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.

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

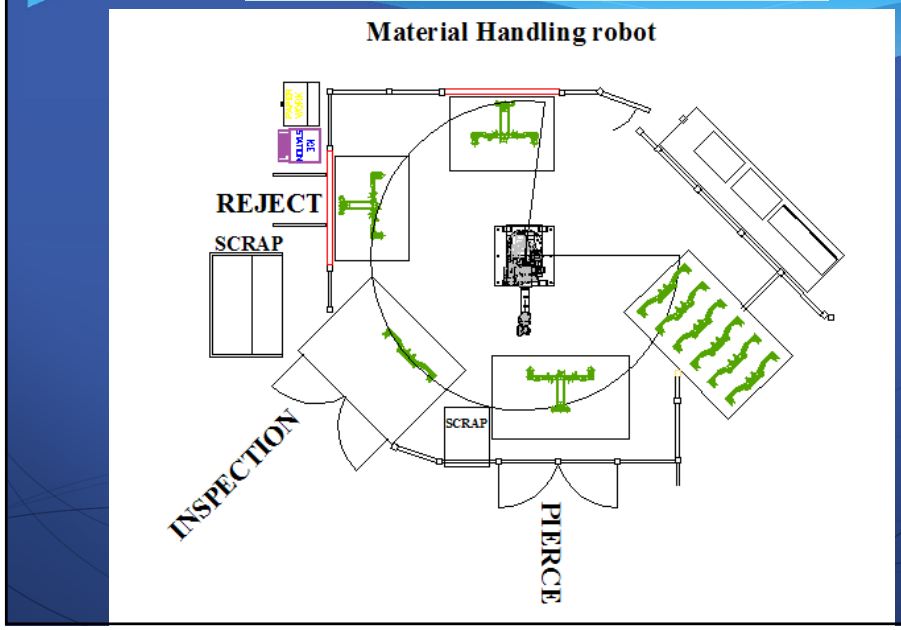
System / Cell Design

- 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?

