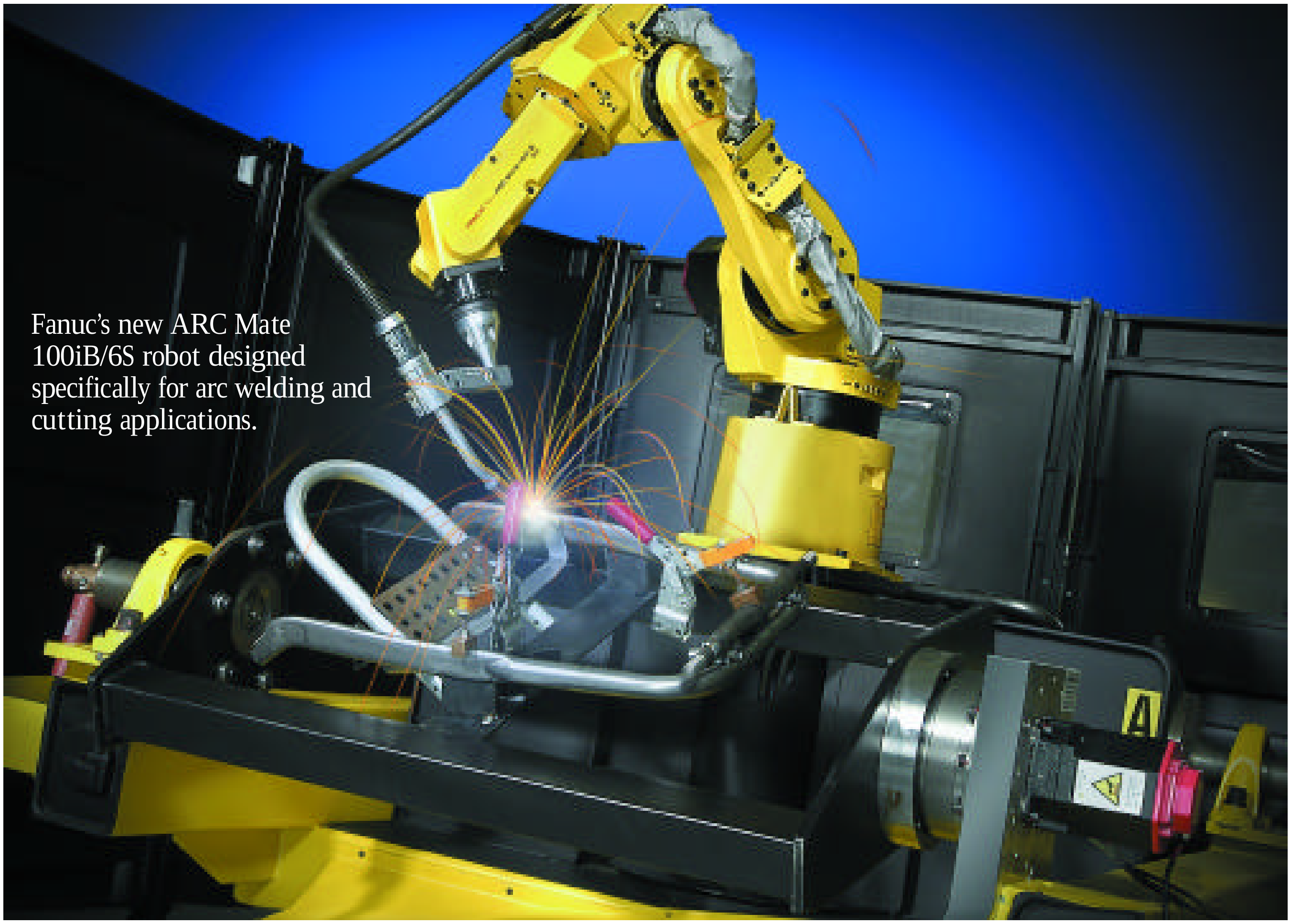

Fanuc's new ARC Mate 100iB/6S robot designed specifically for arc welding and cutting applications.

The XYZ of robot safety

by Doug Nix, C.E.T.

Here's how modern safeguards reduce robot risks

On July 21, 1984, a worker at Diecast Corp. in Jackson, Michigan was horrified when he found one of his co-workers, Harry Allen, a 34-year old a diecast operator, pinned between a factory pole and the back of an industrial robot. Unfortunately, the worker could not do anything to help Allen.

Using the robot's controller, the company's director of manufacturing finally unpinned Allen, who was alive but in cardiac arrest. He died in a hospital five days later.

Allen had entered a restricted area, presumably to clean up scrap metal from the floor. While there, he got in the way of the robot and thus became the first victim of an industrial robot-related accident ever in the U.S. *Forbes* magazine published a story called "In the Lion's Cage" describing this robot-related death.

