Practical Application of Robot Safety

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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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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
- Previous Technical Committee Member CSA Z460 Hazardous Energy Control
Jim Van Kessel 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, 3, and 16 Press standards
  – ISO 10218.1 and 2 Industrial robots
  – ISO 16092 Machine tools — Safety for presses
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 R15.06-2012, CSA Z434-14, and ISO 10218-2011 (Part 1 and 2)
What is a Robot? Robot System?

• Industrial robot
  – An automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes 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.
Layout

• Wherever practicable, the layout shall be designed so tasks can be performed from outside the safeguarded space.

• If it is necessary to perform tasks within the safeguarded space there shall be safe and adequate access to the task locations.

• Access paths and means shall not expose operators to hazards, including slipping, tripping and falling hazards.

• Take into account the frequency and the ergonomic aspects of the task.
• Electric enclosures shall be mounted so that
  – doors can be easily pushed to a closed position, taking escape direction into account;
  – the remaining clearance is not less than 500 mm when the door is fully open

• Safeguarding shall be provided between cells or to bring hazards in adjacent cells to a safe state before an operator can reach them.

• Safeguarding shall be provided to reduce risks to operators due to the transfer of materials into and out of adjoining cells.
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?
Define the Robot(s) to be used

- Payload requirements
- Speeds
- New or redeployed Robots
- Conventional or Collaborative
Space Requirements

Material Handling robot

REJECT
SCRAP
INSPECTION
PIERCE
SCRAP
Typical Mig Welding Cell

Other considerations

• Where do we place the wire spools?
• How do we do the tip dressing?
• Where do we do the tip change?
• What access do we have for maintenance?
• Where is the best location for teaching?
Space Requirements

• Real estate is very expensive

• What space do we need for manual mode?
  – Slow speed or high speed manual mode

• Where does the teacher work?
Cell Clearance

End effector service area: guard in accordance with the requirements of this Standard.

Not required anymore

Teach here

Not required anymore

Interlocked barrier guard

Safety light curtain

Safety mat

Barrier guard fencing

0.5 m (20 in)

Legend:

A Additional safeguards

Sender and receiver of a light curtain

Operating space

Restricted space (includes operating space)

Area requiring additional safeguards

APV cell flow speed

- 0.5 m (20 in) or more clearance shall be provided past 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.
- Robotic movement shall be limited to 250 m/s (10 in/s) or less due to the APV matrix. When 0.5 m (20 in) clearance past the restricted space is not provided.

Robot Range of Movement

90°
APV cell—high speed

- 0.5 m (20 in) or more clearance shall be provided from the restricted space where feasible.
- Where 0.5 m (20 in) of clearance from is not feasible, additional safeguarding shall be provided to operate in APV high-speed mode.
Typical Mig Welding Cell

Guarding considerations

Space for safe distance with light curtains

Inconvenience of an automatic door
Multiple Robots
• Material handling
• Mig welding

Robot reach

Appears that part is not included in the restricted space

Restricted space

Operator Loading Station

Operator Loading Station

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
Operator Load Stations

• Clause 4.1.2 Part 2* “technical measures for risk reduction to prevent operators from coming into contact with hazards or controlling the hazards”

• How do you provide a 1.4m guard without compromising Ergonomics

• ISO/TR 20218-2 “Robotics-Safety requirements for industrial robots—Manual load/unload stations” will provide answers.
End of Arm Tooling

Designed / Constructed so that

1. Loss/change of energy supply does not release load (electrical, pneumatic, hydraulic...)

2. Static/dynamic forces created by load/end effector combined not greater than capacity/dynamic response of robot

3. Wrist plates / accessories properly align

4. Detaching tools only occur in designated locations
5. End effector withstands anticipated forces
Information for use includes life expectancy of end effector
Prior to operation of robot system TCP’s to be adjusted using offset feature provided by robot mfg.
Measures provided to protect pneumatic or vacuum hoses.
End of Arm Tooling

- ISO/TC 299 is presently working on a Technical Report “Robotics-Safety requirements for industrial robots-End-effector(s) (end of arm tooling)
- ISO/TR 20218-1:201X
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...

Each application has its own circumstances that need to be addressed.
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.
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>Item</th>
<th>Task</th>
<th>Hazard - Risk</th>
<th>Evaluation</th>
<th>Countermeasure</th>
<th>Safety Device</th>
<th>Check</th>
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<tbody>
<tr>
<td>1</td>
<td>Operator</td>
<td>R3A</td>
<td>Risk Level</td>
<td>Sketch or description of safety protection and reason why level of safety device was chosen</td>
<td>R1</td>
<td>R3A</td>
</tr>
</tbody>
</table>

**RISK ASSESSMENT Title**

Remember - This evaluation is performed as though there is no guarding on m/c

Performed by: Jim Van Kessel

Revision: A

January

**Countermeasure**

- Sketch or description of safety protection and reason why level of safety device was chosen

**Check**

- Risk Level

And document the results!
Guarding Development

• Let’s look at the choices
• Barrier guards
• Interlocked barrier guards
• Light curtains
• Two hand controls
• Laser scanners
• Floor mats
Guarding Applications

• 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.