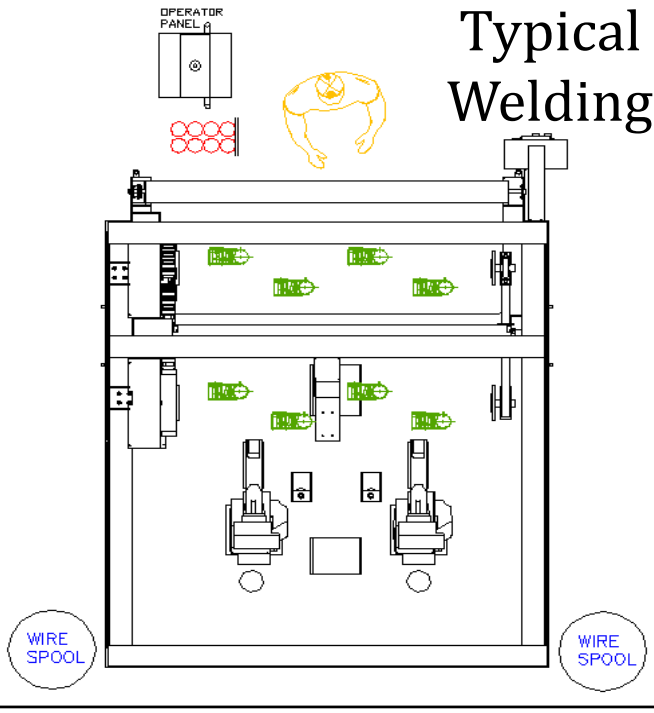
System / Cell Design

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

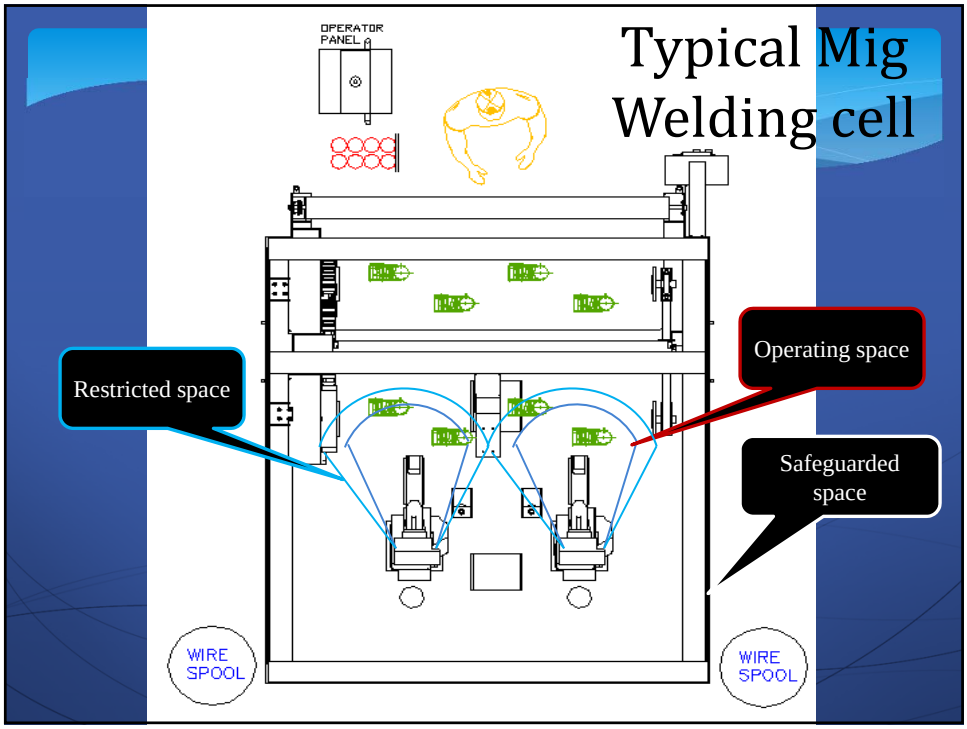
Space Requirements



Typical Mig Welding Cell



Typical Mig Welding cell



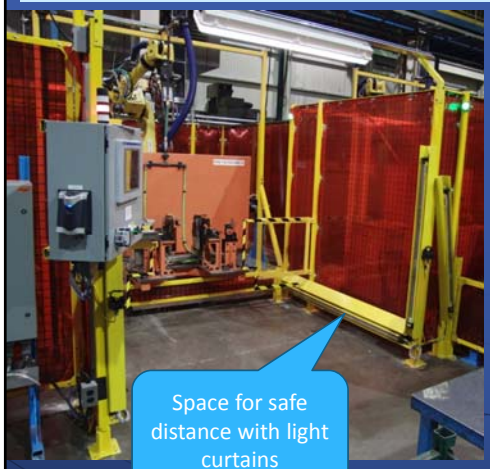
Typical Mig Welding cell

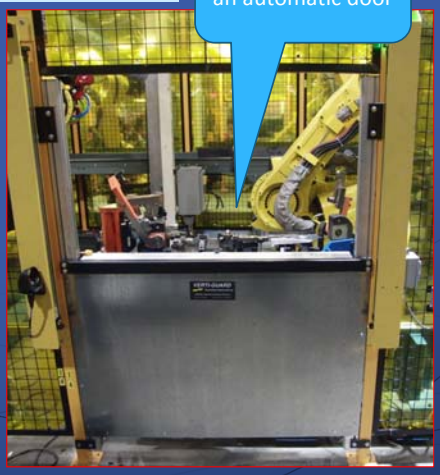
Other considerations

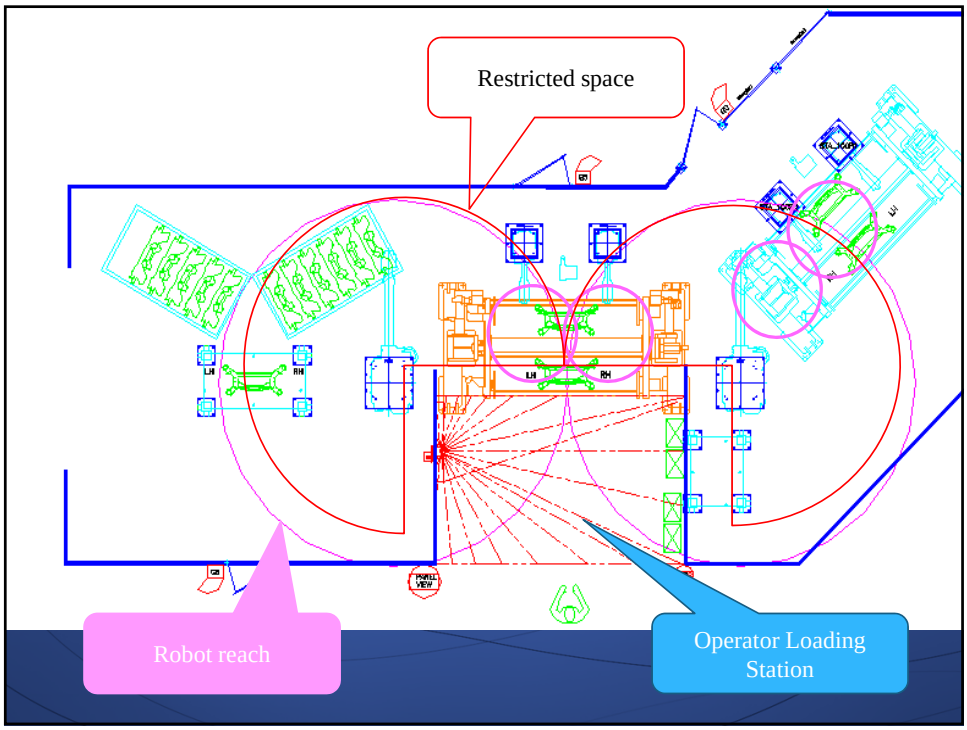
- Where do we place the wire spools
- How do we do the tip dressing
- What access do we have for maintenance?

Typical Mig Welding cell

Guarding considerations







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…

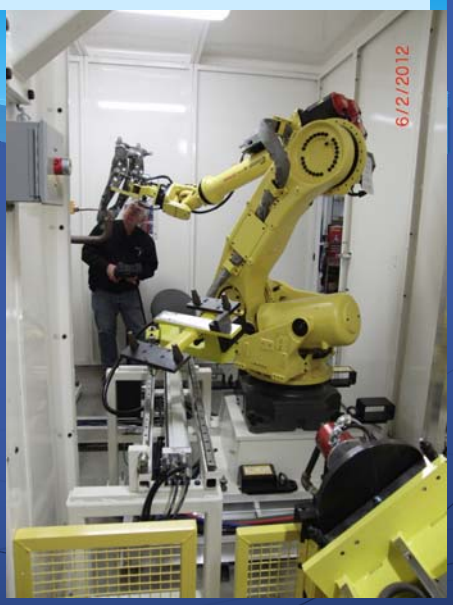
- Paint
- Assembly
- Inspection
- Welding (various types)
- Palletizing or Packaging
- Applying sealant, adhesives, …
- Material transport
- small assembly collaborative
- Combinations of the above and more…

