OSH INFORMATION MEMORANDUM 87-X-74

TO: All Directors, Supervisors, and Field Personnel

FROM: William M. Lybrand, Director of OSH

SUBJECT: Guidelines for Robotics Safety

DATE: November 4, 1987

Attached is Federal OSHA Instruction PUB 8-1.3 pertaining to guidelines for robotics safety.

All compliance personnel will follow the guidelines set forth in this instruction when robotic equipment is encountered in the course of an inspection. Appropriate sections under Part 1910, Subpart O and/or the General Duty Clause will be cited for apparent violations.

OSHA Instruction PUB 8-1.3
Office of Science and Technology Assessment

Appendix A

Guidelines for Robotics Safety

U.S. Department of Labor
Occupational Safety and Health Administration
Washington, D.C.

FOREWARD

The purpose of this instruction is to inform OSHA compliance officers and employers and employees about safety concerns that have arisen with the growing use of robotics systems in manufacturing. Industrial robots can be used to perform hazardous tasks but in doing so they can create new hazards. With the burgeoning use of robots in industry, it is feared that without adequate guarding and personnel training, injury rates for employees working with robots may increase.

Current guidelines for robot safety include the American National Standards Institute (ANSI) ANSI-RIA R15.06-1986, "American National Standard for Industrial Robots and Robot Systems – Safety Requirements," and the National Institute for Occupational Safety and Health (NIOSH) December, 1984 Alert "Request for Assistance in Preventing the Injury of Workers by Robots." Copies of the ANSI Standard are available from the American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018. Its Division of Safety Research, 944 Chestnut Ridge Road, Morgantown, WV 26505, prepared the NIOSH Alert.

This instruction provides general introductory material describing the features of robots and robotics systems which present unusual hazards and will describe some of the more common safety systems employed to alleviate these hazards. The ANSI Standard defines consensus provisions for the construction, reconstruction, modification, installation, safeguarding, care, testing, and start-up of robots and robotics systems as well as training for robot and robotics systems operations and maintenance personnel. The NIOSH Alert contains safety recommendations that are based on its field evaluation of the first identified robot-related fatality in the United States.

INTRODUCTION

Robots are reprogrammable, multifunctional, mechanical manipulators that typically employ one or more means of power: electromechanical, hydraulic, or pneumatic. Industrial robots have been used chiefly for spray painting, spot-welding, and transfer and assembly tasks. A robot performs its tasks in a physical area known as the robot operating work envelope. This work envelope is the volume swept by all possible programmable robot movements. This includes the area where work is performed by robot tooling.

A robot can have one or more arms which are interconnected sets of links and powered joints. Arms are comprised of manipulators which support or move wrists and end-effectors. An end-effector is an accessory tool specifically designed for attachment to a robot wrist to enable the robot to perform its intended task. Examples of end-effectors include grippers, spot-weld guns, and spray paint guns. The ANSI R15.06-1986 Standard defines an industrial robot system as that which includes industrial robots, end-effectors, and any equipment, devices and sensors required for the entire robot system to perform its tasks.

Most robots are set up for an operation by the teach-and-repeat technique. In this technique, a trained operator (programmer) typically uses a portable control device (commonly referred to as a teach pendant) to manually key a robot and its tasks. Program steps are of the up-down, left-right, in-out, and clockwise-counterclockwise variety. Robot speeds during these programming sessions are required to be slow. The ANSI Standard currently recommends that this slow speed should not exceed 10 in/sec (250 mm/sec).

The very nature of robotics systems operations has introduced a new type of employee into the industrial workplace, the corrective maintenance worker. This individual is normally present during all operations of a robotics system and is responsible for assuring continuing operation – adjusting speeds, correcting grips, and freeing jam-ups. The corrective maintenance worker may also be the trained programmer who guides a robot through the teach-and-repeat technique. It is necessary for this individual to be near the robot from time to time, which raises concerns about his or her safety and the safety of other workers who may also be exposed.

Recent studies in Sweden and Japan indicate that many robot accidents do not occur under normal operating conditions but rather during programming, adjustment, testing, cleaning, inspection, and repair periods. During many of these operations, the operator, programmer or corrective maintenance worker may temporarily be within the robot work envelope while power is available to moveable elements of the robot system.

This guideline describes some of the elements of good safety practices and techniques used in the selection and installation of robots and robot safety systems, control devices, robot programming and employee training. A comprehensive list of safety requirements is provided in the ANSI R15.06-1986 Standard.