Since then, many more workers have died and suffered injuries while working around robots. Three groups of workers regularly brave robot-related hazards. The first group, operators who work with robots face hazards, but their interactions with the robots occur in very controlled conditions, so injuries aren't as likely to happen.

Secondly, maintenance workers face much higher levels of danger while maintaining and repairing robots and especially when teaching robots new actions, because they often must work within the operating envelope of the robot.

Thirdly, engineers integrating robots into assembly lines face the greatest dangers, since the processes and the programs are unproven and likely to fail in the early stages. These workers also frequently must work within the operating envelope of the robot.

So how can we safeguard these people? No matter what size of robot or what kind of robots companies use in their facilities, they need to consider safety issues such as:

- hazards present;
- risk reduction methods for robot systems;
- older robots and retrofits; and
- safety standards and regulations.

What is a robot?

Industrial robots range in size from miniature, tabletop arms to car-crushing giants. In their many forms, robots have become a staple tool in factories, laboratories, operating rooms and even around the home.

Not everything that looks like a robot is actually a robot.

The ANSI standard for industrial robots defines one as: "an automatically controlled, re-programmable multi-purpose manipulator programmable in three or more axes. It may be either fixed in place or mobile for use in industrial automation applications."

This definition excludes many X-Yor X-Y-Z manipulators that companies build for a particular purpose. While many of the safety hazards related to robots may exist, the same requirements for safeguarding may not apply.

The definition does apply to multi-purpose robots that can place the end-of-arm tool at any point within their working envelope.

Companies use robots for painting, assembly, welding, in hazardous environments like nuclear power containment rooms and many other tasks.

SCARA type robots (see the welding robot at left) possess many rotary joints and can move through a relatively spherical envelope.

These robots move at high speeds, carrying end-of-arm tools that may be hot, sharp or heavy. Robots all follow step-by-step programs that define exactly what motions and what actions they are going to take.

They pose hazards through these motions — particularly during the robot's teaching process, during routine operating and when they fail. The processes that employ robots pose other hazards. For example, painting processes pose high-pressure fluid injection hazards, fire and explosion hazards and toxicity hazards from the paint. Welding processes pose risks from hot surfaces, sparks, brazing or welding flames and crushing hazards in spot-welding processes.

Meeting standards

Each company's first step to safety is to ensure that the robots the plant uses are either built to current standards, or have been rebuilt to meet them. The current standards are:

- CSA Z434-03 Industrial Robots and Robot Systems — General Safety Requirements
- ANSI RIA 15.06 — 1999 American National Standard for Industrial Robots and Robot Systems — Safety Requirements
- EN 775:92 — Manipulating industrial robots - safety
- ISO 10218:1992 — Manipulating industrial robots — safety

All of these standards share common requirements for safeguarding the teacher and / or operator. They require that each person entering the danger zone bring an enabling device. In addition, the teacher must have single-point control of the robot while it is in teach mode. The operator cannot enable automatic mode from within the guarded enclosure.

In the past, some people called the enabling device the 'dead-man switch.' The term enabling device is more correct since the objective is to prevent injury and death. Designers built early versions — two-position devices built into the robot's teaching pendant that the operator had to press to put the robot in motion.

Experts soon realized that people do not always release their grip on the pendant when they are injured, some maintain a tight grip on the control, maintaining motor power and possibly increasing their own injuries. The current design uses a three-position grip. Squeezing or releasing the device will stop the robot's motion. When the operator holds the device in the mid-position, it allows the robot to move. Designers build these devices into the teaching pendants using good ergonomics so that the operator will naturally hold the device in the correct position.

Standards also require that designers fit the pendant with an emergency stop switch. All motion initiating devices must only allow motion while they are pressed. Finally, the robot's end-of-arm

> No matter what size of robot or what kind of robots companies use in their facilities, they need to consider many safety issues.

The AdeptSix 300 articulated robot and the Adept SmartController with integrated external front panel (bottom left) and operator's manual control pendant (bottom right).

tool is not allowed to move faster than 250 mm/s while in teach mode or in slow-speed automatic program verification (APV).

These design features take care of controlling the robot. Work cell designers can create trapping points if any part of the robot is allowed to approach within 18 to 20 inches of fixed objects such as guarding enclosures, building columns, or conveyors. Arobot could pin a person against these objects. Just as in the example from 1984, the results can be fatal.

Designers use limiting devices to restrict the robot's envelope so that it can only move through enough of its envelope to do the work. These include hard-stops bolted to the axes, limit switches or soft-limits in the robot program. Once manufacturers install these restrictions, they should mark off the restricted envelope of the robot on the floor with paint or by installing chains or single beam detection devices and warning lights. These remind operators that they are now within the most dangerous area inside the guarding enclosure.