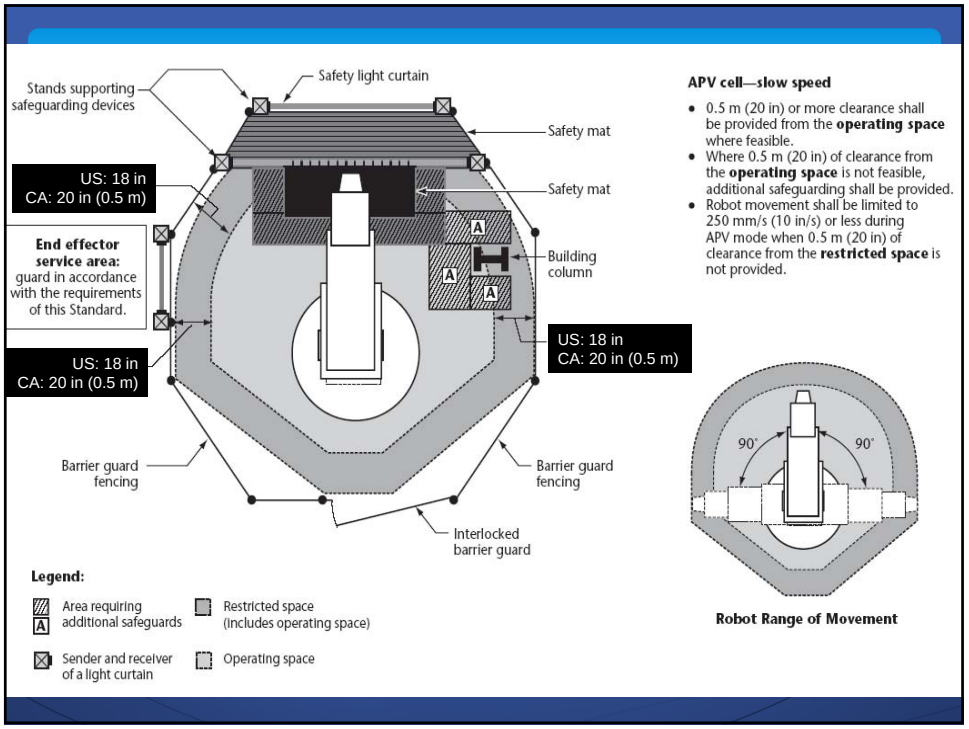
Robots New Vs Redeployed

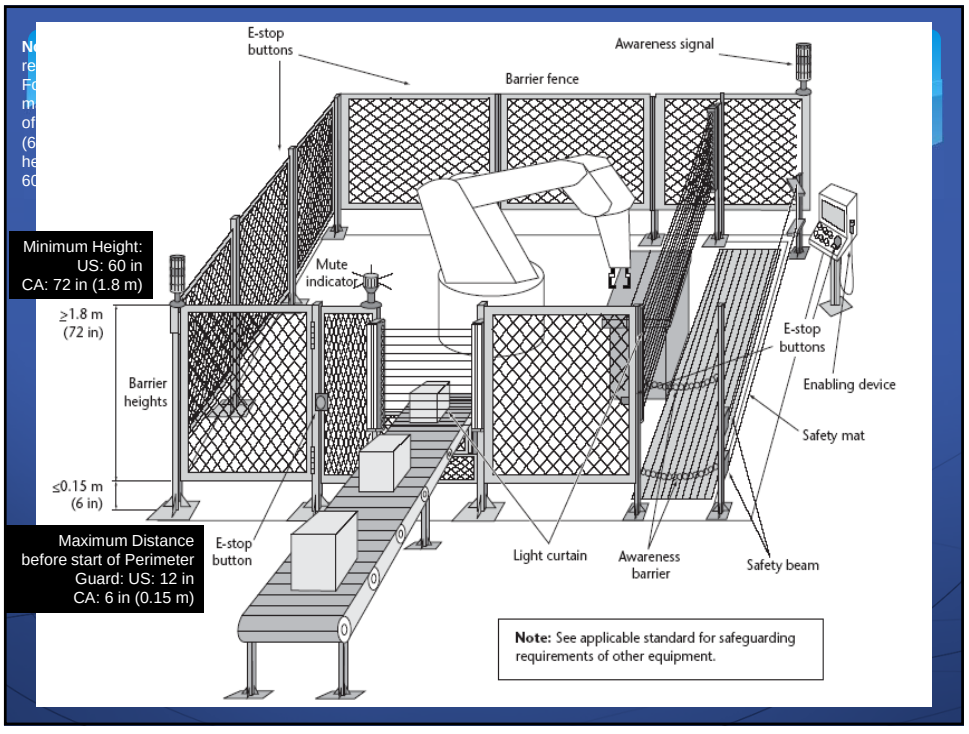
- What is the cost of rebuilding a robot that has already worked through the life of a project?
- What is the cost of the base limits to define the restricted space and safety zones?
- Will the redeployed robot meet the safety requirements of Category 3 Pl “d”?
- The redeployed robot will not be usable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




Stands supporting safeguarding devices
Safety light curtain
Safety mat
Safety mat
US: 18 in
CA: 20 in (0.5 m)
End effector service area: guard in accordance with the requirements of this Standard.
Building column
US: 18 in
CA: 20 in (0.5 m)
US: 18 in
CA: 20 in (0.5 m)
Barrier guard fencing
Barrier guard fencing
Interlocked barrier guard
Legend:
Area requiring additional safeguards
Restricted space (includes operating space)
Sender and receiver of a light curtain
Operating space
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 when 0.5 m (20 in) of clearance from the restricted space is not provided.
90°
90°
Robot Range of Movement


