Professional Safety

# Working with robots

## Supervisor awareness can help prevent fatalities

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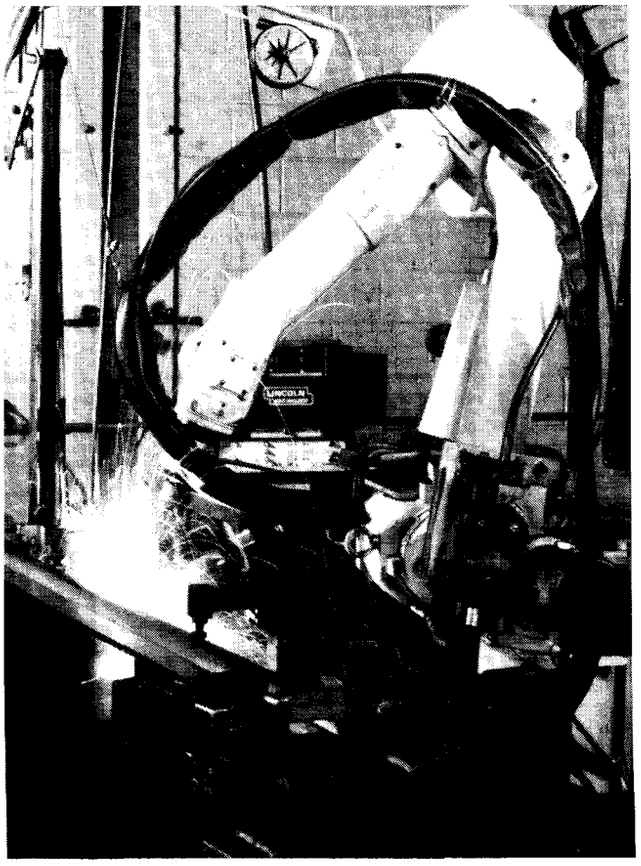

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Researchers from the National Institute for Occupational Safety and Health (NIOSH) investigated two industrial robot-related occupational fatalities in the United States. In one, an operator of an automated die-cast system was pinned between the right rear end of a hydraulic robot and a steel safety pole. In the other, an operator of an automated machining system was found with his back on a conveyor while a robot's end effector applied downward pressure on his chest.

A common factor in these fatalities was that the victims had entered the safeguarded area of the robotic workstation during automatic operation. In both of these cases, the safeguarding was intended to prevent access to the robot's work zone except by opening an interlocked gate which would stop automatic operation of the robot.

Although both work cells were equipped with interlocked gates, the safety perimeters had openings which allowed worker access to the robots' work zone without stopping automatic operation of the robots.

There was a substantial difference in robot system operation experience between the two victims. The operator involved in the first incident had finished his initial training three weeks before the accident while the operator involved in the second incident had nine years' experience. The circumstances of these occupational accidents are described here to help avoid similar incidents.

### Incident # 1

*Fatality involving a newly-trained operator with limited experience*

A robot had been installed in an existing production cell to remove die-cast parts from a die-cast machine and to transfer these parts to a trimmer. These tasks were previously performed by a human worker. The robotic work cell's safeguarding system included two horizontal safety rails with an interlocking gate and a safety pole intended to prevent erratic robot arm movement.

The safety railing consisted of two horizontal metal pipes fixed to stanchions attached to the floor. The upper rail was waist high. The 4-inch diameter steel safety pole was intended to prevent the robot arm from swinging into the aisle if robot control were lost.

The hydraulic robot involved in this accident was purchased used from the original owner, and the safeguarding devices and workstation layout were designed in-house without assistance from the robot manufacturer. The operator had completed a one-week training course in robotics three weeks previously.

The thirty-four-year-old male operator of this automated die-cast system went into cardiorespiratory arrest and died after being pinned between the back end of this industrial robot and the steel safety pole. While the pole was originally intended as a safeguarding device, it created a pinch-point hazard that fatally entrapped the operator.

Prior to the accident, the operator and other workers were apparently unaware of the hazard posed by the pinch point between the rear of the robot and the safety pole.

Despite his training in the robotics course, instructions on the job and warnings by fellow workers, the victim entered the working range of the operating robot presumably to clean up scrap metal that had accumulated on the floor. The operator's exact point of entry into the robot's work envelope is unknown. He may have climbed over or through the two horizontal safety railings or he may have entered through one of two unguarded openings at either end of the safety railings.

Although the safety railing was equipped with an interlocked gate it

was possible to enter the robot's work envelope without opening the interlocked gate.