If it is impossible to prevent the robot from close approach to fixed objects within the working area, companies must guard the areas that are within 18 to 20 inches of these objects with detecting devices such as light beams or safety mats that are interlocked with the robot. This prevents the robot from operating while someone is in this area.

Control over entry into the work cell is an important safety feature. One common way to control entry is to use a trapped-key system. Anyone who enters the guarded area must use a key that is controlled by an administrative procedure so that only authorized personnel has access to the enclosure. The key releases the guard and opens the interlock preventing operation of the robot. It will also prevent the gate from being closed from the outside. In many cases, it will also release another key that must be carried inside the enclosure and inserted in another lock, enabling the teaching mode.

Companies take safety precautions when building equipment that uses robots. Integrating engineers frequently need to run the robots before they construct the final guarding so they can validate the process and the robotic tools. During this work, they put up special temporary barriers to prevent injuries. Some facilities will use additional procedures and training depending on the situation and the number of people needed in the work cell.

Robot operation begins once the work cell is properly guarded, the gates are interlocked to prevent operation in anything except teach-mode while personnel are inside the guards and any other safeguards, such as ventilation or welding screens are in place.

Rebuilt and re-deployed robots

Rebuilt and re-deployed robots pose other problems. The standards do not require that companies upgrade their control systems to the latest requirements in all cases. Standards do require enabling devices on pendants and usually require two-channel interlocking circuits. Otherwise, the company must ensure the robots meet the standards that were in force when they were built.

Re-deployed robots are physically moved with only program and end-of-the-arm-tool modifications. They too must have teaching pendants with enabling devices and two-channel interlock circuits to meet the current standards.

Training counts

The final piece in this puzzle is training. All of the standards mandate specific training for the different levels of operator. All require extensive training programs for people who will be working within the danger zones around the robots. Employers should maintain their training records and regularly retrain workers to ensure that they stay current as the equipment and the methods advance. These records are vital to maintaining evidence of due diligence as well.

Training programs should include the following elements:

- purpose and location of safeguard-

Non-robot hazards

Many of the systems discussed carry dangerous tools. Robots using water-jet cutting heads or lasers for cutting and welding must have suitable guards installed for these devices. Just as arc-welding systems require welding curtains with a level of darkening to protect people's eyes from the weld flash, so lasers require special windows with the right characteristics to absorb the laser light and the plasma flash that occur when the laser is operating.

Arc, flame and laser welding and brazing operations generate fumes that must be removed with ventilation systems.

Painting robots must work within paint booths with suitable ventilation and fire suppression systems.

All of these hazards must be suitably guarded on top of the robot hazards we discussed.

ing devices and their operation;

- procedures relating to robot operation. These may include special start-up and testing procedures when the equipment is under construction or renovation;
- capabilities of the robot system including maximum speeds and forces;
- hazards related to the robot and the particular tools / processes in use;
- safety concepts;
- lockout procedures; and
- emergency response procedures.

Training for operators and teachers will be different. Operators need to know at least these elements:

- robot tasks;
- hazards related to the robot tasks;
- response to abnormal or unexpected events;
- recovery from these events; and
- operation of auxiliary equipment.

Teachers, on the other hand, need to know all of the operator's information, plus they need to know:

- pendant operation;
- single point of control;
- operation in slow speed mode;
- bypassing of safeguarding in teach mode;
- process related safety and control requirements;
- response to abnormal / unexpected events;
- teaching hazards including:
  - pinch point locations;
  - observation points;
  - robot motion at slow versus program speed;
  - robot performance in teach;
  - singularity; and
  - slow speed playback; and
- auxiliary equipment.

Singularities occur when two joints on the robot line-up, sometimes causing unpredictable motions and speeds. Designers create modern robot control systems to detect impending singularities and to stop motion and warn the operator of the impending condition.

Maintenance personnel need to have the operator and teacher training. They must also be trained in the following areas:

- Hazards involving:

The Adept Cobra s600 SCARA robot and the Adept SmartController with integrated external front panel (bottom left) and operator's manual control pendant (bottom right).

  - preventive maintenance / calibrations;
  - troubleshooting;
  - repair;
  - operational checks;
  - singularity;
  - failed safety devices;
  - failed communication systems;
  - process variables; and
  - process materials;
- Emergency operations

The last item is particularly important. If, despite all of the safeguards, training and procedures that you have in place, the robot traps a person, it is critical that personnel in the plant know how to safely extract victims with the aid of emergency personnel. Had these safeguards been in place in 1984, Harry Allen might have lived.

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