E-stop buttons
Awareness signal
Barrier fence
Minimum Height:
US: 60 in
CA: 72 in (1.8 m)
Mute indicator
≥1.8 m (72 in)
Barrier heights
≤0.15 m (6 in)
E-stop buttons
Enabling device
Safety mat
Maximum Distance before start of Perimeter Guard: US: 12 in
CA: 6 in (0.15 m)
E-stop button
Light curtain
Awareness barrier
Safety beam
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

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

Item	Who	Task	Hazard - Risk Type, sketch & description	Evaluation		Countermeasure Sketch or description of safety protection and reason why level of safety device was chosen	Safety Device Individual Protective Equipment	Check	
1	Operator			Severity	Serious		Control reliable	Exposure	Frequent
				Exposure	Frequent			Avoidance	Likely
				Avoidance	Not Likely			Severity	Slight
				Risk Level				Risk Level	
				R1				R3A	

And document the results!

Break

15 minutes

Guarding Development

Lets 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 be 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

Fixed Barriers / Guards

- 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).

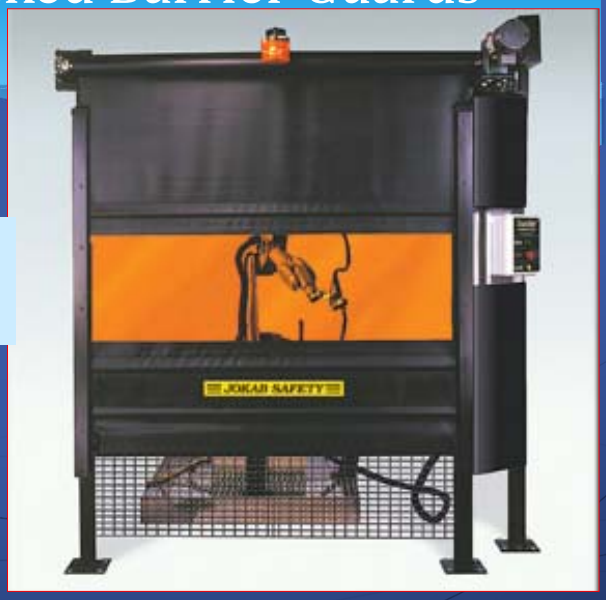
Barriers as Safety Fencing

Devices that signal a stop

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

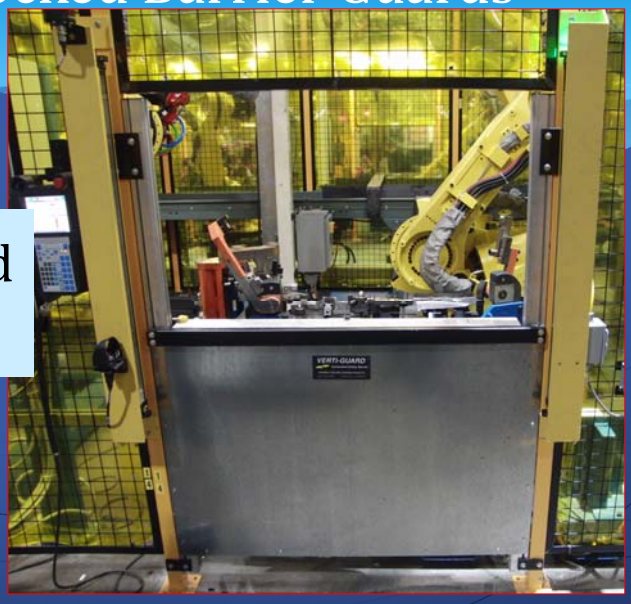
Interlocked Barrier Guards

Roll up Curtain



Interlocked Barrier Guards

Interlocked Lift gate

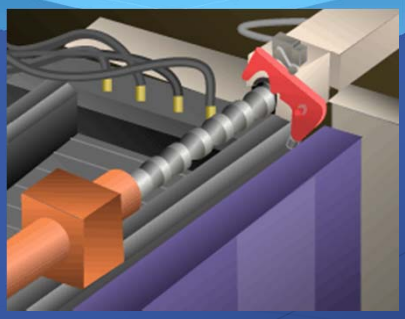


Interlocked Barriers

- 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

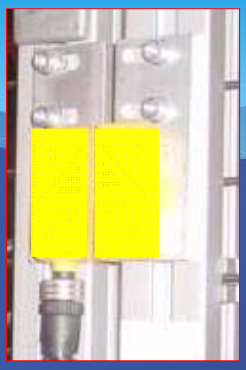
Safety-type Limit Switches



Mechanical Latch

Monitoring Door Position
Rotation Movement

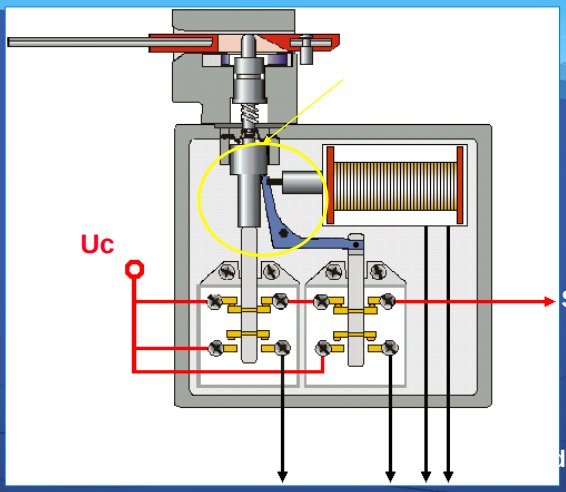
Electro-mechanical solutions



Non-contact solution

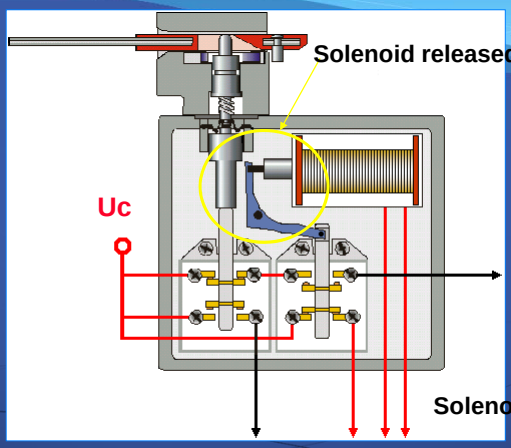
All available from multiple manufacturers

