

Information obtained from officials of the United Kingdom, France, West German, and Sweden during visits to their respective countries indicates that the safety regulations developed by these countries show remarkable similarities and the implementation approach is quite similar. They differ only in method and degree of enforcement.

The safety regulations which have been developed recently (within the last 5 years) and those still in the development stage can be organized into three general topics. The regulations are divided generally into requirements levied upon (1) equipment manufacturers, (2) users, and (3) safety officials.

1. Equipment manufacturers (Press manufacturers). The regulation states, in broad terms, the safety features that the equipment shall have, such as fail-safe characteristics, etc.

2. Equipment users (employers). The regulation states the duties of the user (employer): (1) To provide the equipment manufacturer with the expected use of the equipment; (2) to explain risks involved and provide training, proper facilities and ancillary equipment to the employee (operator); and (3) to adhere to the manufacturers' maintenance recommendations and, in certain instances, certify equipment at periodic intervals.

3. Safety officials. The regulation requires that compliance with the safety regulation be verified by safety officials. This portion of the regulation provides checkpoints, tests, and analyses that will constitute evidence of compliance with the requirements. The successful performance of these checks, tests, and analyses is sufficient evidence of compliance. In some instances, the evidence must be submitted or presented to the safety official to demonstrate compliance.

The implementation of this approach varies from country to country only in the degree of enforcement. For instance, the U.K. Factory Inspectorate does not issue formal acceptance of equipment design; however, he does tacitly approve the design. Factory inspectors in West Germany use the negative approach for approval of a design by stating that they have no objections to its use.

In Sweden, however, use approval by the National Board of Occupational Safety and Health is required before marketing the equipment. The implementation system in France was not clear. It appears that safety officials deal directly with the manufacturer.

Safety criteria and regulations in England are developed by special committees formed by industry, labor, and Government. The regulations are general and focus upon design, operation, use, and maintenance. Specific regulations are developed by other committees who address specific machine types (i.e., mechanical presses, hydraulic presses, press brakes, etc.) individually. These committees are also formed by industry, labor, and Government personnel.

The French approach to inspecting places of employment was not discussed in great detail; however, the personnel at INRS work directly with French industry. They inform industrial personnel of their research and suggest improvements in the design of equipment.

The Berufsgenossenchaften in West Germany is a private organization. It is financed by private industry, labor organizations, and Government insurance. Their task is to enforce the regulations published by different committees covering each industry group. The committees are composed of labor, industry, and Government representatives (both Federal and State). The regulations approved by these committees are general requirements which are incorporated in a top level requirements document. Specifications which delineate specific design requirements are published in a second level document. Each design requirement document has its accompanying checklist or verification section which outlines the tests, inspections, and other pertinent details used by manufacturers, employers, and factory inspectors to verify compliance with design requirements. The system is quite similar to that used by the Department of Defense (DOD) in the U.S.A.

The Berfsgenossenschaften contributes to the formulation of the design and verification requirements, inspects factories, and trains personnel (safety representatives from labor, design engineers from industry, and inspectors) in industrial safety practices.

The training center in Schwelm (which was visited) is dedicated to training personnel in the use, maintenance, and inspection of metalworking presses and to verify prototypes of new or imporved methods used by industry prior to starting production of the equipment.

The Swedish National Board of Occupational Safety and Health is an autonomous body chartered to develop, publish, and enforce safety and health regulations. Their operation is implemented by safety and health inspectors; however, their main thrust is to type test equipment for use in Sweden. Type testing is a procedure similar to qualification tests and design certification used by NASA and DOD, although not as thorough. The manufacturer of equipment covered by safety or health regulations must submit to the Board a series of analyses and tests demonstrating compliance with the regulations. The Board has contracted two Government bodies to study and comment on the adequacy of the data submitted. These organizations are: The Forsvarets Forskningsaustalt (National Defense Research Institute) for electrical and electronic systems and components, and the Institute for Verlestadsteknisk Forskning (Institute of Production Engineering Research) for integration, mechanical, structural, ergonomics, and man/machine interfaces.

Upon receipt of the comments from these two bodies, the members of the National Board of Occupational Safety and Health will either approve or disapprove the use of the equipment in Sweden. This approval or disapproval power is exercised on Swedish as well as foreign-manufactured equipment. This power has the effect of creating defacto monopolies and trade barriers. Meetings with both of these Swedish Government contractors indicated that they are manned with personnel who are competent but who do not make political decisions. They present facts based on their technical analysis of submitted data and conduct research on safety; health research is conducted by another group.

Another common denominator found in British, West German, and Swedish safety activities is the integrated approach to safety and health. Their regulations cover an entire system. In the course of meetings, the Swedish and French personnel suggested that a better coordination of safety and health activities could be accomplished if regular (yearly) meetings among French, Swedish, and American safety and health officials were held. The British and West German personnel also expressed similar views, but were weaker in those recommendations.

The Swedish further recognize that safety and health regulations are a means of trade barrier which they would like to eliminate by standardizing safety and health regulations.

The U.S. presence sensing device manufacturers supplied approximate sales figures and the number of units sold. The sales figures do not distinguish between domestic and foreign customers. The application data include mechanical power presses and other types of metalworking equipment. The reluctance of U.S. manufacturers to provide more definitive sales data was based on their consideration that their total sales effort was proprietary.

The market survey indicated that industry is purchasing presence sensing devices for application as intangible safety barriers on mechanical power presses and on equipment which is not specifically controlled by an OSHA regulation. This indication was confirmed when we inquired about the type of applications on which these units are being used. Presence sensing devices are used on guillotine, riveting, stamping, drawing, pressbrake, hydraulic press, textile machinery, woodworking, and other types of equipment. From the above, it follows that presence sensing device performance criteria should be developed considering the total potential application and not be restricted to mechanical power presses. This approach was taken. The developed criteria and safety requirements are applicable to any application in which presence sensing devices could be used.

The usage estimates provided by industry, when compared to potential applications, reveal that only 3.4 percent of the potential market has been realized. The 3.4 percent value could be reduced to 1.8 percent if it is assumed that only 10,000 units are actually in use in the U.S. (This 10,000-unit value was supplied by Sick Optik-Elektronik.) Regardless of the amount of error in either this estimate or the estimate supplied by Sick Optik-Elektronik, the result is basically the same.

The market survey revealed that:

1. Old equipment, in general, is not suitable for safe application of presence sensing devices unless the response time of the braking system is improved. However, retrofitting old machines with faster brake systems may not be feasible because the shock load on the moving part of the machine may be too great, thus creating a greater danger.

2. Machines with a demonstrated capability of stopping the dangerous motion in less than approximately 200 milliseconds can be candidates for application of presence sensing devices.

Additionally, the market survey provided some idea as to the potential economic benefits of using presence sensing devices in industry and identified some limitations on their use.

Performance estimates obtained by the Department of Labor--OSHA and European studies (Swedish and German)--are as follows: Productivity was increased by approximately 25 percent when the presence sensing devices were used only as safety devices (allowed by current OSHA standards). When presense sensing devices were used as safety devices and tripping mechanisms (not allowed by current OSHA standards), productivity increased by approximately 27 percent. Productivity increases of the magnitude reported could significantly improve the current productivity of one major section of the U.S. economy.

# PERFORMANCE CRITERIA DEVELOPMENT

The development of performance criteria for presence sensing devices presented two problems which required early resolution. The resolution of these two problems broadened the scope of the developed criteria.

The first problem was that safety requirements for presence sensing devices are included in OSHA Regulation 1910.217, which applies only to mechanical power presses. This regulation does not cover industrial equipment which uses presence sensing devices such as press brakes, hydraulic and penumatic power presses, textile presses, guillotines, and conveyors. When presence sensing devices are used with the above mentioned equipment, the danger to employees is similar to the danger encountered in mechanical power press applications.

The above consideration suggested that the performance criteria for presence sensing devices should apply in any application, and that the specific application of these devices to mechanical power presses should be included as an appendix to the general safety criteria. This decision broadened the scope of the developed criteria.

The second problem was that there is no consensus among the Occupational Safety and Health Administration, U.S. industry management representing employers, and labor unions representing employees, on what constitutes acceptable performance criteria. This problem is yet to be resolved.

Safety regulation promulgated and proposed by OSHA, as well as ANSI and NIOSH documentation, do not provide criteria to choose one uniform format and wording acceptable to all parties. This lack of consensus indicated that the format and wording of the performance criteria should be established as early in the project as possible. The format and wording chosen for the development of the performance criteria were established by analyzing the Occupational Safety and Health Act.