The victim was discovered by the operator of the adjacent die cast machine. Although the accident site was not directly observable from the neighboring workstation, the operator stated that he became curious when he heard the steady hissing of the air hose for 10 to 15 minutes. When the operator of the neighboring workstation investigated the noise, he found the victim pinned between the right rear of the robot and the safety pole in a slumped but upright position.

The robot stalled when it pinned the man's body; however, it continued to apply pressure on his chest. The victim went into cardiorespiratory arrest and died a short time later.

When the director of manufacturing arrived on the scene, co-workers were attempting to free the victim with a hand-held teach pendant which is connected to the robot's controller. The teach pendant is a hand-held device which is used to program the robot.

After several unsuccessful attempts with the teach pendant, a second teach pendant was brought from another robot. Using this pendant, the director of manufacturing finally unpinned the victim approximately 30 minutes after he was entrapped.

### Safety improvements

After a fatality or serious injury occurs, employers often make changes in the system and method of work to prevent similar incidents. These changes can be of interest to other safety professionals who are responsible for similar work situations. Some of the safety changes made after this fatality included:

- The safety rails were replaced with a six foot high chain link fence which made unauthorized entry more difficult.
- Fixed fencing was installed at the unguarded openings in the perimeter barrier to completely enclose the robot's work zone.
- The steel pole was removed.

## Incident # 2

*Fatality of an operator with nine-years' experience*

On Oct. 11, 1986, a fifty-one-year-old employee of an automotive parts manufacturing plant was fatally pinned by an industrial robot. The robot transferred heavy-duty starter motor frames into and out of three milling machines. Each milling machine had a loading conveyor which carried starter housings up to the machining area and an unloading conveyor which returned finished housings to a point where the robot could pick them up and transfer them out of the cell.

The industrial robot was programmed to randomly load and unload a conveyor on demand. A safety fence with a bi-fold gate enclosed the workstation. The bi-fold gate was designed to allow for reconfiguration of the barrier to permit safe manual operation of one milling machine while the other two machines were operating automatically.

The operator of this system had been involved with the initial installation of this automated workstation and had worked with it for nine years. This utility operator was responsible for the continuous operation of the robotized work cell.

**If interlock barriers are used, they should not be easily bypassed and there should be enforcement of proper use in the safeguarding system.**

The utility operator of this automated machining system was found near death with his back pinned against a loading conveyor and the robot's end effector (end-of-arm tooling) applying downward pressure on his chest.

For some unknown reason the employee had entered the robot work envelope during automatic operation of the robot. The robot arm was executing a normal programmed move when it hit the operator in the chest and knocked him back and down onto the loading conveyor.

This pinch point, which is a part of the robot's normal operation sequence, is created when the robot delivers or retrieves a starter housing from the conveyor.

Entry into the robot work envelope was possible through two unguarded openings which were not equipped with interlocked gates or safety devices. In addition, only half of the bi-fold gate was equipped with an interlock.

When the victim was discovered, co-workers entered the robot's work zone through the interlocked gate and used a teach pendant to raise the robot arm off the victim's chest. An emergency medical team arrived, administered CPR and then transported the victim to the hospital where he was pronounced dead.

The autopsy report indicated compressional asphyxia as the cause of death, with eight fractured left ribs, compression and abrasion marks on the chest and abdomen, a lacerated spleen and lung and a contusion of the diaphragm.

In another incident 10 months prior to this fatality, this worker had been struck in the head by the same industrial robot. In that incident, the operator had also entered the robot's work zone during automatic operation and momentarily positioned himself between milling machines.

As the robot attempted to retrieve a starter housing from one of the milling machines, the robot arm struck the operator in the back of the head and knocked him to the floor. The worker crawled out of the work envelope and went to the first aid room for treatment of minor injuries.

Subsequent to this incident the bi-fold gate with an electric interlock was added. This modification to the perimeter guard eliminated the condition of doing manual loading and unloading of one milling machine while inside the perimeter guard.

In addition, the employee was again instructed to stop the robot prior to entering the work cell.

### Safety improvements

- A six foot high fence with an interlocked gate was installed to replace the existing robotic perimeter safeguarding system. This gate did not incorporate the bi-fold feature.
- Fixed fencing was installed at unguarded openings in the perimeter barrier to completely enclose the robot's work zone.
- A taut cord which can be pushed or pulled to initiate an emergency stop switch was installed in the workstation to provide a readily accessible

means of removing power to the robotic system.

• A point-to-point time limit was added to the robot's program. If preprogrammed movement of the robot is stopped or continues to move beyond an allotted time, drive power to the robot is automatically removed.