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)



Safety Distance

- Ds = [K * (T_s + T_c + T_r)]+Dpf
- 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
- Dpf = 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.

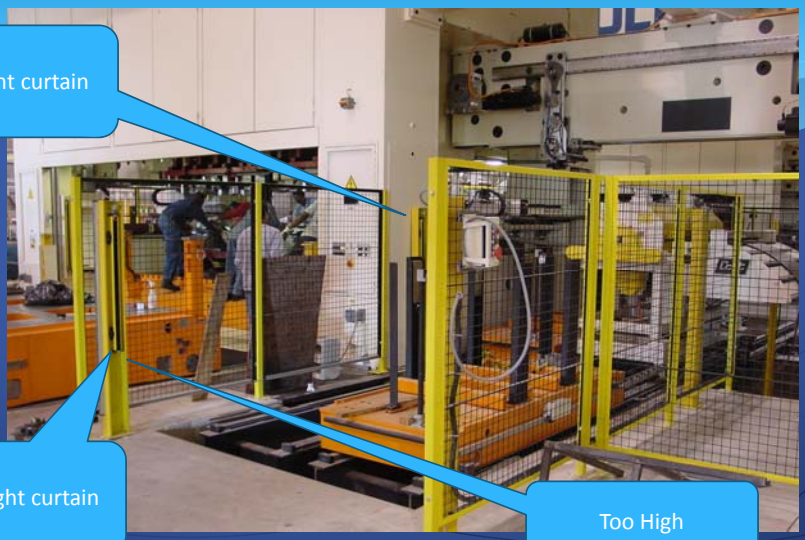
Muting

- 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.

Muting

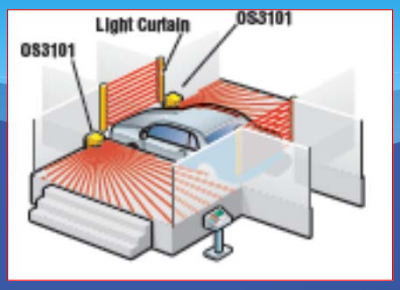
- Photo eye detects the allowed object to pass through the light beam without stopping the machine
- If one of the photo eyes is broken before the other then the machine will stop
- All Muting circuits must be of the same quality as the safety circuit being muted.
- An indication showing the status of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

