Practical Application of Robot Safety

Presented By: Roberta Shea Nelson, Jim Van Kessel, Tom Eastwood

NOTE: This presentation is intended to be vendor-neutral. No particular product or solution is best and none are specifically recommended.

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Roberta Nelson Shea
Tom Eastwood Introduction

- Chairperson Safeguarding of Machinery Standard CSA Z432
- Chairperson Industrial Robot Standard CSA Z434
- Vice Chairperson Canadian delegation ISO 10218
- Previous Technical Committee Member CSA Z142 Press Safety

JVK Introduction

- Electrical Engineer
- Performs Pre-start Health and Safety reviews
- Participated in the development of
  - CSA Z142 Press Standard
  - CSA Z432 Machinery Standard
  - CSA Z434 Industrial Robots
  - CSA Z460 Energy control and Lockout
  - ANSI B11.1, 2 and 3 Press standards
  - ISO 10218.1 and 2 Industrial robots
DISCLAIMER

Any circuits used in this presentation are illustrative only and not intended to be used literally for your application. Each machine is unique and has individual characteristics that must be considered when designing a safety circuit.

* Always perform a complete risk assessment of all machine hazards, to acquire an in-depth understanding of your machine/application.

* Check all relevant standards/regulations applicable to your machine/application. There may be many additional local, state, national, and international standards as well as machine function specific standards pertinent to your machine.

Objectives of the Workshop

* Familiarize participants with
  * How to design a robot cell
  * Risk Assessment
  * Safeguarding application
  * Safe distance calculations.
  * Determining “stopping time”.
  * Hints that safeguards are working as expected or not working
  * Safety reviews

Ref: ANSI RIA R15.06, CSA Z434-03, and ISO 10218-1
What is a Robot? Robot System?

- **Industrial robot**
  - An automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axis which may be either fixed in place or mobile for use in industrial automation applications

- **Industrial robot system**
  - Equipment that includes the robot (hardware and software), consisting of the manipulator power supply and control system, the end-effector(s), and any other associated machinery and equipment within the safeguarded space

Some Other Definitions

- **Space** — the three-dimensional volume encompassing the movements of all robot parts through their axis

- **Safeguarded space** — the space defined by the perimeter safeguarding devices.

- **Restricted space** — that portion of the maximum space to which a robot is restricted by limiting devices. The maximum distance that the robot, end-effector, and work piece can travel after the limiting device is actuated.

- **Operating space** — that portion of the restricted space that is actually used by the robot while performing its task program.
System / Cell Design

- Functional Specification
  - What will the cell do?
- Space restrictions
  - Where will the cell be installed?
  - Where are the traffic aisles (people & materials)?
  - Space for the teacher
- Interlocks with adjacent machines
  - Will other automation be needed for the productive use of the cell?

Functional Specification

- Define the operation
  - Part details
  - Auxiliary equipment
  - Through put requirements
- Define the process
  - Are parts manually loaded
  - Location of parts to be used in the process
  - How will finished parts exit the cell
System / Cell Design

- Operating Personnel
  - How many personnel will be required?
  - What tasks will they do?
  - What skills are needed to perform the tasks?
  - What training is needed?
  - What procedures are needed?
  - How to make “safe use” be as intuitive as possible?

System / Cell Design

- Define the Robot(s) to be used
  - Payload requirements
  - Speeds
  - New or redeployed Robots
  - Conventional or Collaborative
Other considerations

• Where do we place the wire spools
• How do we do the tip dressing
• What access do we have for maintenance?
Typical Mig Welding cell

Guarding considerations

- Space for safe distance with light curtains
- Inconvenience of an automatic door

Restricted space

Robot reach

Operator Loading Station
Typical Multi-robot Weld cell

Other considerations

• Overlapping robots therefore we can only teach one at a time
• Multiple zones for each robot

Some other applications...

- Paint
- Assembly
- Inspection
- Welding (various types)
- Palletizing or Packaging
- Applying sealant, adhesives, ...
- Material transport
- small assembly collaborative
- Combinations of the above and more...
Robots New Vs Redeployed

* What is the cost of rebuilding a robot that has already worked through the life of a project?
* What is the cost of the base limits to define the restricted space and safety zones?
* Will the redeployed robot meet the safety requirements of Category 3 Pl “d”? 
* The redeployed robot will not be usable as a collaborative robot. What will the fixtures and other automation cost?