The Act establishes that the employer is responsible for employees' safety and health in the place of employment, and the duty of employees is to observe and act according to the safety and health rules and regulations prevalent in the place of employment. This basic premise indicates that safety and health regulations should be addressed to employers, since they can implement actions at the place of employment.

From the above, it was decided that the performance criteria should be written in language that the employer could use. The performance criteria should provide the employer with conditions which establish: (1) When the use of a presence sensing device is allowed; (2) which presence sensing device should be used for the application; and (3) how the device should be installed.

The performance criteria included in this report follow this outline.

## RECOMMENDED SAFETY PERFORMANCE CRITERIA AND REQUIREMENTS

## FOR PRESENCE SENSING DEVICES

### GENERAL

The employer must decide whether presence sensing devices can be used in the selected application by analyzing the application, and determining that the selected application complies with the safety criteria for presence sensing devices. If the application is such that presence sensing devices can be used, the employer must select presence sensing devices which meet the performance characteristics described in the paragraph entitled "Selection Criteria." Upon selection of a device, the employer must perform verification tests to assure proper operation and selection of presence sensing devices and establish procedures for using and maintaining presence sensing devices which comply with paragraphs "Application Requirements" and "Demonstration Tests."

### DEFINITIONS

A presence sensing device is an apparatus designed, constructed, and arranged to create a sensing field which detects the presence of an object when the object is within the boundaries of the sensing field.

Sensing field is the volume of energy created by the presence sensing device.

Effective sensing field plane is the imaginary plane parallel to the equipment (press slide) motion plane, and defined by the position of an object at the time the presence sensing device is triggered by the object.

Fail-safe is the design feature of a part, component, piece of equipment, or system which causes the item to fail in a nonhazardous mode.

Hazard analyses are the activities which: (1) Identify hazards, (2) eliminate, control or counteract the identified hazards, (3) evaluate the risks of the identified hazards and their resolutions, and (4) provide the decisionmaking cycle which accepts residual risks.

Hazard controls are the actions taken to reduce the risk of injury.

Hazard counteraction measures are the provisions made to minimize the effect of the hazard when it occurs.

Residual risks are all hazards which are not eliminated by design.

Hazard acceptance is the reason the residual hazard can be accepted. Normally, a system which can tolerate a failure or a human error without causing injury to employees shall be considered acceptable.

Reliability is the probability of specified performance for a given period of time when used in the specified manner.

## SAFETY CRITERIA

Presence sensing devices shall be acceptable as guarding devices when (1) they guard equipment which can be stopped at any point of its cycle; (2) the presence sensing device signal will eliminate the source of danger in time to prevent injury or loss of life; and (3) the application of energy to the dangerous portion of the equipment is prevented so long as any portion of or the whole human body is within the danger zone.

The employer should perform a hazard analysis* on the presence sensing device specific application. He shall identify hazardous operations, equipment, or system failures that may cause injury to personnel. The employer should use the results of the hazard analysis to select presence sensing devices that have design and operational features which eliminate or control the identified hazards to an acceptable level.

## SELECTION REQUIREMENTS

Employers who have determined that the application of presence sensing devices complies with the preceding safety criteria shall select presence sensing devices which, as a minimum, shall:

1. Have an identifiable effective sensing field plane which will not change more than 1 percent of the safety distance for the application operating environments and conditions.

   The safety distance shall be determined by formulas (a) and (b):

   (a) Safety distance $S_d \geq V_h \times Ta$

   Where $V_h$ = Human or object speed penetrating the sensing field (for human hand speed, use 2.5 meters/second).

   Ta = Total time available in seconds to stop the equipment.

* Hazard analyses on power press applications were conducted, and this report reflects the findings of those analyses.

The equipment stopping time (Tps) at any point of the equipment cycle shall be equal to or less than the total time available (Ta).

$$T_{ps} \leq T_a$$

(b) $$Ta = \frac{D_{eff}}{V_h}$$

Where $D_{eff}$ = Effective distance, in meters, measured from the effective sensing field plane to the danger zone perimeter closest to the operator.

2. Provide fail-safe features for the safety of personnel during installation, operation (startup, normal operation, shutdown, and emergency shutdown), maintenance, repair, or interchanging of a complete assembly or component part thereof.

3. Prevent the generation of false operational or output signals due to failed parts, transients, power interruptions or outages, environmental external conditions and/or changes thereof, or human error.

4. Deliver and maintain specified performances for steady-state and transient-state conditions for any combinations of specified primary input power.

5. Deliver and maintain specified performances for any combination of the specified environmental and operational conditions of the application.

6. Provide a self-checking function to prove that each element of the presence sensing device is functioning properly prior to each presence sensing device operating cycle. Self-checking tests shall not interfere with the normal operation of the presence sensing device, nor shall the tests cause generation of false operations or signal output.

7. Protect by location and/or guards power switches, adjustments, or calibration controls to prevent accidental activation and/or deliberate tampering by personnel.

APPLICATION REQUIREMENTS

The application of presence sensing devices shall comply, as a minimum, with the following requirements.

1. Make access possible to the danger zone of the equipment being guarded only through the presence sensing device sensing field.

2. Interlock the signal(s) of guards or guarding devices (which assure that access to the danger zone exists only through the sensing field of

the presence sensing device) with the equipment control system to prevent the application of energy to the dangerous portion of the equipment.

3. Maintain the presence sensing device in a nondegraded operational condition by:

   a. Performing maintenance on the presence sensing device acording to presence sensing device manufacturer's recommended time intervals.

   b. Performing repairs of the presence sensing device according to presence sensing device manufacturer's repair instructions.

   c. Certifying the nondegraded operational condition of the presence sensing device at least once a year and after each maintenance and/or repair activity.

4. Do not allow the use of the presence sensing device on any equipment without the performance of a hazard analysis and verification that the application specified operational and environments conditions are compatible with the presence sensing device operational and design specifications.

DEMONSTRATION TEST REQUIREMENTS

Verification of design and application compliance with safety requirements shall be demonstrated by a combination of analyses and tests.

Verification by Analysis

Fail-Safe Features--
The performance of a qualitative failure modes, effects, and criticality analysis on the proposed application shall be considered sufficient evidence of compliance for fail-safe design features of the presence sensing device.

False Operational or Output Signals--
Delivery and maintenance of steady-state and transient-state signals, and self-checking characteristics shall be demonstrated by a combination of analysis and tests.

Presence Sensing Devices Guarding Dimensions--
The user shall specify dimensions of the plane(s) in meters required to guard the danger zone application.

Verification by Test

Detection and isolation of a failure, protection, and security provisions shall be demonstrated by installation tests.

Press Application Environment--
The selected presence sensing device should withstand, as a minimum, the following environment:

Temperature = -20$^{o}$C to +50$^{o}$C

Humidity = 99 percent

Vibration (shock) = 45 g's for 1 ms per stroke, when device is mounted on press frame.

Tests performed by presence sensing device manufacturers, demonstrating that the design and parts and components used in the fabrication and assembly of the presence sensing device will sustain the above mentioned environment, shall be acceptable as evidence of compliance.

Thermal Tests--
Cycle ambient temperature seven times from +26$^{o}$C to +50$^{o}$C to -20$^{o}$C to +26$^{o}$C at a thermal rate of change of 1$^{o}$ to 4$^{o}$ per minute. Cycle the cold plate surface temperature in phase with the ambient temperature.

The temperature at each temperature extreme shall be maintained for 60 minutes minimum after thermal stabilization. The device shall be cycled on and off seven times (cycles) at each temperature extreme.

The tests shall be considered a success when the device exhibits no out-of-specification performance.

Detection Zone Tests--
The objective of the detection zone test is to determine the effective plane from which the safety distance is to be measured and the perimeter of the sensing field (width and height) so that mechanical guards can be installed.

The user or manufacturer may develop the appropriate tests. The test results shall identify the sensing field plane within 3.175 mm (1/8 inch approximately) using dowels 19 mm (3/4 inch) and 31 mm (1-1/4 inch) in diameter.

Reaction Time Tests--
Definition of reaction time--Reaction time of a presence sensing device is the time, in seconds, it takes a signal to travel from the beginning of the presence sensing device detection circuit through the circuit and produce an output (or change of state) in the presence sensing device.

Test objective--The objective of the reaction time tests for presence sensing devices is to measure the reaction time in order to select the proper device for the application.

Test signal generation--The generation of the test signal introduced into the presence sensing device for measuring reaction time shall be such that the initiation time can be established with an error of less than 0.5 percent of the maximum reaction time allowed. (Maximum reaction time allowed for presence sensing devices used as guards in partial revolution clutch press application is 0.020 second.)