Dual zone Control



Discussion

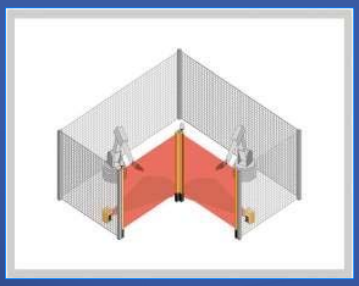
Safety Laser Scanners



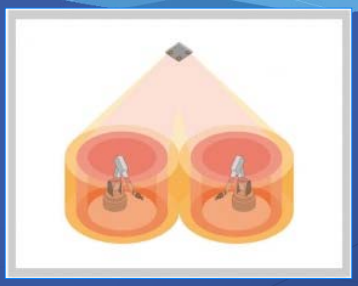
Safety Scanners

- 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



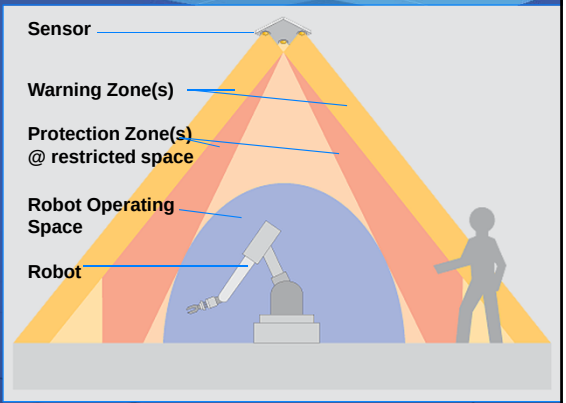
Conventional PSSD solution



PSSD that is
Vision-based monitoring

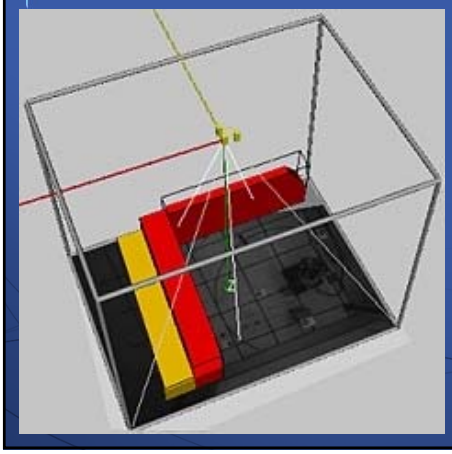
Safety vision system

- 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

- 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

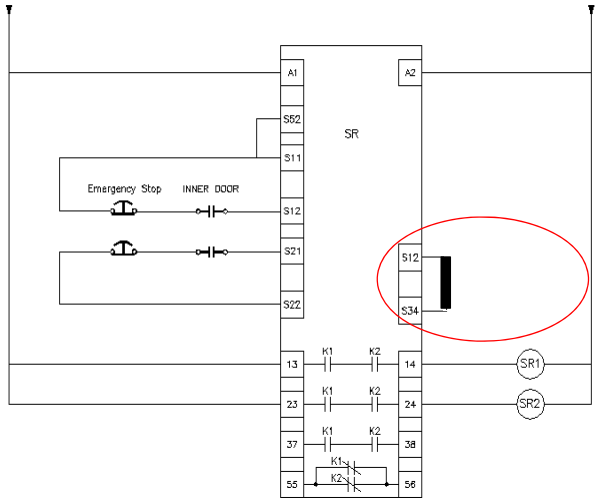
60 minutes

Safety beyond the Electrics

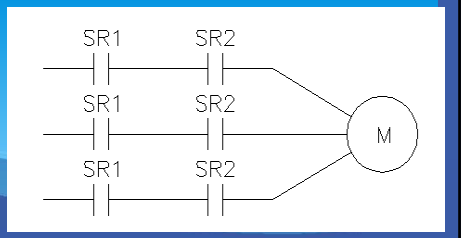
Control reliability

- 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

Typical safety relay circuit

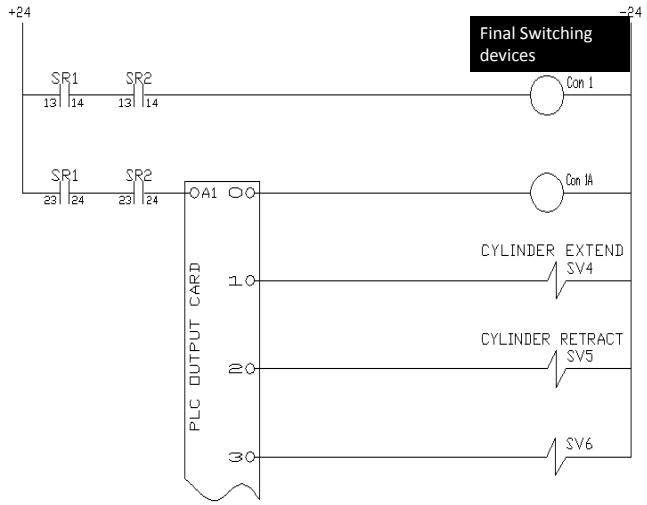


Which integrates fine with a motor

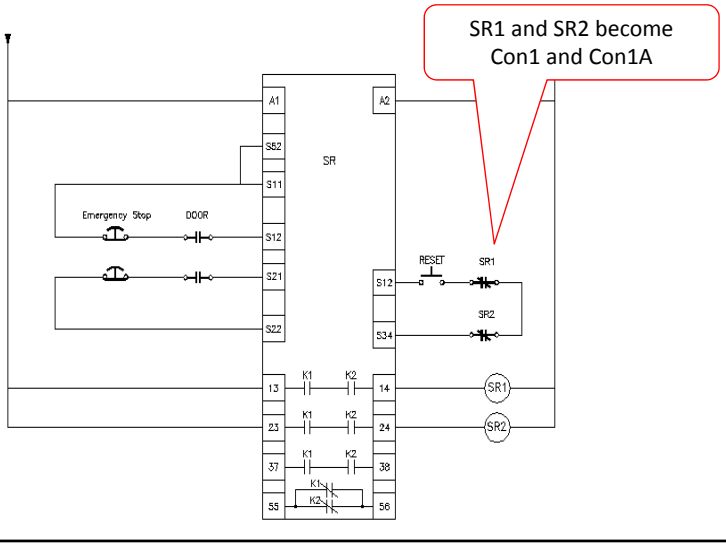


- This works fine to control a motor but how does this relate to Pneumatics or Hydraulics
- Very serious hazards can exist when using fluid power to control a machine
  - Presses
  - Clamps
  - Fixture controls

Final Switching device



Final Switching device



Hidden hazards

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

Different types of valves

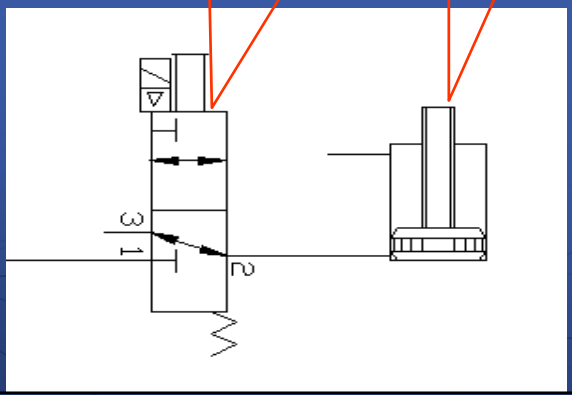
- 2 position
  - returns to home position when power is removed
- 2 position detented
  - stays in the last position when power is removed.
- 3 position center blocked
  - Returns to center position when power is removed and traps the energy between the valve and actuator
- 3 position center open
  - 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



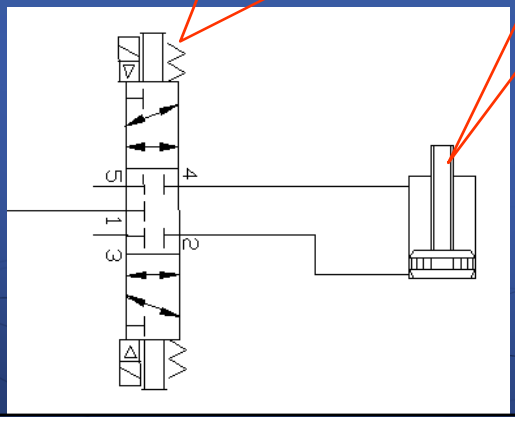
Hazardous motion

Typical pneumatic circuit

(Category 1)