• An emergency stop button was retrofitted on the teach pendant.

• Personnel who work in the vicinity but are not normally assigned to the robotic system were trained on the basic operation of the robot to prepare them for emergencies.

## Supervisors' considerations

Supervisors have a responsible role to play in preventing robot-related accidents. Supervisors must spot safety problems that other employees may not be aware of and motivate the workers they supervise to take necessary safety precautions.

The job description for a supervisor who is responsible for robot operators should include the following requirements:

• Establish safe work methods that inform employees of safe work procedures for the specific robots they work on, including de-energization and lockout/tagout procedures. The procedures should include identifying and avoiding pinch points, safe methods when two people use controls during the same maintenance action, effective use of emergency stop devices and how to help a fellow worker who may become entrapped in the workstation.

• Provide job safety instructions on the purpose and effectiveness of safeguards on the robot. These should include instruction on the dangers of bypassing safeguards and how to test safeguards to ensure that they are functional.

• Assign qualified people to perform robot operation, maintenance, and programming jobs. Workers who are not qualified by training or experience are likely to make errors which could harm them or fellow workers, or damage the work cell.

• Supervise operators as they work. This means checking on workstations where someone works alone and correcting unsafe practices such as entering workstations with the robot operating automatically.

• Maintain equipment and the workplace in a safe condition. This requires knowing what safeguards are intended to be used on robotic workstations, what makes them individually effective, how they work as a system, and what needs to be done if their effectiveness is being compromised. Supervisors should work with those assigned to implement the safety system on robotic work cells, making them aware of shortcomings of elements in proposed or operational safety systems. This includes ensuring that safety system designers adequately understand the actual tasks that can expose workers to robotic system hazards. Safety devices which fail in a safe state should be identified and corrective action taken.

Supervisors should be familiar with design considerations for robot work cells. This will help supervisors carry out their responsibility to monitor the use of the safeguarding system and prescribed work practices.

The supervisor should be able to convey to employees that effective safeguarding systems are those which are used as intended and also that it is the responsibility of employees to use effective systems and work practices as intended.

These two incidents suggest that if interlock barriers are used, they should not be easily bypassed and there should be enforcement of the proper use of these interlocks in the safeguarding system.

In both accidents the perimeter barriers were equipped with interlocked gates but had unprotected openings. That made it easier for workers to bypass the intended safeguards and enter the working range of the industrial robot without interrupting automatic operation.

The fatality involving the worker with nine years' experience shows that relying on human experience to protect some robot operators is not sufficient without disciplining the workers to use the safeguard methods intended.

Management should ensure that the company has a written robotics safety policy that has been explained to all personnel who will be working with the robot. Additionally, this policy should state who is authorized to operate, program, and maintain the robot.

Supervisors should strictly enforce the rules in the safety policy and ensure that safeguards are in place and functioning as intended. Supervisors should recognize that with the passage of time experienced employees working at automated workstations may become complacent, overconfident, or unattentive to the hazards inherent in working with complex automated equipment.

Supervisors should be aware that newly trained employees may also require close supervision until they are thoroughly familiar with the robotic system.

In the course of their work, supervisors should remember the following points about robotic work cells:

• There are many different ways to safeguard robots. When an interlocked barrier is used there are certain important things to remember.

To prevent unauthorized entry of workers into robot work cells, the safety fence or other appropriate perimeter barrier should be at least six feet high with an interlocking gate. It should completely enclose the robotic work cell.

Avoid using easily moved barriers and/or sections of fencing or unguarded openings which can provide paths of entry other than through the interlocked gate.

In addition to perimeter guarding, visible markings outlining the full range of robot motion should be indicated on the floor with highly visible paint or tape.

• In reference to the interlocking feature associated with perimeter guarding or fencing, the American National Standard for Industrial Robots and Robot Systems—Safety Requirements,[1] states that "an interlocked barrier guard shall prevent access to the restricted work envelope except by opening an interlocked gate. Opening of the interlocked gate shall either stop the robot and remove drive power to the robot's actuators or stop automatic operation of the robot and any other associated equipment that may cause a hazard.

"Returning the system to automatic operation shall require both closing the interlocked gate and deliberately activating the controls used to restart automatic operation."

Care should be taken to install interlock devices that cannot be easily bypassed. The effectiveness of interlocks should be checked during normal maintenance tasks by opening the interlock to verify that the switch and its connections are working properly and that the robot actually stops.

• Emergency stop buttons or devices should be installed near areas of frequent exposure to hazards.