The test signal introduced into the presence sensing device circuitry shall simulate an intrusion into the detection zone. A second test signal shall be introduced simulating the withdrawal of an intrusion out of the detection zone.

Test signal output measurement--The presence sensing device output shall be measured at the electrical terminals which have been designated by the manufacturer of the presence sensing device as the output terminals. Where the output of the presence sensing device is a change of state, measurement of the signal producing the change of state shall not be considered as output.

Test instrument accuracy--The instrument(s) used to measure the reaction time shall be calibrated and certified to be accurate within 0.0001 second.

Test results--The test results of the reaction time for the simulated intrusion and withdrawal of an object out of the sensing field shall be recorded, as well as the time differential. Test results shall be documented and signed by the test conductor designated by the management of the user or manufacturer.

Test procedures--The test procedures used by employers and/or manufacturers of presence sensing devices shall be documented and required as evidence of proper selection of the presence sensing device.

The test procedures shall, as a minimum, provide a schematic of the test setup, identify equipment used, show location of connections, list steps required to take the measurements, and specify pass or fail criteria.

## PRESENCE SENSING DEVICE PRESS GUARDING APPLICATION

1. Presence sensing devices shall not be used with presses having full revolution clutches (safety criteria 1.).

2. Time constraints to evaluate press application are (safety criteria 2.):

   a. Response time of presence sensing device shall be no greater than 1/10 of the total time available (Ta) to stop the equipment (or no greater than 0.020 second).

   b. Safety distance shall be correlated with human reach characteristics for sitting and standing work stations (human reach characteristics are as shown in [specification to be determined]).

   $$\text{Total time available} = Ta = \frac{D_{eff}}{V_h} \geq Tps$$

   $D_{eff}$ = Effective distance, in meters, measured from the effective sensing field plane to the danger zone perimeter closest to the opertor.

   $V_h$ = Human hand speed = 2.5 meters/second

The press stopping time (Tps) at any point in the press cycle shall be equal to or less than the total time available (Ta).

The press stopping time consists of the summation of the discrete time of each subsystem; i.e., the press stopping time = Tps = Tpsd + Tpc + Tpb + Tde.

Tps = Press stopping time.
Tpsd = Response time of presence sensing device $\leq$ 1/10 Ta = $\leq$ 0.020 second.
Tpc = Response time of press controls $\leq$ 1/10 Ta $\leq$ 0.020 second.
Tpd = Response time of press brake.
Tde = Response time of dissipation of energy by brake.

3. Presence sensing devices shall not be used on presses that can allow a person to enter the danger zone or in any way completely cross the sensing field of the device (safety criteria 3.) unless provisions are made to render the press inoperative when a person or persons are within the press danger zone or have completely crossed the sensing field of the device.

## SAFETY PERFORMANCE CRITERIA AND REQUIREMENTS JUSTIFICATION

RECOMMENDED SAFETY PERFORMANCE CRITERIA AND REQUIREMENTS FOR PRESENCE SENSING DEVICES

DEFINITIONS

A presence sensing device is an apparatus designed, constructed, and arranged to create a sensing field which detects the presence of an object when the object is within the boundaries of the sensing field.

Sensing field is the volume of energy created by the presence sensing device.

Effective sensing field plane is the imaginary plane parallel to the equipment (press slide) motion plane, and defined by the position of an object at the time the presence sensing device is triggered by the object.

Fail-safe is the design feature of a part, component, piece of equipment, or system which causes the item to fail in a nonhazardous mode.

Hazard analyses are the activities which identify hazards, eliminate, control or counteract the identified hazards, evaluate the risks of the identified hazards and their resolutions, and provide the decisionmaking cycle which accepts residual risks.

Hazard controls are the actions taken to reduce the risk of injury.

Hazard counteraction measures are the provisions made to minimize the effect of the hazard when it occurs.

Residual risks are all hazards which <u>are not</u> eliminated by design.

JUSTIFICATION

DEFINITIONS

Definitions are necessary so that users of the Recommended Safety Performance Criteria and Requirements have a common understanding of the terms used.

Hazard acceptance is the reason the residual hazard can be accepted. Normally, a system which can tolerate a failure or a human error without causing injury to employees shall be considered acceptable.

Reliability is the probability of specified performance for a given period of time when used in the specified manner.

SAFETY CRITERIA

1. Presence sensing devices shall be acceptable as guarding devices when (1) they guard equipment which can be stopped at any point of its cycle; (2) the presence sensing device signal will eliminate the source of danger in time to prevent injury or loss of life; and (3) the application of energy to the dangerous portion of the equipment is prevented so long as any portion of or the whole human body is within the danger zone.

SAFETY CRITERIA

The criteria provide the considerations which should be used for determining whether presence sensing devices can be used in an application.

The analyses performed on presence sensing devices indicate that:

1. Presence sensing devices produce a change of state on one or more output relays.
2. Applications of presence sensing devices to equipment are time dependent and, therefore, are to be limited to those applications where the dependence on time is satisfied.

These limitations are identified as conditions that must exist to accept these devices as guards.

2. The employer should perform a hazard analysis on the presence sensing device application which shall include identifying hazardous operations, equipment, or system failures that may cause injury to personnel. The employer should use the results of the hazard analysis to select presence sensing devices that have design and operational features which eliminate or control the identified hazards to an acceptable level.

This paragraph suggests the performance of a hazard analysis by the employer as a means of identifying hazards. Although the employer may use other means to identify hazards and their solutions, this report identifies hazards present when using presence sensing devices.

SELECTION REQUIREMENTS

Employers who have determined that the application of presence sensing devices complies with the preceding safety criteria shall select presence sensing devices which, as a minimum, shall:

1. Have an identifiable effective sensing field plane which will not change more than 1 percent of the safety distance for the application operating environments and conditions.

   The safety distance shall be determined by formulas (a) and (b):

   (a) Safety distance $S_d \geq V_h \times Ta$

   Where $V_h$ = Human or object speed penetrating the sensing field (for human hand speed, use 2.5 meters/second).

   Ta = Total time available in seconds to stop the equipment.

   The equipment stopping time (Tps) at any point of the equipment cycle shall be equal to or less than the total time available (Ta).

   $$T_{ps} \leq Ta$$

   (b) $$Ta = \frac{D_{eff}}{V_h}$$

   Where $D_{eff}$ = Effective distance in meters, measured from the effective sensing field plane to the danger zone perimeter closest to the operator.

SELECTION REQUIREMENTS

The hazard analyses disclosed that a consistent safety distance is critical for safety. Our analyses of commercially available devices disclosed that changes in safety distance are possible because of changes in the relative position of the effective sensing field plane. Therefore, a design requirement limiting the allowable change is required.

A 1 percent maximum change was selected because a 1 percent error in the determination of safety distance assures greater safety in view of the wide range of possible hand speeds.

The selection of 2.5 meters per second as recommended hand speed is a compromise. Safety distance calculation is based on European regulations.

Studies in England and France (but not documented) indicate that maximum hand speed is between 4.1 and 4.5 meters/second.

The value of 1.6 meters per second was obtained by timing hand speed when the operator was handling "large" parts. The hand speed of 2.5 meters/second is applicable when operators handle "small" parts. (No definition of what constitutes a "large" or "small" part was found in Swedish regulations.)

The development of this formula is included in the text.

2. Provide fail-safe features for the safety of personnel during installation, operation (start-up, normal operation shutdown, and emergency shutdown), maintenance, repair, or interchanging of a complete assembly or component part thereof.

This requirement acknowledges hazards associated with electrical energy used to maintain, install, and operate the presence sensing device.

3. Prevent the generation of false operational or output signals due to failed parts, transients, power interruptions or outages, environmental external conditions and/or changes thereof, or human error.

This requirement addresses inadvertent operation of presence sensing devices identified in our study.

The employer should give special attention to identifying and advising the manufactures of the environments in which the device will be operated (e.g., traffic pattern; temperature; humidity; presence of corrosive, flammable, and explosive substances; etc.). Light should be considered even though none of the devices examined were susceptible to external light changes.

4. Deliver and maintain its specified performance for steady-state and transient-state conditions for any combination of specified primary input power.