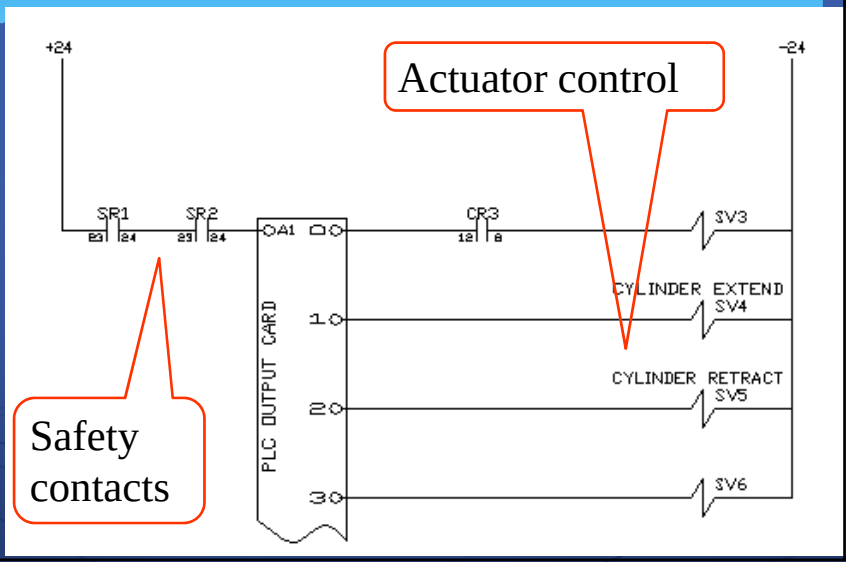
3 position center blocked valve

Actuator



Hazardous motion

Safety Control circuit (category 1)



Issues

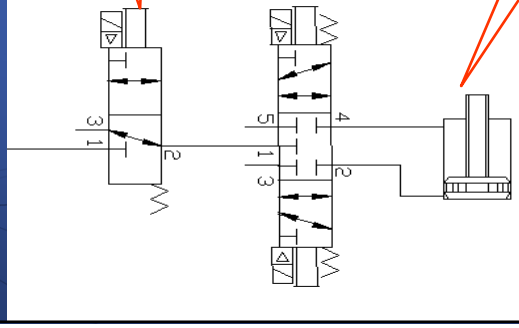
- Failure of the directional control valve and we lose the safety function
- No monitoring means we can not detect a fault when it occurs
- Additional measure are required to deal with trapped energy

Adding a dump valve (Category 2)

2 position valve

3 position center blocked valve

Actuator



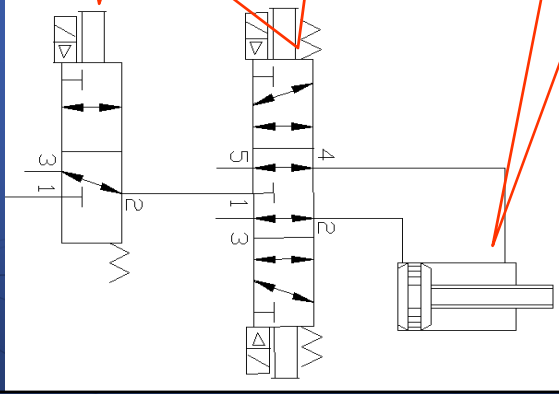
Hazardous motion

Center Open Valve (Category 2)

