UNEXPECTED MOTION HAZARD EXPOSURES ON A LARGE ROBOTIC ASSEMBLY SYSTEM

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SUMMARY

This report contains the results of a case analysis to identify potential exposures to robotic hazards during maintenance activities. The operation studied was a 19-cell automated assembly line that included 25 robots dedicated to assembling a unit with a large number of small parts. The methodology for this study was to use logs of maintenance actions and discussion with maintenance personnel to identify and quantify potential exposures to hazards during maintenance activities. In this study, time of potential hazard exposure was defined as the time a robot was logged in a "down for maintenance" status, i.e., time that a maintenance person performed a troubleshooting, repair, or adjustment task. For the maintenance actions studied, 76% were described as done with power available to the robot and 43% as done, in part, inside the robot's work envelope with power available. Data was also collected on the number of pinch points in each robot's work envelope. For each robot in this assembly system, there was an average 5.4 min. per workday during which an injury in the course of normal maintenance might have been possible. The data for the five months under evaluation indicated that the mean exposure time for troubleshooting jobs was twice as long as for simple repair and adjustment jobs. Based on the results of this study, suggestions are made for: (1) identifying ways the manufacturer can enhance the level of safety on its robotic production lines and (2) evaluating exposure times for calculating injury incidence rates for personnel who perform maintenance on robotic and programmable systems. Manufacturing engineers should consider periodically reviewing robot system troubleshooting procedures with maintenance personnel to identify potentially dangerous situations, and develop safer methods for completing the work.

INTRODUCTION

Fast robot motion toward fixed objects can injure robotics technicians who unexpectedly get in the way (Ref. 1-4). Two ways that workers may become exposed to the hazard of fast robot motion toward fixed objects are: (1) they enter the robot's work zone while the robot is operating automatically, and (2) during a maintenance task, which must be done with drive power available, unexpected high speed motion is inadvertently initiated because of a human error in operating motion control switches or a control failure occurs. To assess the degree of unexpected motion hazard exposure among robot maintenance personnel, a data collection and analysis project was carried out by a researcher from the National

Institute for Occupational Safety and Health (NIOSH) with the cooperation of a large manufacturing company.

The manufacturer's safety staff had been instructed to look for ways to enhance the level of safety on the facility's robotic assembly lines. This activity coincided with a NIOSH project to evaluate risk factors and exposures in robotic and programmable systems. Jones and Dawson (Ref. 5) have partially quantified exposures to welding robot hazards during maintenance downtime. A unique aspect of the analysis reported here is that it is the first attempt to quantify potential hazard exposures on a robotic assembly system.

BACKGROUND

The potential for interaction between robot downtime and injury and the possibility of using downtime records to assess potential exposures have been discussed in other studies on robotic system safety assessment (Ref. 6 and 7). Also, quantitative information is slowly being gathered and analyzed on how programmable automation affects safety performance. Primovic and Karwowski (Ref. 8) compared safety performance for the year before and the year after programmable automation was introduced into a dishwasher assembly line. This comparison found that the overall incidence rate for medical cases and first aid cases decreased from 11.2 to 5.7 injuries per 200,000 worker-hours. However, further research is needed in this area because this study, which calculated an overall rate for the entire facility, did not focus on high-risk occupations, such as the maintenance personnel, who would be expected to have greatest exposure to programmable automation hazards.

THE SYSTEM STUDIED

To conduct this study, a collaborative understanding was developed between NIOSH and the manufacturer. Management of one of the manufacturer's automated lines was already keeping records on maintenance actions which facilitated the data collection for this study. A protocol for using this data for safety research was prepared by the NIOSH Project Officer and sent to the manufacturer for comment. Having received approval to proceed, the on-site phase of this project took place in April of 1987.

The assembly line used in this study has 25 SCARA robots in 19 cells through which the parts being assembled progress. Some of these cells are located along automatic transfer lines while at other cells, production personnel place filled toteboxes into loading stations.

Production personnel also monitor the cells and clear jam-ups. The working area is well lighted, relatively quiet, and clean. Some of the safety features on robotic cells in this system are: perimeter fencing, safety mats, light curtains, warning lights, and interlocks which engage when access doors are opened.

The worst credible injury on this line would be a fatality due to someone's head being struck by the robot arm or end effector as it unexpectedly moves at high speed (for instance, toward one of the pinch areas in the robot's maximum work volume.) Exposure to this hazard occurs whenever someone works inside the robot's work envelope with drive power available to the robot.

ASSUMPTIONS

In conducting this analysis it was assumed that:

- the safety system in place on this line was effective, but improvements might be possible;
- the risk of robot-related injury decreases as duration of exposure to potentially unexpected robot motion is decreased;
- access to the line while the line is in automatic operation, even though unlikely, is possible;
- a human error initiating automatic operation while someone is near a robot on this line, even though unlikely, is possible and;
- this is an operational line for which early control system problems have been solved. Given the short time period studied, the failure rate for the control system is probably too low to measure its effect on the degree of unexpected motion hazard.