This requirement addresses the problem associated with electrical power conditions at individual plants and manufacturer's design specification of the device. Voltage variations of up to 20 to 30 percent of rated power may be encountered because of start and stop of large electrical loads. The user should be aware of his power distribution system limitations and variations. The manufacturer of the device should also be aware of unusual power fluctuations which may affect the device.

| | |
|---|---|
| 5. Deliver and maintain its specified performance for any combination of the specified environmental and operational conditions of the applications. | This requirement addresses the problems created by environmental and operational demands placed upon the device. The environmental and operational conditions should be known by the employer and supplied to the device manufacturer or to the manufacturer's representative who has seen the potential application. In this way the employer will assure himself that he will buy a product that will be compatible with the application. |
| 6. Provide self-checking functions to prove that each element of the presence sensing device is functioning properly prior to each presence sensing device operating cycle. Self-checking tests shall not interfere with the normal operation of the presence sensing device, nor shall the tests cause generation of false operations or signal outputs. | This requirement addresses the features found in several of the devices studied and the single failure point present in all systems (relay failure) plus those other single failure points which are peculiar to each design. It assures that at least the presence sensing device does not have single failure points. The self-checking feature is within the state of the art of the industry. |

7. Protect by location and/or guards, power switches, adjustments, or calibration controls to prevent accidental activation and/or deliberate tampering by personnel.

This requirement addresses the security problem. It requires additional safeguards to prevent tampering with controls, adjustments, etc. Attempts were made during the study to specify security methods that should be used. However, it was decided that to do so would hamper both employer's and manufacturer's ability to design security measures or implement practices suitable for each application and place of employment. Further, to specify "how to" methods would be contrary to the concept of performance regulation. Security (locks) and susceptibility to circumvention for each device analyzed is shown in Table II under "packaging" which considered security.

APPLICATION REQUIREMENTS

The application of presence sensing devices shall comply, as a minimum, with the following requirements:

1. Make access possible to the danger zone of the equipment being guarded only through the presence sensing device sensing field.

2. Interlock the signal(s) of guards or guarding devices (which assure that access to the danger zone exists only through the sensing field of the presence sensing device) with the equipment control system to prevent the application of energy to the dangerous portion of the equipment.

APPLICATION REQUIREMENTS

These sets of requirements were derived from the hazard analyses, recommendations made by device manufacturers and users, and existing OSHA regulations.

Requirements 1. and 2. address the problem created by improper installation where the operator can enter the danger zone from above, below, back, or side of the device. To prevent this problem, it is required that any guard be interlocked with the machine control system. The interlock system should be designed in such a manner that removal or alteration of the proper guard configuration will render the machine inoperative. (Selection of interlocking device should be made in such a way that the interlock would not introduce an additional hazard.)

3. Maintain the presence sensing device in a nondegraded operational condition by:

   a. Performing maintenance of the presence sensing device according to presence sensing device manufacturer's recommended time intervals.

   b. Performing repairs of the presence sensing device according to presence sensing device manufacturer's repair instructions.

   c. Certifying the nondegraded operational condition of the presence sensing device at least once a year and after each maintenance and/or repair activity.

Requirement 3. addresses the maintenance and repair of devices. Implied in these requirements is the task of performing maintenance analysis by the manufacturer. The manufacturer should advise the user which parts and components need replacement and at what time intervals. The time interval could be specified in cycles of operation, by time, or both. Further, the manufacturer should also provide a repair manual. The repair manual should include part identification and rating, as well as tests that should be conducted upon repair to verify integrity of performance and nondegraded condition.

Certification of nondegraded operational condition should be made by either the user or the manufacturer's appointed officer. This means that the user and/or manufacturer are aware of the condition, age, usage factor, etc., of the device and, therefore, are responsible for the proper operation of the device. Eventually, either user or manufacturer may require the replacement of the device because it cannot be certified to be in a nondegraded operational condition.

4. Do not allow the use of the presence sensing device on any equipment without the performance of a hazard analysis and verification that the application specified operational and environmental conditions are compatible with the presence sensing device operational and design specifications.

Requirement 4. addresses the problem of determining if presence sensing devices can be used or changing the original application and/or equipment for which the device was intended. For example, device A was purchased to operate with machine B. Machine B is no longer needed or is obsolete and placed out of service. However, device A could be used with machine C. Requirement 4. prevents this change unless a hazard analysis is performed and verifies that device A and machine C are compatible and device A can perform safely in its new application. It is assumed that a hazard analysis has been made to determine if device A and machine B are compatible.

DEMONSTRATION TEST REQUIREMENTS

Verification of design and application compliance with safety requirements shall be demonstrated by a combination of analysis and tests.

DEMONSTRATION TEST REQUIREMENTS

Verification by Analysis

Fail-Safe Features--
The performance of a qualitative failure modes, effects, and criticality analysis shall be considered sufficient evidence of compliance for fail-safe design features. The fail-safe design features shall be as defined by the hazard analysis of the application.

Verification by Analysis

These paragraphs provide the user and/or manufacturer with basic evidence needed to satisfy the requirements levied in the three previous sections, so that objective judgment of compliance with the requirement can be demonstrated. OSHA inspectors should use this section to determine satisfactory compliance with regulations. In this manner both OSHA and employers will know what is needed.

It is important to note that the user should perform a hazard analysis unless the application is so prevalent that a hazard analysis developed for an equal application has been performed and its findings applied.

False Operational or Output Signals--
Delivery and maintenance of steady-state and transient-state signals, and self-checking characteristics shall be demonstrated by a combination of analysis and tests.

Presence Sensing Devices Guarding Dimensions--
The user shall specify the plane(s) dimensions in meters required to guard the danger zone.

False Operational or Output Signals--
Analyses and tests conducted by the manufacturer of the presence sensing device shall be considered sufficient evidence. FMEA on the design shall be considered sufficient. Tests performed by the manufacturer to established design limits will be considered sufficient.

Verification by Test

Detection and isolation of a failure, protection and security provisions shall be demonstrated by installation tests.

Verification by Test

Each application requires an integrated test after installation has been made to assure integrity of installed system. (Attempts to develop an integration test for power press systems were beyond the scope of the contract because it deals with press controls and hookups to plant facilities.)

This section provides the user and/or manufacturer with discrete values that should be met and what is considered to be the success criteria. Additionally, it establishes the minimum amount of reports required to demonstrate compliance with these specifications.

The sample tests and applications shown are self-explanatory. Their intent is to provide guidance to the user and/or manufacturer on the type of tests and the specific application of presence sensing devices to a partial revolution press.

Press Application Environment--
The selected presence sensing device should withstand, as a minimum, the following environment:

Temperature = $-20^{\circ}$C to $+50^{\circ}$C

Humidity = 99 percent

Vibration (shock) = 45 g's for 1 ms per stroke, when device is mounted on press frame.

Tests performed by presence sensing device manufacturers, demonstrating that the design and parts and components used in the fabrication and assembly of the presence sensing device will sustain the above mentioned environment, shall be acceptable as evidence of compliance.

Thermal Tests--
Cycle ambient temperature seven times from $+26^{\circ}$C to $+50^{\circ}$C to $-20^{\circ}$C to $+26^{\circ}$C at a thermal rate of change of $1^{\circ}$ to $4^{\circ}$ per minute. Cycle the cold plate surface temperature in phase with the ambient temperature.

The temperature at each temperature extreme shall be maintained for 60 minutes minimum after thermal stabilization. The device shall be cycled on and off seven times (cycles) at each temperature extreme.

The tests shall be considered a success when the device exhibits no out-of-specification performance.

Press Application Environment--

Thermal Tests--
The worst temperature exposures of any electronic device occur while the devices are being transported during summer and winter months. Temperature extremes may cause degradation of performance.

Humidity Tests--
May be combined with thermal test by assuring that the ambient within the last chamber is maintained at 99 percent relative humidity.

Vibration Tests--
No suitable test was found to simulate the vibration of power presses. Acoustical analysis of presses indicate a maximum saw tooth vibration environment of 40 to 54 g's at the frame of the press.

Detection Zone Tests--

The objective of the detection zone test is to determine the effective plane from which the safety distance is to be measured and the perimeter of the sensing field (width and height) so that mechanical guards can be installed.

The user or manufacturer may develop the appropriate tests. The test results shall identify the sensing field plane within 3.175 mm (1/8 inch approximately) using dowels 19 mm (3/4 inch) and 31 mm (1-1/4 inches) in diameter.

Detection Zone Tests--

Reaction Time Tests--

Definition of reaction time--Reaction time of a presence sensing device is the time, in seconds, it takes a signal to travel from the beginning of the presence sensing device detection circuit through the circuit and produce an output (or change of state) in the presence sensing device.

Test objective--The objective of the reaction time tests for presence sensing devices is to measure the reaction time in order to select the proper device for the application.