Collaborative vs conventional

Fixture table and slide mechanism was required to hand off the part from one cell to the next material handling robot
**Future Space requirements**

US: 18 in
CA: 20 in (0.5 m)

**Note:** Above describes Canada. For US (per R15.06: 1999) clearance is 18 in, while Canada (per Z434) clearance is 20 in.

**Note:** This describes requirements for Canada per Z434. For the USA, per R15.06: 1999, the maximum opening (floor to bottom of the perimeter guard) is 12 in (6 in for Canada) and the minimum height for the perimeter guard is 60 in (72 in for Canada).

- **Minimum Height:**
  - US: 60 in
  - CA: 72 in (1.8 m)

- **Maximum Distance before start of Perimeter Guard:**
  - US: 12 in
  - CA: 6 in (0.15 m)

**APV cell—slow speed**
- 0.5 m (20 in) or more clearance shall be provided from the operating space where feasible.
- Where 0.5 m (20 in) of clearance from the operating space is not feasible, additional safeguarding shall be provided.
- Robot movement shall be limited to 250 mm/s (10 in/s) or less during APV mode where 0.5 m (20 in) of clearance from the restricted space is not provided.

**Legend:**
- Area requiring additional safeguards
- Restricted space (includes operating space)
- Sensor and receiver of a light curtain
- Operating space

**Robot Range of Movement**

**Note:** See applicable standard for safeguarding requirements of other equipment.
**Risk Assessment**

- List all Tasks to be performed by workers
- Assess the hazards associated with the tasks
- Determine the severity/frequency of exposure/and probability of avoidance
- Document the facts.

**Perform the Risk Assessment**

<table>
<thead>
<tr>
<th>Task</th>
<th>Hazard - Risk</th>
<th>Evaluation</th>
<th>Countermeasure</th>
<th>Severity</th>
<th>Exposure</th>
<th>Risk Level</th>
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Remember - This evaluation is performed as though there is no guarding on m/c.

Who: Jim Van Kessel

Revision: A

January

Performed by Safety Device Task Individual: Protective Type, sketch & description

Exposure: Frequent

Avoidance: Likely

Severity: Slight

Countermeasure: Sketch or description of safety protection and reasons why level of safety device was chosen.
Break

15 minutes

Guarding Development

Let's look at the choices:
- Barrier guards
- Interlocked barrier guards
- Light curtains
- Two hand controls
- Laser scanners
- Floor mats
Safety Distance & Barriers*

* The barrier (and any barrier openings) needs to be sized such that a person cannot reach A.U.T.O.
  * Around
  * Under
  * Through
  * Over
  * And access a hazard.

*This is a fundamental and is the same in the USA, Canada, and Europe.

Fixed Barriers / Guards

* SECURELY INSTALLED
  * Requires TOOLS to install/ remove
  * Not easily removed

NOTE:
Expect new requirements such that fastening hardware must remain attached to the machine or the guard!
However this is not required for guards that will rarely be needed to be removed (for major overhaul, re-deployment of a system, ...).
Solid Barriers

- The number of fasteners is NOT specified, however one or two most likely are NOT sufficient.
- The guard should not be able to be propped in place (and appear secured when it is not secured).
- Means of affixing the removable guard shall remain attached to the machine or guard, if it will be removed for expected tasks.
- Flat black painted barriers are the easiest to “see through” (recommendation, not a requirement).