METHOD

A computer generated listing of manually logged maintenance actions involving robot system maintenance on this assembly line over a five month period was reviewed by the NIOSH Project Officer. This task was done with the help of personnel responsible for the system's maintenance and safety. Information is normally logged into the maintenance management data base as follows. The line operator calls in that a cell is "down." This call establishes the start of downtime. The end of downtime is established when the maintenance personnel log in that the job is completed. Therefore, "wait for maintenance" is included in the total elapsed downtime. The listing categorized maintenance actions according to workcell affected, date, maintenance done, and maintenance duration. For consistent downtime evaluation in this analysis, only actions which were completed the same day they were started were considered. This information was designated confidential by the company.

For this study, each maintenance action was further described by three factors which were added by safety and maintenance personnel. These were: task type, degree of robot drive power available, and whether or not some of the action was done inside the robot's work envelope. The three task types were: troubleshooting (finding a part placement problem), repairing (replacing a part), or adjusting (adjusting a stop). The task type was assigned by the Project Officer and the manufacturer's safety engineer based on the maintenance action described. The maintenance personnel who had performed the work were asked to code each action according to degree of drive power available and whether the action was done inside the robot work envelope. Three levels of drive power availability were: (A) the problem could be fixed without downtime, (B) robot power would normally be available (possibly because motion was needed to correct the problem), and (C) drive power can be fully removed. [The personnel filling in the codes indicated that no tasks were done in category A.] The number and approximate size of potential trapping volumes in each robot's maximum work envelope were noted by the NIOSH Project Officer (See Figure 1).

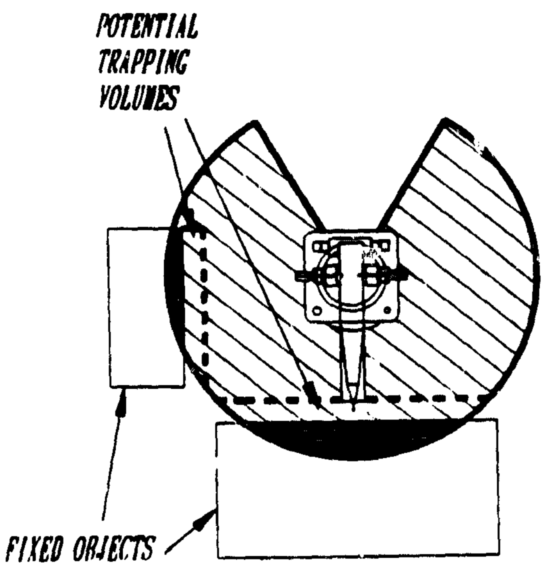

Fig. 1. Potential trapping volumes in the robot work envelope.

A computer generated listing of automatically logged stops at workcells was also examined during the data collection phase of this analysis. It was anticipated that this listing would provide exposure information on interventions into the robot work envelope by production personnel to correct jam-ups and workflow disruptions. However, when a line stopped for a problem at one work cell, several workcells would be logged stopped at the same time. It was not clear which robot cell was the cause of the stop nor what was the nature of the intervention. Therefore, potential hazard exposures by production personnel are not considered in this analysis.

The robot maintenance safety data collected by the NIOSH Project Officer were manually entered into a data base on an IBM 4361 computer at the NIOSH facility in Morgantown, WV. A SAS procedure, LIFETEST, was used to analyze potential exposure times. LIFETEST is a statistical procedure suited to analysis of survival times (potential exposure times) under the influence of covariants. The covariables here are the groupings of task type, robot power availability, and work location. The output from this procedure included within group ranking of exposure times and mean exposure times.

RESULTS

Normal Maintenance Exposures at This Robotic Assembly System

The mean repair time was 115.3 min. for 120 manually logged maintenance actions during the 102 workdays studied. Of these, 76% were described as done with power available to the robot, with 43% being "In/Available" actions. In/available means that the maintenance was performed inside the work envelope with power available to the robot. For the 25 assembly robots in this system, a normal maintenance exposure rate of 5.4 min./robot-workday was calculated. In other words, for each robot in this assembly system, there was on the average 5.4 min. per workday during which an injury in the course of normal maintenance might be possible. This does not include corrective action exposures for production personnel.

Maintenance actions were about equally divided between those done inside the work cell safety perimeter and those done outside the envelope (54% vs 46%).

Exposures Inside the Safety Perimeter While Robot Power Was Available (In/Available)

The mean time of actions done inside the safety perimeter with power available was 144 min. Figure 2 shows a comparison between the frequency and duration of In/Available actions and all other actions. The frequency and duration of In/Available actions were significantly different from other actions (p<.05, Wilcoxon Rank Test). Mean exposure for In/Available tasks was much longer than for all other actions (144 min. vs 93.4 min.)