TYPICAL ACCIDENTS

The following are documented accidents involving robots that occurred recently in Japan, Sweden, and the United States:

- A worker attempted to remove an imperfectly formed piece from a conveyor with both hands while the operation limit switch of a material feed and removal robot remained in its active position. The worker's back was forced against the robot.

- After adjusting a metal shaving machine, an operator was caught between the machine and a just-extended arm of a material feed and removal robot.

- A welding robot went functionally awry and its arm flung a worker against another machine.

- A worker removed the cover of an operating assembly robot to retrieve a fallen part and caught his hand in the robot's drive train.

- A robot's arm functioned erratically during a programming sequence and struck the operator.

- A fellow employee accidentally tripped the power switch while a maintenance worker was servicing an assembly robot. The robot's arm struck the maintenance worker's hand.

- An operator performing troubleshooting on a metal plater robot maneuvered the robot's arm into a stopped position. This triggered the robot's emergency stop mode which delayed venting of a pneumatic air storage device. When the return mode was activated, the robot's arm moved suddenly and jammed the operator's thumb against a structural member.

- An automatic welder robot operator made a manual adjustment without stopping the robot. He was hit in the head by one of the robot's moving parts when the next batch of weldments arrived.

- A materials handling robot operator entered a robot's work envelope during operations and was pinned between the back end of the robot and a safety pole.

SAFETY SYSTEMS

The proper selection of an effective robotics safety system must be based on hazard analysis of the operation involving a particular robot. Among the factors to be considered in such an analysis are the task a robot is programmed to perform, the start-up and the programming procedures, environmental conditions and location of the robot, requirements for corrective tasks to sustain normal operations, human errors, and possible robot malfunctions. Sources or robot hazards include:

1. Human errors;
2. Control errors;
3. Unauthorized access;
4. Mechanical hazards;
5. Environmental hazards; and
6. Electric, hydraulic, and pneumatic power sauces.

An effective safety system protects operators, engineers, programmers, maintenance personnel, and others who could be exposed to hazards associated with a robot's operation. A combination of methods may be used to develop an effective safety system. Redundancy and backup systems are recommended, particularly if a robot can create serious hazardous conditions.

Guarding Methods:

1. Interlocked Barrier Guard

This is a physical barrier around a robot work envelope incorporating gates equipped with interlocks. These interlocks are designed so that all automatic operations of the robot and associated machinery will stop when any gate is opened. Restarting the operation requires closing the gate and reactivating a control switch located outside of the barrier. A typical practical barrier is an interlocked fence designed so that access through, over, under, or around the fence is not possible when the gate is closed.

2. Fixed Barrier Guard

A fixed barrier guard is a fence that requires tools for removal. Like the interlocked barrier guard, it prevents access through, over, under, or around the fence. It provides sufficient clearance for a worker between the guard and any robot reach, including parts held by an end-effector, to perform a specific task under controlled conditions.

3. Awareness Barrier Device

This is a device such as a low railing or suspended chain that defines a safety perimeter and is intended to prevent inadvertent entry into the work envelope but can be climbed over, crawled under, or stepped around. Such a device is acceptable only in situations where a hazard analysis indicates that the hazard is minimal and interlocked or fixed barrier guards are not feasible. Interlocked or fixed barrier guards provide a positive protection needed to prevent worker exposure to robotic systems hazards.

4. Presence Sensing Devices

The presence detectors that are most commonly used in robotics safety are pressure mats and light curtains. Floor mats (pressure sensitive mats) and light curtains (similar to arrays of photocells) can be used to detect a person stepping into a hazardous area near a robot. Proximity detectors operating on electrical capacitance, ultrasonics, radio frequency, laser, and television principles are correctly undergoing reliability testing in research laboratories because of recognized limitations in their capability of detecting the presence of personnel. Although some of these devices are already available in the safety equipment marketplace, care must be used in their selection to insure adequate safety and reliability. At this time, such proximity detectors are not recommended for such use unless a specific analysis confirms their acceptability for the intended use.

Effective presence sensing devices stop all motion of the robot if any part of a worker's body enters the protected zone. Also, they are designed to be fail-safe so that the occurrence of a failure within the device will leave it unaffected or convert it into a mode in which its failed state would not result in an accident. In some cases this means deactivation of the robot. Factors, which are considered in the selection of such devices, include spatial limitations of the field, environmental conditions affecting the reliability of the field, and sensing field interference due to robot operation.

5. Emergency Robot Braking

Dangerous robot movement is arrested by dynamic braking systems rather than simple power cut-off. Such brakes will counteract the effects of robot arm inertia. Cutting off all power could create hazards such as a sudden dropping of a robot's arm or flinging of a work piece.