Test signal generation--The generation of the test signal introduced into the presence sensing device for measuring reaction time shall be such that the initiation time can be established with an error of less than 0.5 percent of the maximum reaction time allowed. (Maximum reaction time allowed for presence sensing devices used as guards in partial revolution clutch press applications is 0.020 second.)

The test signal introduced into the presence sensing device circuitry shall simulate an intrusion into the detection zone.

Reaction Time Tests--

These two requirements are needed because presence sensing devices may exhibit different response times when an object is introduced into the field and is withdrawn from the field. (The test performed on the devices studied showed very little change; however, other devices not tested may show some significant difference.)

A second test signal shall be introduced simulating the withdrawal of an intrusion out of the detection zone.

Test signal output measurement--The presence sensing device output shall be measured at the electrical terminals designated by the manufacturer of the presence sensing device as the output terminals.

This requirement is needed because self checking circuitry in the devices studied did not check for relay welded contact. This failure may be present and not be detected. Some devices use relays which have two sets of contacts mechanically connected so that failure of one set will drive the other contact to an unwanted position.

Where the output of the presence sensing device is a change of state, measurement of the signal producing the change of state shall not be considered as output.

Test instrument accuracy--The instrument(s) used to measure the reaction time shall be calibrated and certified to be accurate within 0.0001 second.

The requirements to use an instrument with a specific error is made to prevent users from testing for time measurements with equipment which does not have sufficient resolution; i.e, it is impossible to measure time within 1 millisecond accuracy with a wristwatch.

Test results--Test results shall be documented and signed by the test conductor designated by the management of the user or (employers) manufacturer.

Test results--These requirements are needed to establish a minimum of documented evidence of what was done in the test and verify degree of rigor when the test was performed.

Test procedures--The test procedures used by users (employers) and/or manufacturers of presence sensing devices shall be documented and required as evidence of proper selection of the presence sensing device.

The test procedures shall, as a minimum, provide a schematic drawing of the test setup, identify equipment used and location of connections, and list actions required to take the measurements and pass or fail criteria.

## SAMPLES OF TEST PROCEDURES AND SCHEMATICS

### GENERAL

The following test procedures and schematics are supplied as guides for the development by users and/or manufacturers of their own tests.

1. Reaction time measurements (sample tests 1, 2, and 3 for variable voltage, variable current, and radio frequency devices, respectively).

2. Definition of sensing field plane for light and infrared systems.

3. Definition of minimum diameter of object required.

4. Evaluation of effect of maximum and minimum distance on sensitivity.

The last two tests were not included in the set of demonstration tests because each manufacturer of a presence sensing device should advertise in the sales brochure (1) the dimensions of the minimum size object that the device detects, (2) the maximum distance that the receiver-transmitter can tolerate, and (3) the maximum acceptable misalignment.

The use of a specific brand name in these schematics does not reflect endorsement of that brand name device, but reflects the equipment used to develop these tests. The users and/or manufacturers are free to use any equipment or test setup or scheme they wish as long as the objectives of the test are satisfied.

The criteria were that tests should be simple and technically sound, and use the least expensive test equipment and test setups, yet provide adequate measurements. All of the equipment used in these tests can be bought at a local hardware store, except for the timer-counter which costs approximately $1,000.000. (It can be rented for less than $200.00 per month.) The three sample tests shown in this section are the tests that the user may perform to measure the response time of presence sensing devices. Whatever test is chosen, the user must insist on rigorous discipline and verification of test results.

The other significant parameter is the determination of the sensing field plane so that safety distance can be measured. The tests used to define the sensing field plane are simple and can be made with components purchased at a local hardware store. The total cost of the test setup was less than $20.00, and consisted of a sliding rode mounted on a pedestal (hat hanger), a plumbline, measuring tape, paper, and pencil.

REACTION TIME MEASUREMENTS

Sample Test No. 1 - Variable Voltage Devices

Equipment--

1. Hewlett Packard 5304-A Timer/Counter.

2. Batteries, "D" cell, 1-1/2 volt.

3. Wire.

4. Two test leads with a male BNC connector on one end, one alligator clip on the center conductor, and an alligator clip on the ground wire on the other end.

Procedure--

1. Connect power to device and set up according to the manufacturer's instructions.

2. Connect the center conductor of one test lead to pin of IC; connect the ground wire to the ground. Connect the BNC connector to the "A" jack of the H.P. 5304-A.

3. Connect a battery across the machine control relay contacts. Connect the second test lead's center conductor and ground wire across the same contacts. Connect the BNC connector of this test lead to the "B" jack on the H.P. 5304-A.

4. Set the "Comm/Sep/Chk" switch on the H.P. 5304-A to "Sep." Turn the function switch to T.I. A to B. Set the range to .1 ms. Turn the delay switch fully counterclockwise. Set the "Atten." and "Level" controls to the point where a reading is obtained on the H.P. 5304-A when an object is introduced or withdrawn from the detection zone.

5. Record results.

# TEST SET-UP FOR MEASURING REACTION TIME OF VARIABLE VOLTAGE DEVICES

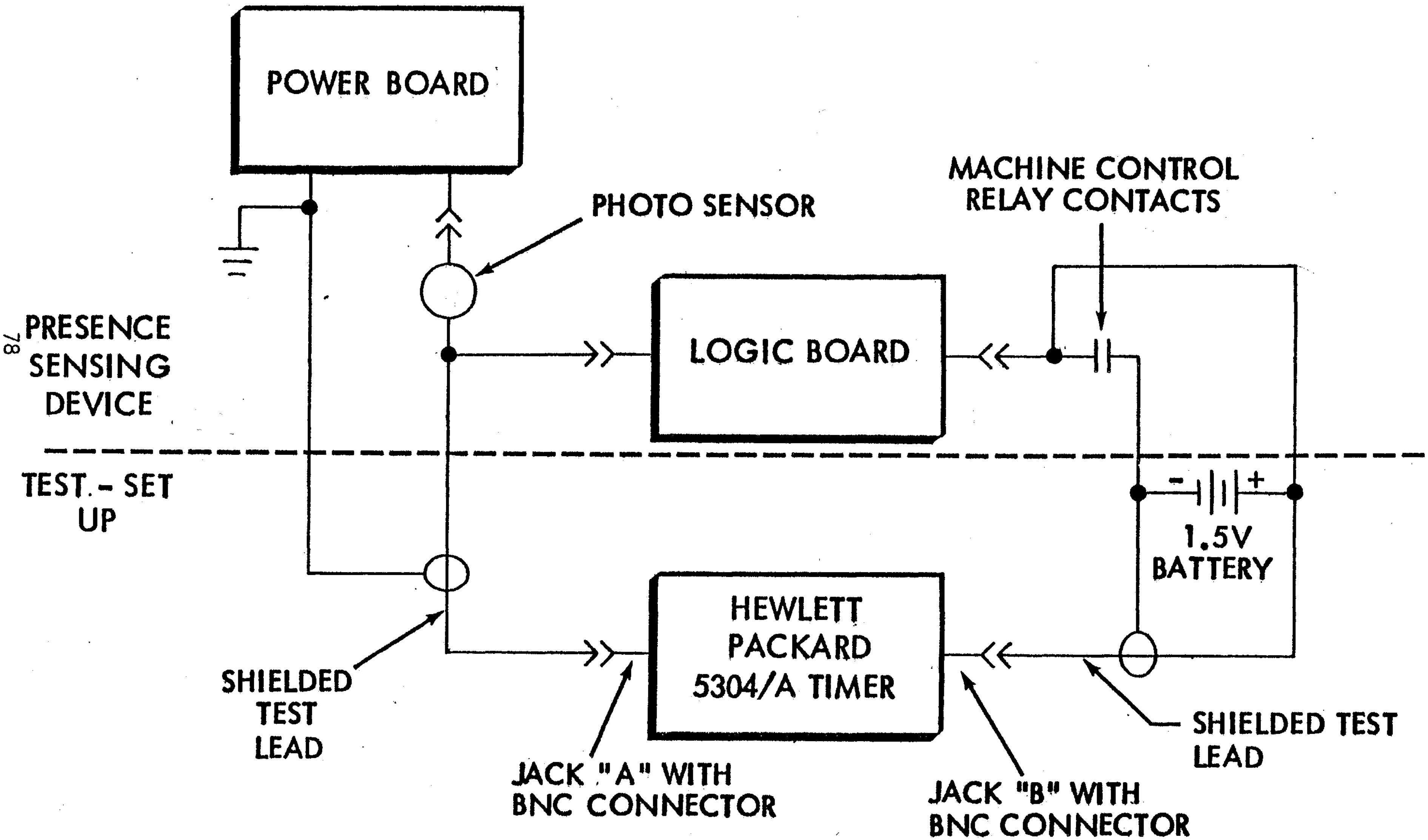



FIGURE 4

REACTION TIME MEASUREMENTS

Sample Test No. 2 - Variable Current Devices

Equipment Required--

1. Flashlight.

2. Hewlett Packard 5304-A Timer/Counter.

3. Batteries, "D" cell, 1-1/2 volt.

4. Two test leads with male BNC connectors on one end and alligator clips on ground and on the center conductor.

5. Wire.

6. Screwdriver, blade.

7. Stand for flashlight.

Procedure--

1. Punch a small hole in the flashlight.

2. Run two wires through the hole to the batteries. Connect one wire to the "+" (positive) terminal of the batteries and the other to the "-" (negative) terminal of the batteries.