Fixed Barriers / Guards
Barriers as Safety Fencing

Devices that signal a stop

- **Protective Devices**
  (Engineering Controls)
  - Interlocked guards
  - Light curtains
  - Laser scanners
  - Safety mats
  - Two-hand control
  - Safe vision systems
Interlocked Barrier Guards

Roll up Curtain

Interlocked Lift gate
Interlocked Barriers

- How is this done?
  - Electromechanical safety switches
    - Safety limit switches
    - Safety hinge switches
    - Other safety switches
  - Safety sensors (non-contact safety sensors)
    - These devices are used to sense movement of the barrier / door (lateral or rotation).
  - Doors shall swing away from the hazard

Monitoring Door Position
Lineal Movement

Safety-type Limit Switches

Mechanical Latch
Monitoring Door Position Rotation Movement

Electro-mechanical solutions

Non-contact solution
All available from multiple manufacturers

Safety Locking
EM (Electro-Mechanical) Switch

Guard Locked (Held in Place)
Safety Locking EM Switch

guard closed & unlocked
(actuator released, able to be removed from the switch)

Guard is closed but can be opened

Guard Unlocked

Safety Distance

\[ D_s = [K \times (T_s + T_c + T_r)] + D_{pf} \]

- \( K \) = Hand speed constant 63”/sec
- \( T_s \) = Stop time of the machine
- \( T_c \) = Reaction time of the controls
- \( T_r \) = Reaction time of safety device
- \( D_{pf} \) = Depth of penetration
Stop time measurement

- By Roberta Shea Nelson

Light Curtain Muting

Disable the light curtain function during a part of the cycle

- Large opening for product to exit
- Light Curtain has muting to allow the product to pass through without stopping the process
- Other solutions would be a dual light curtain zone. The outer zone mutes the inner zone.
Muting

- Photo eye detects the allowed object to pass through the light beam without stopping the machine
- If one of the photo eyes is broken before the other then the machine will stop
- All Muting circuits must be of the same quality as the safety circuit being muted.
- An indication showing the status of the muting circuit should be supplied.
Dual zone Control

Discussion
Safety Laser Scanners

Safety scanners use the same safety distance formula.

* There are additional factors that may need to be included in the safe distance calculations (measurement error, for example).
* The MOS / resolution increases as the distance increases from the unit.
* There may be a maximum safety distance zone (to ensure maintaining a specific MOS / resolution).
Safety Vision System

- Sensor unit (camera assembly) is installed above the area to be monitored.
- Zones define the system’s responses to intrusions (response may vary depending on the location of the intrusion and the robot’s location at the time and place of the intrusion.
- An object or person entering the safeguarded area will be detected by the safe vision system.

Safety vision system

- Conventional PSSD solution
- PSSD that is Vision-based monitoring
3D Zone Monitoring

Action and reaction
- ... Flexible recognition and response

- Warning Zone
  - the process slows, but can continue.
  - the process continues but AWAY from the warning zone(s).

- Protection Zone
  - protective stop or emergency stop issued (or alarm)

Issues

- Obstructions / shadows may restrict “view”
  - Cranes, supports, gantries, etc.
- Some airborne obstructions may be an issue
  - Dust, mist, smoke, steam
- Vibration must be minimized by installation
- Lighting
  - Background lighting needed (not for “lights-out”)
- Guarding may still be required (as with any PSSD)
  - To “contain” ejected materials, sparks, parts, etc.
  - Due to traffic / movement considerations
What will Safe Vision Systems mean in the future?

* If the robot has safe speed control and safe motion control AND the safe vision system has similar specifications as a safety scanner (response time and resolution), then we will see tighter, smaller floor space because the combination could allow much smaller workspaces by situational logic (reduced speed(s) and/or the robot positioning itself further and further away from the approaching person).

Lunch

60 minutes
Control reliability

- Control reliability is a buzz word that has been floating around the safety world for some years now.
- All presentations in the past talked about the control system from an electrical point of view.
- We will take this to the next step to show you how to bring the pneumatics and hydraulics to that same level.
This works fine to control a motor but how does this relate to Pneumatics or Hydraulics

Very serious hazards can exist when using fluid power to control a machine

- Presses
- Clamps
- Fixture controls
Final Switching device

SR1 and SR2 become Con1 and Con1A
Hidden hazards

- With fluid power we can have hazards that are not really obvious
  - Gravity fall due to component failures
  - Trapped energy
  - Valves switch when power is removed
  - Components move as the pressure within the system gets vented
  - Cylinders can leak causing machines to drift

Different types of valves

- 2 position
  - Returns to home position when power is removed
- 2 position detented
  - Stays in the last position when power is removed.
- 3 position center blocked
  - Returns to center position when power is removed and traps the energy between the valve and actuator
- 3 position center open
  - Returns to center position when power is removed and vents the pressure in the actuator
Valve basics