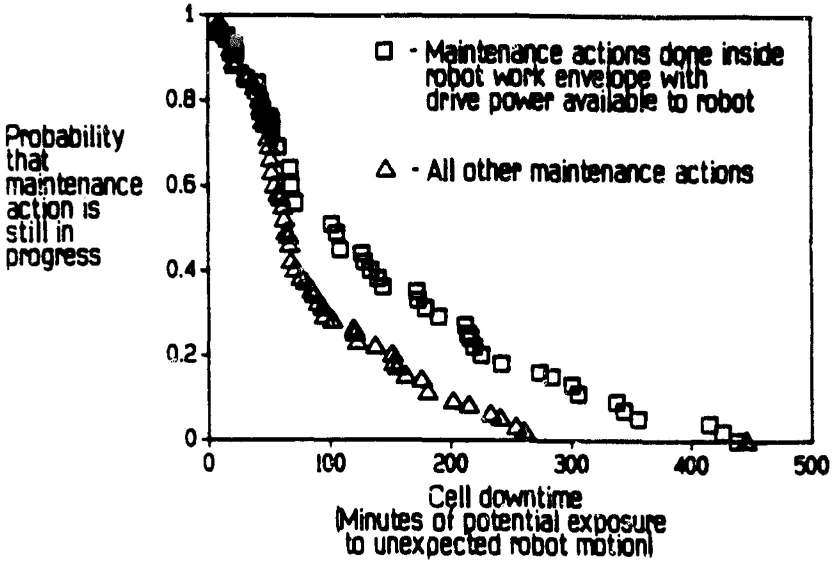

Fig. 2. Comparison between probable exposures of In/Available actions and all other maintenance actions.

When work was done inside any of 19 cells with power available (See Table 1) it was done in the same manner whether there were few or many potential trapping volumes.

TABLE 1

Potential trapping volumes inside a cell's protective perimeter	0	1	2	3	4	5
Number of In/Available actions	4	10	11	5	9	8

Table 2 shows mean exposure times (in minutes) and number of actions for troubleshooting, repair, and adjustment tasks among all actions analyzed, In/Available actions only, and other actions. Examination of this table reveals that troubleshooting takes the longest time. Adjustment is the next lengthiest but perhaps only for In/Available actions. Repair takes the least time, and seems to take about equal time for both types of action.

TABLE 2

Task type	Other actions: Mean time (min)	n	In/Available actions: Mean time (min)	n	Total: Mean time (min)	n
Troubleshooting	353.3	2	222.8	13	240.2	15
Adjustment	80.2	26	138.1	25	108.6	51
Repair	88.9	40	81.5	14	87.0	54
Total	93.3	68	144.0	52	115.3	120

Furthermore, In/Available actions take more time overall, but only because the task type distribution is different between the actions. The other actions are more heavily weighted toward repair while the In/Available actions are weighted more toward adjustment and troubleshooting.

CONCLUSIONS

The manufacturer should consider:

- Periodically reviewing safe robot system troubleshooting procedures with maintenance personnel. These reviews should highlight hazardous pinch points to avoid, safe procedures to use if interlocks are bypassed, and vigilance against inadvertent use of manual restart switches. This recommendation is made because the data for the five months under evaluation on this 25 robot, 19 cell system, indicated that the mean exposure time for jobs which required troubleshooting was twice as long as for simple repair and adjustment jobs.

- Investigating ways to ensure effective energy control during actions done inside a workcell's safety perimeter with power available to the robot (In/Available actions). Safety devices which protect workers inside current safety perimeters (e.g., ultrasonic, voice recognition, capacitance, pressure mats) should be considered. The mean time of In/Available actions was 144 min. The frequency and duration of In/Available actions were significantly different from other tasks. Mean exposure for In/Available actions was much longer than for all other actions (144 min. vs 93.4 min.).

- Using Table 2 as a maintenance hazard exposure baseline against which to compare contemplated changes in system design. Design changes which can reduce maintenance exposure times below the mean values shown in Table 2 would have a positive effect on hazard level.

- Adding a category to maintenance logging programs which would permit maintenance personnel to log safety concerns. Maintenance data systems such as the one which was used for this analysis could provide an important resource for identifying safety concerns. If maintenance data reprogramming for better safety surveillance is undertaken, safety surveillance compatibility with the programs which automatically log production stops should be part of the project.

NIOSH should consider:

- Using type of robot application as a factor in epidemiology studies of risks associated with robotics. As reported here, reliable data was available on potential robotics hazard exposures for an assembly application. NIOSH should make prudent use of this kind of resource on other applications when determining robot-related injury incidence and severity rates. For example, the small size of trapping areas and elevated locations of assembly robots make it seem unlikely that someone's body would be entrapped, while injuries to the head and hands would seem more likely.

- Using small normal exposure time per robot maintained as a factor when comparing injury incidence rates at robot systems with rates at conventional machines. For each robot in this assembly system, there was an average 5.4 min. per workday during which an injury in the course of normal maintenance might be possible. At conventional machine systems with high numbers of worker compensation injury cases there is frequent intervention into zones of potential, unexpected machine motion.

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