6. Audible and Visible Warning Systems

Audible and visible warning systems are not acceptable safeguarding methods but may be used to enhance the effectiveness of positive safeguards. The purposes of audible and visible signals need to be easily recognizable.

<u>CONTROL DEVICES</u>

The following characteristics are essential for control devices:

1. The main control panel is located outside the robot system work envelope in sight of the robot.

2. Readily accessible emergency stops (palm buttons, pull cords, etc.) are located in all zones where needed. These are clearly situated in easily located positions and the position identifications are a prominent part of personnel training. Emergency stops override all other controls.

3. The portable programming control device contains an emergency stop.

4. Automatic stop capabilities are provided for abnormal robot component speeds and robot traverses beyond the operating envelope.

5. All control devices are clearly marked and labeled as to device purpose. Actuating controls are designed to indicate the robot's operating status.

6. Controls that initiate power or motion are constructed and guarded against accidental operation.

7. Each robot is equipped with a separate circuit breaker that can be locked only in the "off" position.

8. User-prompt displays are used to minimize human errors.

9. The control system for a robot with lengthy start-up time is designed to allow for the isolation of power to components having mechanical motion from the power required to energize the complete robot system.

10. Control systems are selected and designed so that they prevent a robot from automatically restarting upon restoration of power after electrical power failure. The systems also prevent hazardous conditions in case of hydraulic, pneumatic or vacuum loss or change.

11. A robot system is designed so that it could be moved manually on any of its axes without using the system drive power.

12. All control systems meet OSHA 29 CFR 1910 Subpart S standards for electrical grounding, wiring, hazardous locations, and related requirements.

INSTALLATION, MAINTENANCE AND PROGRAMMING

Good installation, maintenance, and programming practices include the following:

1. The robot is installed in accordance with the manufacturer's guidelines and applicable codes. Robots are compatible with environmental conditions.

2. Power to the robot conforms to the manufacturer's specifications.

3. The robot is secured to prevent vibration movement and tip over.

4. Installation is such that no additional hazards are created such as pinch points with fixed objects and robot components or energized conductor contact with robot components.

5. Signs and markings indicating the zones of movement of the robot are displayed prominently on the robot itself and, if possible, on floors and walls.

6. Stops are placed on the robot system's axes to limit its motions under rated load and maximum speed conditions.

7. A lock-out procedure is established and enforced for preventive maintenance or repair operations.

8. The robot manufacturer's preventive maintenance schedule is followed rigorously.

9. A periodic check of all safety-critical equipment and connections is established.

10. Stored energy devices, such as springs and accumulators, are neutralized before robot servicing.

11. Only programmers have access to the work envelope and full control of the robot when it is in the teach mode.

12. All robot motion initiated from a teach pendant used by a programmer located within the robot work envelope is subject to the current ANSI slow speed recommendation of 10 in/sec (250 mm/sec).

TRAINING

Effective accident prevention programs include training. Some points to be considered in training program include:

1. Managers and supervisors in facilities that use robots are trained in the working aspects of robots so that they can set and enforce a robotics safety policy from an informed viewpoint.

2. The employer insures that his or her company has a written robotics safety policy that has been explained to all personnel who will be working with robots. This safety policy states by name which personnel are authorized to work with robots.

3. Robot programming and maintenance operations are prohibited for persons other than those who have received adequate training in hazard recognition and the control of robots.

4. Robot operators receive adequate training in hazard recognition and the control of robots and in the proper operating procedure of the robot and associated equipment.

5. Training is commensurate with a trainee's needs and includes the safeguarding method(s) and the required safe work practices necessary for safe performance of the trainee's assigned job.

6. If it is necessary for an authorized person to be within the work envelope while a robot is energized, for example during a programming sequence, training is provided in the use of slow robot operation speeds and hazardous location avoidance until the work is completed. Such training also includes a review of emergency stops, and a familiarization with the robot system's potentially hazardous energy sources.

REFERENCES

- National Institute for Occupational Safety and Health (NIOSH) Alert "Request for Assistance in Preventing the Injury of Workers by Robots." National Institute for Occupational Safety and Health, Division of Safety Research, 944 Chestnut Ridge Road, Morgantown, West Virginia 26505.

- American National Standards Institute (ANSI) American National Safety Standard ANSI-RIA R15.06-1986, "Industrial Robots and Industrial Robot Systems – Safety

Requirements." American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018

- Robotic Industries Association, 900 Victors Way, P.O. Box 3724, Ann Arbor, Michigan 48106.

- Occupational Safety and Health Administration publication 3067, Concepts and Techniques of Machine Safeguarding, U.S. Department of Labor, 1980 (reprinted 1983). Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20210.