• Supervisors should strictly enforce rules against employees entering the working range of the robot while it is operating automatically, except under strictly controlled circumstances for maintenance and servicing tasks.

• Potential pinch points within the robot work cell should be eliminated where possible. To avoid the creation of pinch points, space utilization problems should be carefully considered during design and installation of robotic workstations.

• Potential safeguarding devices should be carefully evaluated to ensure that they will not create new hazards.

## Conclusions

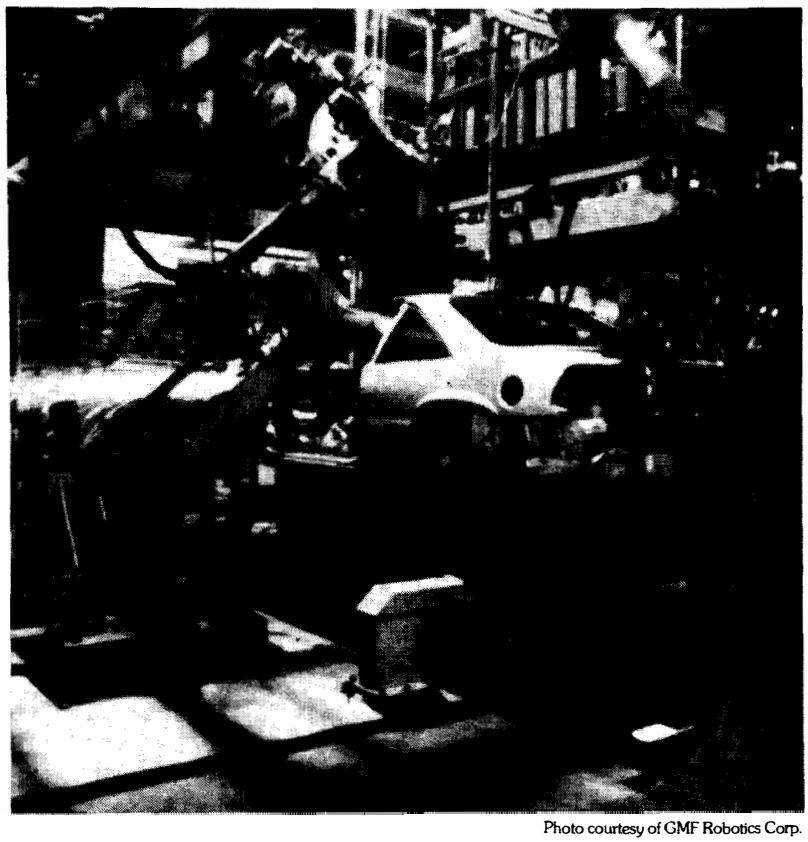
Despite training in robotics, instructions on the job and warnings by fellow workers and supervisors, both operators described in this report had entered the working range of the robot while it was operating automatically.

In addition to being familiar with the robotic workstation and safeguarding system, supervisors should be well aware of the inherent dangers inside safety perimeters when robotic equipment is in automatic operation. The supervisor's role in preventing injury to personnel assigned to monitoring robotic workstations cannot be over emphasized.

Supervisors need to take an aggressive role in identifying and recommending fail safe robot workstation controls and safe work procedures.

Safety information for robotic maintenance personnel can be found in NIOSH's Safe Maintenance Guide for Robotic Workstations.[2] Robot safety training information is available from robot manufacturers, automated systems specialists, labor unions, the Robotic Industries Association, and government agencies such as NIOSH or the Occupational Safety and Health Administration.[3,4,5]

Information regarding lockout/tagout procedures can be obtained from the NIOSH Document "Guidelines for Controlling Hazardous Energy During Maintenance and Servicing."[6]



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## Additional considerations

*Human/robot interface.*

There are some work tasks which require human intervention into the robot work zone with drive power available. For example, during certain types of maintenance and programming tasks. Robots should be restricted to a maximum speed of 25 centimeters per second when it is necessary for humans to work near robots with power available[1]. Supervisors need to assure that *no one* is allowed to enter the operational area of a robot without first putting the robot on "hold," in a power down condition, or at a reduced operating speed mode.

*Buddy system*

A qualified person can be posted at the control panel during brief corrective or preventive maintenance. This person should be given the specific responsibility of protecting against unauthorized actuation of the controls that initiate automatic operation. A buddy system has shortcomings in that when two people are involved confusion can be a source of risk.

### References


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5. Request for Assistance in Preventing the Injury of Workers By Robots, National Institute for Occupational Safety and Health, Publications DHHS 85-103, Cincinnati, 1984.
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