3. Connect the wires to one of the test leads with the positive wire going to the center conductor and the negative wire going to ground.

4. Connect the BNC connector of the test lead to the "A" (input) jack of the H.P. 5304-A Timer/Counter.

5. Connect two wires, one to the "+" (positive) terminal and one to the "-" (negative) terminal, of separate battery. Connect the other side of these wires to the contacts of the machine control relay on the device. Connect the second test lead to the same relay contacts with which the battery is connected. Make sure that the center conductor is connected to the same relay contact that has the positive terminal of the battery connected to it and the ground side is connected to the same relay contact with which the negative terminal of the battery is connected. Connect the BNC connector of this test lead to the "B" jack on the front to H.P. 5304-A.

6. Connect power to the device and set it up according to the manufacturer's instructions. Blank Channels 1, 2, and 4 of the presence sensing device. (These channels are applicable to the specific device tested and were blanked to prevent interference.)

7. Set the flashlight at a height at which it will shine into Channel 3 of the device which corresponds to one specific set of LED's. Adjust the angle and distance of the flashlight from the device so the relays will operate when the flashlight is turned off and on.

8. H.P. 5304-A setup procedures: Set the "Com/Sep/Chk" switch to "Sep." Turn the function switch to T.I. A to B and the range to 0.1 ms. Adjust the "Level" and "Atten." controls until a reading is obtained on the H.P. 5304-A when the flashlight is turned off.

9. Record results.

10. An easy way to turn the flashlight on and off without distrubing its position is to short the two wires coming out of the flashlight together.

# TEST SET-UP FOR MEASURING REACTION TIME OF VARIABLE CURRENT DEVICES

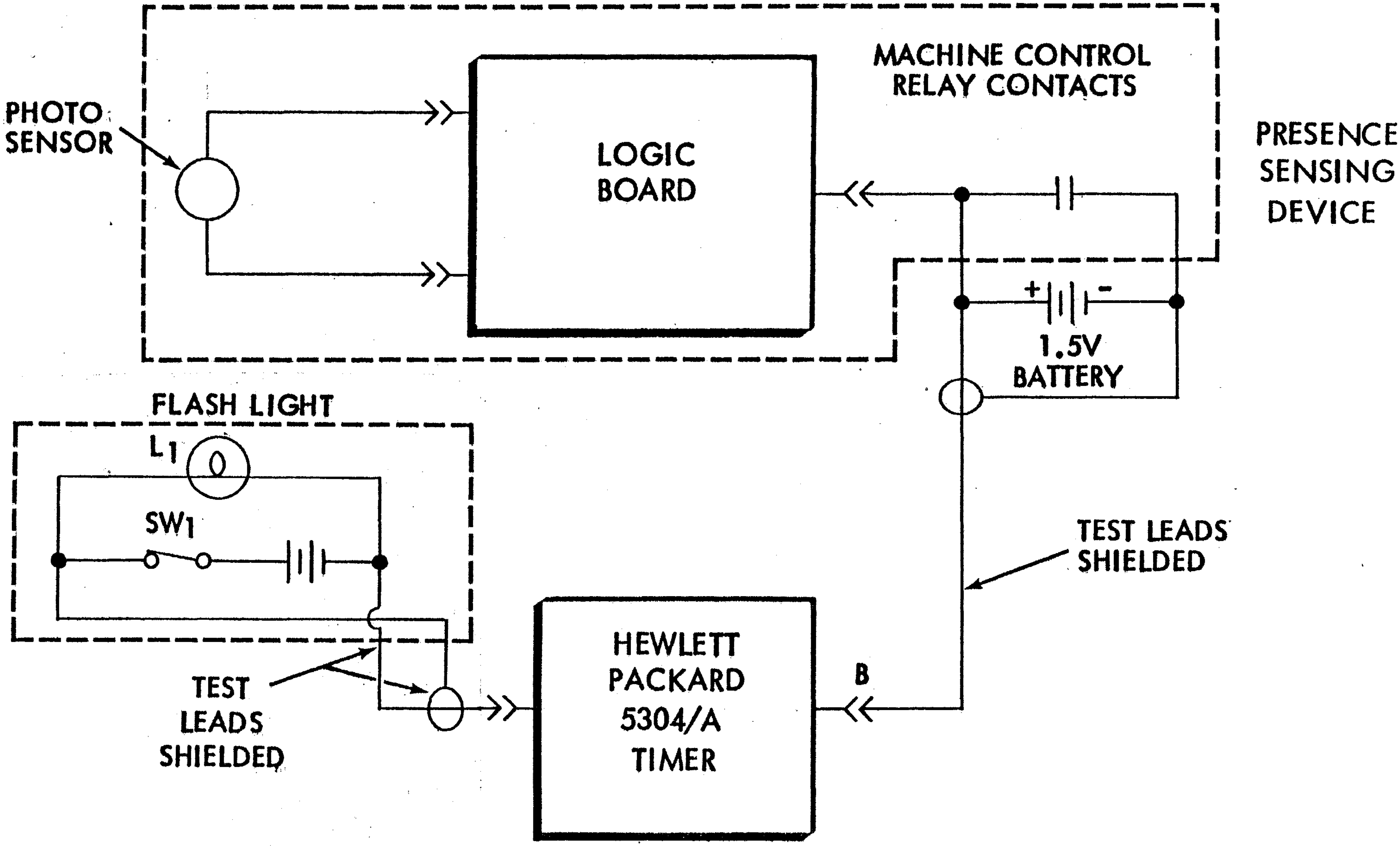



FIGURE 5

REACTION TIME MEASUREMENT

Sample Test No. 3 - Radio Frequency Devices

Equipment Required--

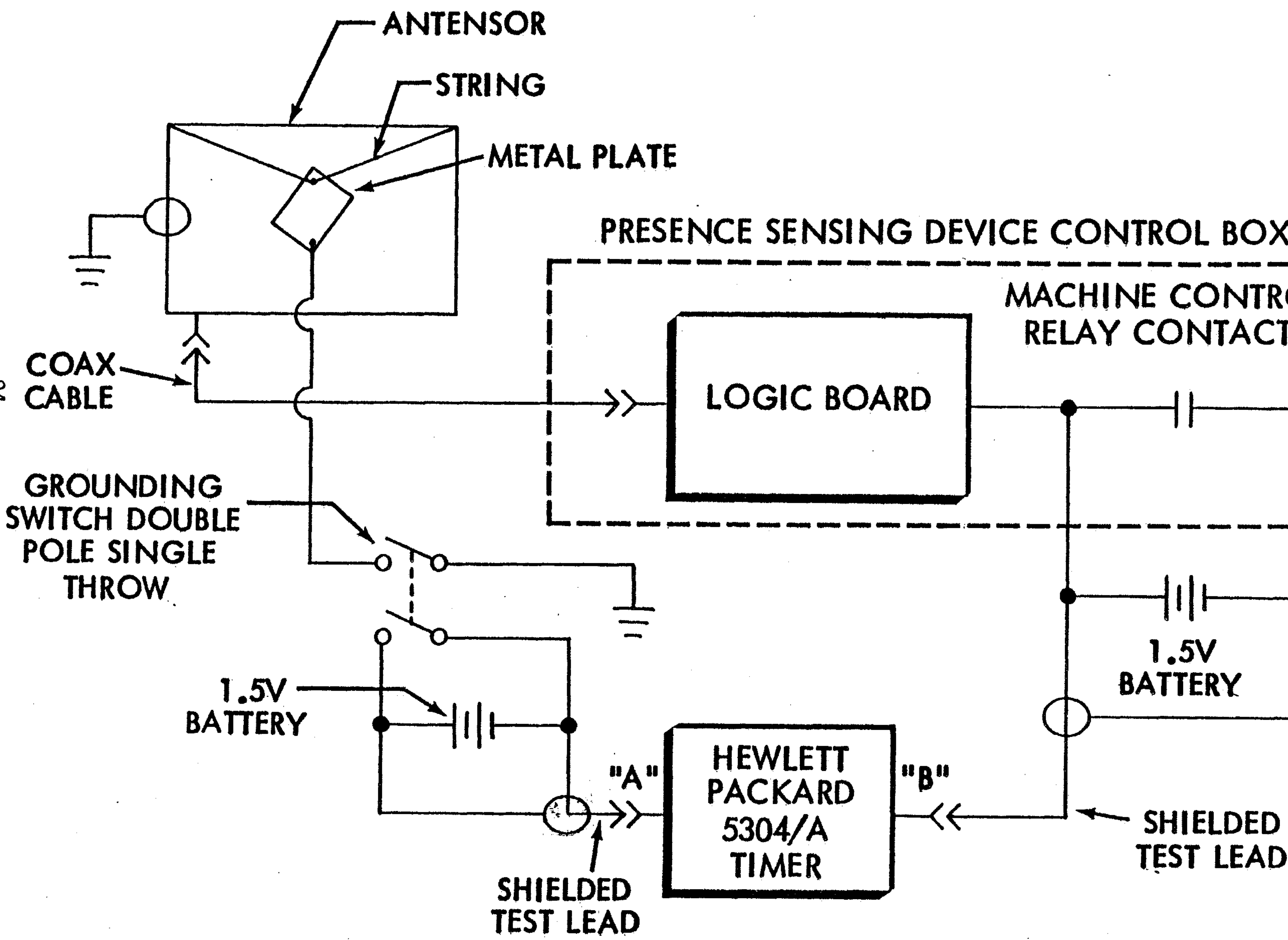
1. Hewlett Packard 5304-A Timer/Counter.
2. Two test leads with male BNC connectors on one end, and on ther other end alligator clips on the ground shield and conductor.
3. Batteries, "D" cell, 1-1/2 volt.
4. 25- x 30-cm (10- x 12-inch) metal plate.
5. One double-pole, single-throw switch.
6. Wire.
7. Screwdriver.
8. String.