When power is applied the actuator moves out/up
When power is removed the actuator returns home

2 position valve
Actuator

Typical pneumatic circuit
(Category 1)

3 position center blocked valve
Actuator

Hazardous motion
Safety Control circuit (category 1)

Actuator control

Safety contacts

Issues

- Failure of the directional control valve and we lose the safety function
- No monitoring means we can not detect a fault when it occurs
- Additional measure are required to deal with trapped energy
Adding a dump valve (Category 2)

2 position valve

3 position center blocked valve

Actuator

Hazardous motion

Center Open Valve (Category 2)

2 position valve

3 position center open valve

Actuator

Hazardous motion
Adding a dump valve (Category 2)

- Dump Valve control
- Actuator control
- Safety contacts

Add monitoring (Category 3)

- 2 position monitored valve
- Monitor position
- Hazardous motion
Safety circuit with monitored dump valve

Category 4

Pressure switch to monitor valve
Dual safety valve

Hazardous motion
Performance levels

- Pneumatic circuits like the electrical can have different levels of integrity
- Adding additional hardware can increase the level of safety
  - Pilot operated check valves
  - Rod lock system
  - Position monitoring to detect motion

Ross Category 2 valve

Schematics shown for 3/4 and 1 1/4 bodies.*

EN 954-1, ISO 13849-1, & AS4024-1
(3/4 bodies only, other sizes approval pending)
DM2 Series E Size 2 3/2 Double Valve with dynamic monitoring

Hydraulic System

- Hydraulic circuits are very similar but we need to provide a path for the oil to flow through the system or we end up with a spill.
- With a pneumatic system we can vent the components to the atmosphere.
- Oil requires a path because it cannot be compressed like the air can.

Hydraulic System

- Rapid response time to minimize stopping time.
- Dynamic memory of abnormal function retains lockout condition and this prevents unintentional reset with removal of air or electricity.
- Self-contained dynamic monitoring system requires no additional valve monitoring controls.
- Electrical reset valve.
- Status indicator switch for valve condition (ready to run) feedback.
- Highly contaminant tolerant poppet construction.
- Line mounted.

Do not use in power press clutch/brake applications.

<table>
<thead>
<tr>
<th>Model Number*</th>
<th>Port Size</th>
<th>In</th>
<th>Out</th>
<th>C^2 In-Out</th>
<th>C^2 Out-Exh.</th>
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<td>DM2EN420**21</td>
<td>1/4</td>
<td>1/2</td>
<td>1.94</td>
<td>2.43</td>
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<tr>
<td>DM2EN421**21</td>
<td>3/8</td>
<td>1/2</td>
<td>1.92</td>
<td>2.43</td>
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* NPT port threads. For BSPP threads replace “N” in the model number with a “D”.
** Insert voltage code: “A” = 24 volts DC; “B” = 110 volts AC; “C” = 220 volts AC; “D” = 12 volts DC. M12 connectors available, consult ROSS.
Wiring kits and accessories available, see pages 19 thru 23.
Category 1 Hydraulic Circuit

Add some monitoring and it increases to Category 2

Hazardous motion
Add a blocking valve (Category 3)

Safety Control
Dual channel gate monitored

Safety module disables all valves

Safety controller monitors the status of the valves

Gravity fall

- A cylinder could have a seal failure
- The rod or its connection could break
- A hose or fitting ruptures
- And the platen or attached hardware will fall
Single Cylinder C/W Counter Balance System

Example of single cylinder system using a hydraulic safety cylinder.

Single Cylinder C/W Mechanical Restraint

Example of single cylinder system using a mechanical restraint device.
Multiple Cylinders

The Double Valve controls the incoming oil and the release of pressure in the hazardous direction.
Example of self-monitoring hydraulic double valve

Common Mistakes

By Roberta Shea Nelson
The Team

Tom Eastwood – Workplace Safety and Prevention Services (WSPS)
Jim Van Kessel – JVK Industrial Automation
Roberta Shea Nelson - Rockwell Automation

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