• Internationally applied
Fixed Barriers / Guards

Securely Installed

- Removal=tools
- Not easily removed
- Captive Fasteners
- Mesh dark colours
- Fasteners (2+)

[Image of machinery with barriers]
Reach Over Tables

Robots too Close to the Fence (QP)

Robot # 10 A
### Table 6 – Horizontal minimum (safe) distance for HIGH RISK situations reaching OVER a guard or protective structure

![Diagram](image)

\[ a = \text{Height of Hazard Area} \]
\[ b = \text{Height of Protective Structure} \]
\[ c = \text{Horizontal Safety Distance to Hazard Zone} \]

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Devices That Signal a Stop

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

– 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
Safety Locking
EM (Electro-Mechanical) Switch

Solenoid supply

Monitor signals

Guard Locked (Held in Place)

Safety circuit

Solenoid locked the key
Safety Locking EM Switch

- Shown as Guard Unlocked
- Guard is closed but can be opened
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
- 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..
Dual Zone Control

Outer light curtain

Inner light curtain

Too High
Discussion
Safety Laser Scanners
Safety Scanners

Safety scanners use the same safety distance calc.

– There are additional factors that may need to be included in the safe distance calculations (measurement error, for example).
– The Min Object Sensitivity / 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.
3D Zone Monitoring

- **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
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 good specifications (response time and resolution), then
• We will see tighter, smaller floor space
• Using logic to suit the situation
  — reduced speed(s) and/or the robot positioning itself away
Break

30 minutes
Recap

• We have looked at how to layout a cell
• The space requirements
• Operator and Maintenance considerations
• The various guarding methods and devices
Measurement of Stopping Time – Practical Methods
In The Blink Of An Eye!

How to capture the stopping time of your complex system.

Source: ANSI B11.19-2010 / RIA15.06-1999 and CSA 434-14
What Tools Do I Need?
Keeping It Simple
Stop Time Elements – Time

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

- **Ts** = Stopping time of the machine (Robot)
  - Category 0 (Brakes On at initiation)
  - Category 1 (Controlled deceleration, delayed brakes)
    - Speed, Payload and Trajectory dependent

- **Tc** = Stopping time of the Control system
  - Direct Acting Contacts
  - Relay Action / Logic time
  - Safety Network Time

- **Tr** = Stopping time of the protective Device
  - Detection Time
  - Output Action / Logic Time
Stop Time Elements

• Some elements are fixed
  – $K =$ Intrusion speed 1.6m/sec / 63 in/sec

• Some Element are changeable by design
  – $Ts =$ Stopping time of the machine (Robot)
    • Safety Rated Space Limiting/ Speed limiting device
  – $Dpf =$ intrusion distance depending on device type and resolution setting.
Stop Time Elements

• Safe Distance Formula  $S = (K \times T) + C$ (ISO)
• $T =$ Overall Stopping Time
• $K =$ Intrusion speed 1.6m/sec / 63 in/sec
• $S =$ Intrusion distance depending on device type and resolution.
Record Your Scenario

• Important items to keep in the image view
  – Good perspective of major motion direction to see a clear stop frame.
  – Good perspective of the activation of the device for a clear start frame.
  – Indicator lights of the devices to see transition of “clear” to “blocked” are helpful but not required.

• Take several measurements to average the response time and capture a “Long” cycle of \((T_s+T_c+T_r)\). Use the longest measured value.
Movie Frame By Frame Method

• Use a video tool in Frame mode to count the frames from the device actuation to the robot movement stop.
  – QuickTime is popular and easy to get.

• Take a video of a Stopwatch to verify frame rate of your setup.
  – Default is 30 fps on many cameras.
  – $30 \text{ fps} = 33.3 \text{ ms/f}$  $60 \text{ fps} = 16.6 \text{ ms/f}$
  – Some inexpensive cameras go up to 240 fps.
Sample Videos

- VID00001 60 frames per sec.MP4
- VID00003.MP4
- VID00004.MP4
- VID00006.MP4

Use arrow keys to move one frame at a time
Frame Counting Validation

• Ending event Frame Count (240)
• Starting event Frame Count (91)
• 240-91=151 frames in 5 seconds = 30 fps = 33ms per frame
Record Your Scenario

• Important items to keep in the image view
  – Good perspective of major motion direction to see a clear stop frame.
  – Good perspective of the activation of the device for a clear start frame.
  – Indicator lights of the devices to see transition of “clear” to “blocked” are helpful but not required.

• Take several measurements to average the response time and capture a “Long” cycle of $(Ts + Tc + Tr)$. Use the longest measured value.
Document Your findings

• Keep measurement movies / images

• Summarize in a test report for your risk assessment.

• Sanity Check comparison with Simulation or estimated scenarios.
Questions?
Contact Information

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