Procedure--

1. Set up RF device following the manufacturer's instructions.
2. Suspend metal plate in the antenna field on a piece of string or other nonconducting material.
3. Set up grounding switch double pole single throw:
   a. Connect one pole by running a wire from the metal plate to a switch; connect the other side of switch contact to ground.
   b. Connect the other pole across a "D" cell battery. Connect associated switch terminal to the other side of the "D" cell battery and also to a test lead. Connect the test lead to the "A" (input) jack on the H.P. 5304-A.
4. Set sensitivity of RF device to range where the relays will activate when the switch is thrown.
5. Connect another battery across the machine control relay. Connect the second lead across the same relay contacts. This test lead should be connected to the "B" jack on the front of the H.P. 5304-A.

6. Set the "Com/Sep/Chk" switch to "Sep." Turn the function switch to T.I. A to B. Set the range to 0.1 ms. Turn the delay switch fully counterclockwise. Set the "Atten." and "Level" controls to the point where a reading is obtained when the switch running from the metal plate to ground is thrown.

# TEST SET-UP FOR MEASURING REACTION TIME OF RADIO FREQUENCY PRESENCE-SENSING DEVICES




NOTE: DIFFERENTIATE BETWEEN TEST SET-UP CONNECTIONS AND PRESENCE - SENSING DEVICES

FIGURE

## DEFINITION OF SENSING FIELD PLANE FOR LIGHT AND INFRARED SYSTEMS

### Objective

To define the detection zone effectve plane, width of zone, and height.

### Equipment Required--

1. Mounting stands for presence sensing devices.
2. Mounting stand for probe insertion in sensing field with attachment to insert probes laterally and from top and bottom.
3. Level or plumbline; floor surface for marking.
4. Measuring tape.

Note: The selection of equipment required was made considering that the user may not have sophisticated equipment to determine detection zone dimensions. All equipment can be easily obtained at hardware stores.

### Procedure--

1. Set horizontal probe tip with a plumbline which is barely off the floor.
2. Set up the presence sensing device on a mounting stand at optimum spacing between transmitter and receiver. (Follow manufacturer's instructions.)
3. With horizontal probe set midway between top and bottom of device at approximately 1/4 the distance of the transmitter/receiver spacing, determine exact point at which probe activates device by marking the position of the plumb on the floor (at least four measurements are required to define the sensing field plane perpendicularity with the floor).
4. Move the horizontal probe to the other side of the presence sensing field and proceed as in step 2. above.
5. With the vertical probe attached to measure the top boundary of the detection zone, determine the exact point at which the probe activates the device. Measure the distance to the floor. (Take at least four measurements.)
6. Repeat step 4. with vertical probe attached to measure the bottom boundary of the detection zone. (Take at least four measurements of vertical distance to the floor.)

Figure 7

**DEFINITION OF DETECTION ZONE**

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| FRONT PLANE (HORIZONTAL) | | | | | | |
| BACK PLANE (HORIZONTAL) | | | | | | |
| WIDTH | | | | | | |
| VERTICAL DISTANCES: | | | | | | |
| TOP | | | | | | |
| BOTTOM | | | | | | |

## DEFINITION OF MINIMUM DIAMETER OF OBJECT REQUIRED

### Objective

To define the minimum diameter of an object that can be detected by presence sensing devices.

Equipment Required--

1. Mounting stand for presence sensing device.

2. Mounting stand for probe insertion in sensing field with attachment to insert probes laterally and from top and bottom.

3. Level or plumbline; floor surface for marking.

4. Measuring tape.

5. Set of wooden dowels from 19 mm to 50 mm in diameter in increments of 10 mm.

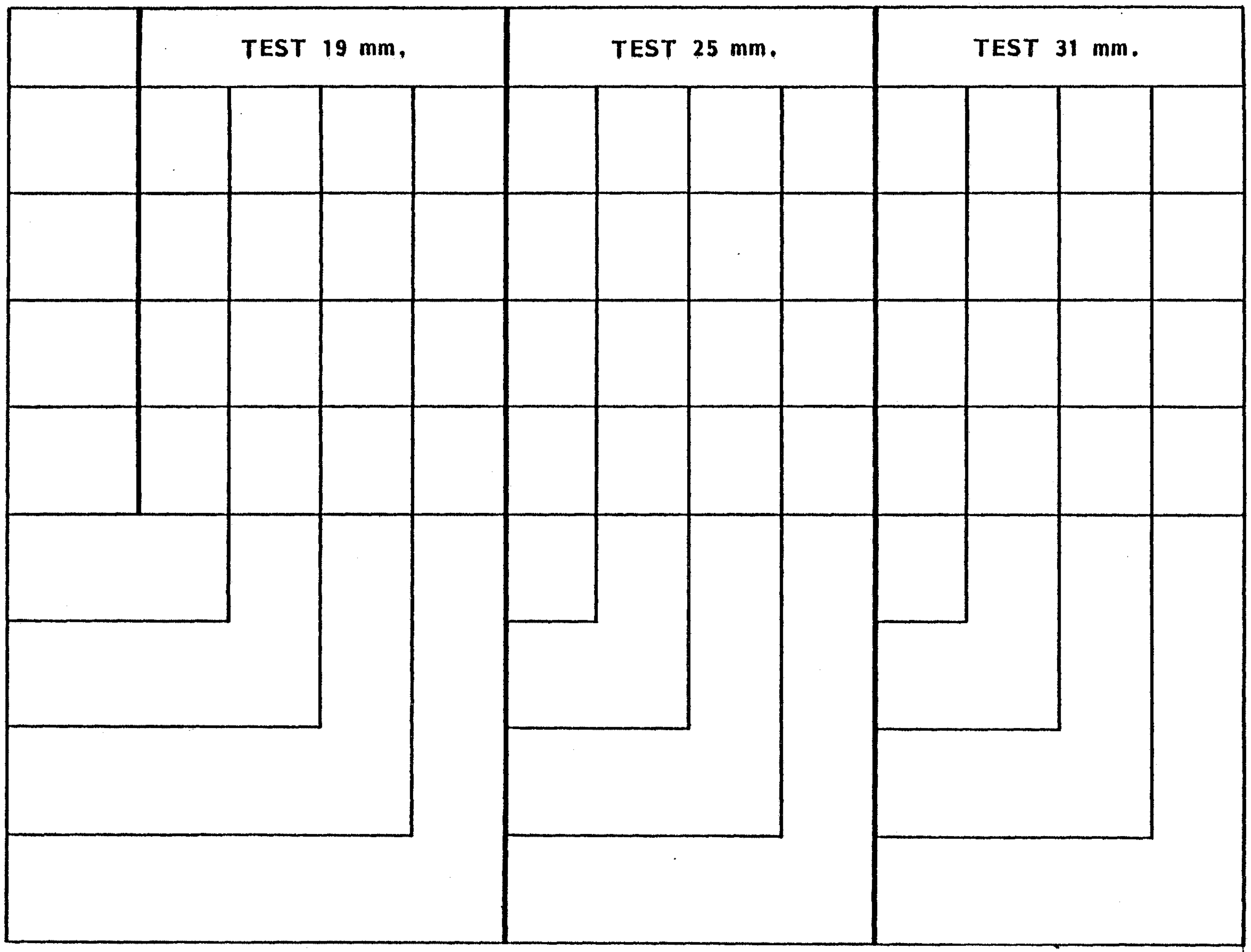
Procedure--

1. Set up sensing device on mounting stand at optimum spacing between transmitter and receiver. (Follow manufacturer's instructions.)

2. Attach dowels to the horizontal probe. (Make at least four tests at four different heights and at 1/5, 2/5, 3/5, and 4/5 of the overall length, with the dowel of the smallest diameter that is detected.)

Figure 8

**DEFINITION MINIMUM DIAMETER OF OBJECT REQUIRED**



EVALUATION OF EFFECT OF MAXIMUM AND MINIMUM DISTANCE ON SENSITIVITY

Objective

To define the maximum and minimum distances at which a standard size object is detected by the device.

Procedure--

1. Set up presence sensing device on mounting stand at optimum spacing between transmitter and receiver.

2. Using a rod size recommended by manufacturer, move the transmitter away from the receiver in steps until the presence of the object is <u>not</u> detected. (Record distance and sensitivity).

3. Repeat the same procedure as above, but move the transmitter toward the receiver in steps until the presence of the object is not detected (Record distance and sensitivity).

4. Repeat steps 2. and 3. and vary the sensitivity settings from the optimum set by the manufacturer.

   a. Increase sensitivity in steps of 20 percent of total sensitivity range.

   b. Decrease sensitivity in steps of 20 percent of total sensitivity range.

5. Concurrently, take response time measurements for varying sensitivity adjustments (in $\pm$ 20 percent increments starting from the factory setting).

<u>Note</u>: Prior to making voltage variations, evaluate circuit voltage tolerance.

Figure 9

## EVALUATION OF EFFECT OF MAXIMUM AND MINIMUM DISTANCE ON SENSITIVITY

### SENSITIVITY SETTINGS

| | FACTORY ADJUSTMENT | +20% | +40% | +60% | +80% | +100% | -20% | -40% | -60% | -80% | -100% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIXIMUM DISTANCE | | | | | | | | | | | | |
| MINIMUM DISTANCE | | | | | | | | | | | | |
| RESPONSE TIME (MS) | | | | | | | | | | | | |

### INPUT VOLTAGE VARIATION

| | NOMINAL | +10% | +20% | -10% | -20% | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RESPONSE TIME | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

## SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

### SUMMARY

The study identified 12 generic hazard causes in the mechanical power press system attributable to presence sensing devices. The 12 identified hazards can be effectively controlled. Seven of these hazards may cause injury to workers without system failure. Six of these can be controlled by the effective application of presence sensing devices to the equipment being guarded. One hazard can be controlled by modifying existing OSHA regulations. Four hazards may cause injury to workers only through presence sensing device failure, and one hazard may cause injury only when there is a power failure that affects only the presence sensing device. An additional generic hazard identified in the study which may cause injury is failure of the equipment control system.

Presence sensing devices using radio frequency-capacitance principles to detect objects exhibited characteristics which tend to limit their applicability to industrial environments which are fairly static.

### RECOMMENDATIONS

Specifically, the study indicates that:

1. The current method required by OSHA Standard 1910.217 (C) (3) (iii) (e) to measure safety distance should be modified to apply to presence sensing device industrial applications. The hand speed constant used to calculate the safety distance should be increased from current 1.6 meters per second to 2.5 meters per second.

   The formula to calculate the safety distance should be changed from:

   $D_s$ = 1.6m/second x $T_s$ (63 inches/second x $T_s$)

   Where $D_s$ = Minimum safety distance; 1.6 meters/second = hand speed constant, and $T_s$ = Stopping time of the press measured at approximately $90^o$ position of crankshaft rotation (seconds).

   To: Safety distance $S_d \geq V_h$ x Ta

   Where $S_d$ = Safety distance in meters, measured from the effective sensing field plane to the danger zone perimeter closest to the operator.

$V_h$ = Human or object speed penetrating the sensing field (for human hand speed use 2.5 meters per second).

Ta = Total time available to stop machine (in seconds).

The equipment stopping time (Tps) at any point of the equipment cycle shall be equal to or less than the total time available (Ta).

2. Radio frequency presence sensing devices should not be used to provide protection of the press operator when performing "hands-in-die" operations or any other operation that requires exposure of portions of the operator's body to injury resulting from the downward movement of the press ram.

   Radio frequency presence sensing devices provide adequate protection for operations in which automatic feed of stock material is used or for perimeter guards.

   The study of radio frequency devices has shown that the sensing plane (detection capability) of radio frequency presence sensing devices is susceptible to change resulting from changes in the quantity of conducting mass in the electromagnetic field, the physical characteristics of the press operator, the quality of the electrical path between the operator and ground, and the conditions existent at the time of presence sensing device adjustment. These factors cannot be adequately controlled for extended periods of time in the plant environment.

   These changes affect the operation of the device in two ways:

   a. The safety distance increases when the capacitance-resistance ground is decreased. This change causes the device to initiate a stop signal too soon to the machine being guarded. The operational indication for this condition is that the machine will stop without apparent cause.

   b. The safety distance decreases when the capacitance-resistance ground is increased. This change causes the device to initiate a stop signal too late to the machine being guarded. No operational indication exists for this condition.

3. The employer should provide the manufacturer of presence sensing devices with as much information as possible on the specific application (perform a hazard analysis of his application) because presence sensing devices are only one source of danger (hazards) in the total presence sensing device (machine controls) operator system studied. The adequacy of presence sensing devices alone will not significantly improve the safety of the system. Sources of danger (hazards) inherent in the design of the machine, machine controls, and in its operations by an employee must be eliminated or controlled to significantly reduce the likelihood of injury.

CONCLUSIONS

Study findings which may be of interest to the users and manufacturers of presence sensing devices are as follows:

1. The failure modes and effects analyses indicate that:

   a. Presence sensing device designs which were analyzed use the latest proven engineering technology.

   b. The interface between the presence sensing device and machine control system is critical.

   c. The use of electromechanical relays in this interface makes the selection of relays and their arrangement (series or parallel) critical. Therefore, relay failures must be monitored. Relays should be derated by at least 10.0.

   d. Parts and components selected for use in the presence sensing device should be derated. Derating factors should be selected according to part usage, duty cycle, and environment. Selection of high reliability parts as a means to improve reliability is not recommended.

   e. Expected failure rates for the presence sensing devices analyzed varied from 400 to 800 failures per $10^6$ hours of operation. The expected failure rates were calculated using the method described in MIL-HBDK-217C, 9 April 1979, "Reliability Prediction of Electronic Equipment." (No attempt was made to correlate these findings with actual failures.)

   f. Manufacturers should implement a reliability program as an integral part of their management philosophy. As a minimum, they should perform failure modes and effects analyses on their designs and keep these analyses current.

2. The inspection of the devices supplied by manufacturer indicates that manufacturing and assembly proficiency should be improved, especially soldering and serviceability.

3. The market analysis of U.S. and foreign countries shows that:

   a. An estimated 21,000 units have been sold in the U.S., of which approximately 18,000 are in use on all types of machines. This represents 3.4 percent of the total potential market of approximately 544,000 pieces of equipment (mechanical power presses and other equipment with similar operating principles). The total market employs from 280,000 to 300,000 workers.

   b. Industry has designed braking systems which can bring the moving part to a stop in approximately 200 milliseconds. Retrofitting old machines with faster brake systems should be carefully studied, because the shock load on the moving part of the machine may be too great, thus creating a greater danger.

c. Studies conducted in Sweden and Germany indicate that a productivity increase of 25 percent can be realized by the use of presence sensing devices as guards. (Actual studies not obtained.)

4. No standard test protocols were found to exist either in the U.S. or in European countries to assess the characteristics of presence sensing devices. Some tests were developed in the performance of this contract to help employers to assess the adequacy of presence sensing devices.