2 position valve

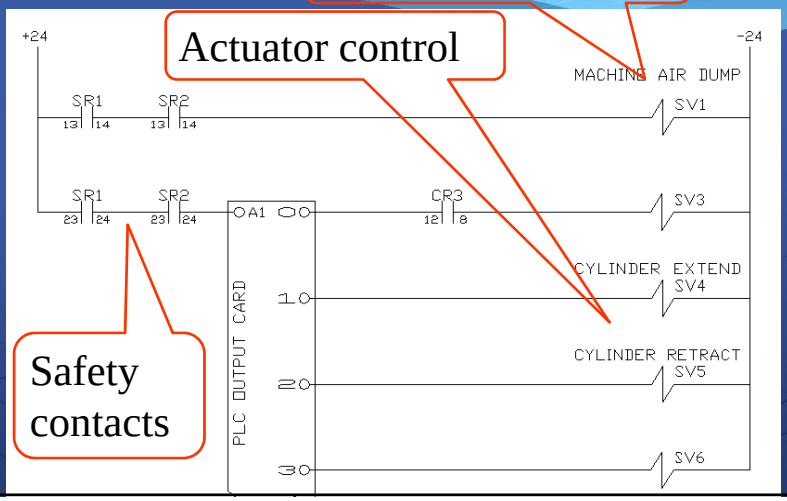
3 position center open valve

Actuator

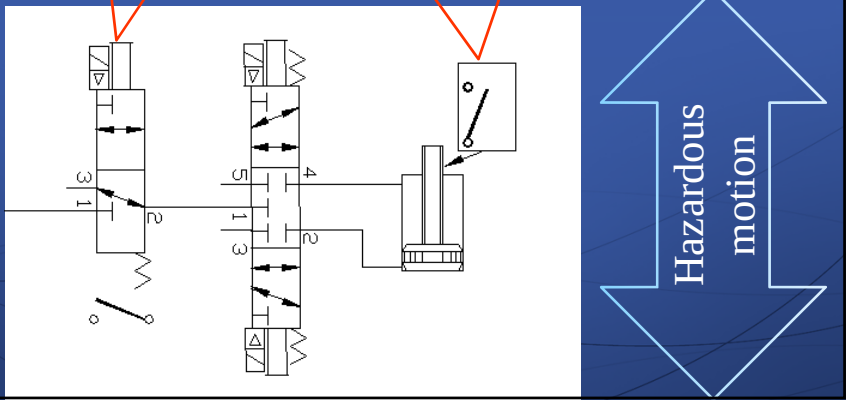


Hazardous motion

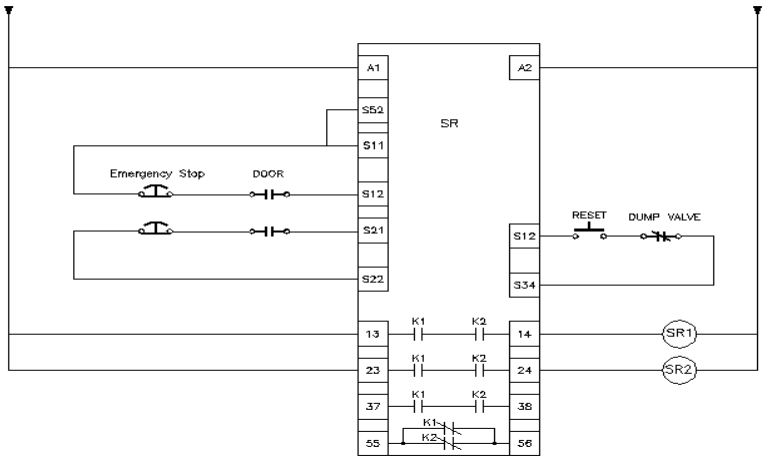
Adding a dump valve (Category 2)



Add monitoring (Category 3)



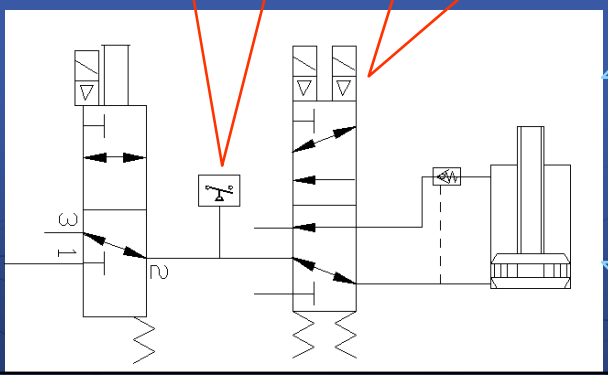
Safety circuit with monitored dump valve



Category 4

Pressure switch to monitor valve

Dual safety valve

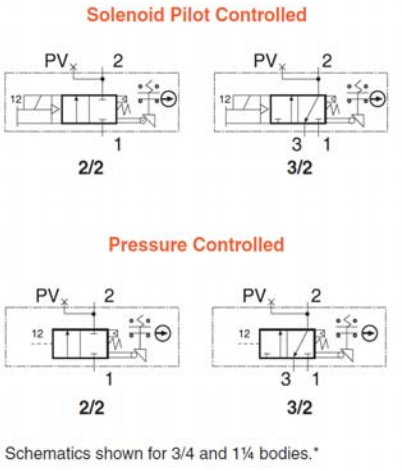


Hazardous motion

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 1¼ bodies.*

3/2 Sensing Valve
(solenoid model shown)

EN 954-1, ISO 13849-1,
& AS4024-1
(3/4 bodies only,
other sizes approval pending)

TÜV
TUV Rheinland of North America

CONTROL CATEGORY 2

DM2 Series E Size 2 3/2 Double Valve with dynamic monitoring

DM²® Series E Size 2
3/2 Double Valve with Dynamic Monitoring and Memory

- 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.

Model Number*	Port Size In	Port Size Out	C_v In-Out	C_v Out-Exh.
DM2ENA20**21	1/4	1/2	1.34	2.43
DM2ENA21**21	3/8	1/2	1.92	2.43

* 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.

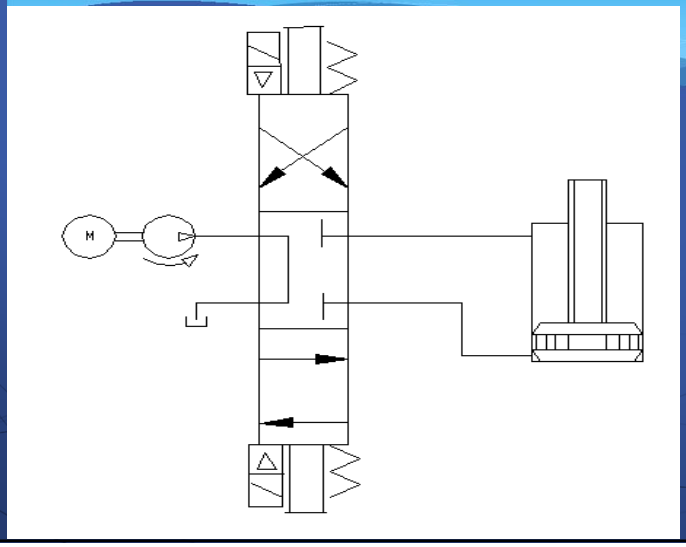
ISO 13849-1:2006 Category 4
PL e applications
(approval pending)

Air Dump / Release

Hydraulic System

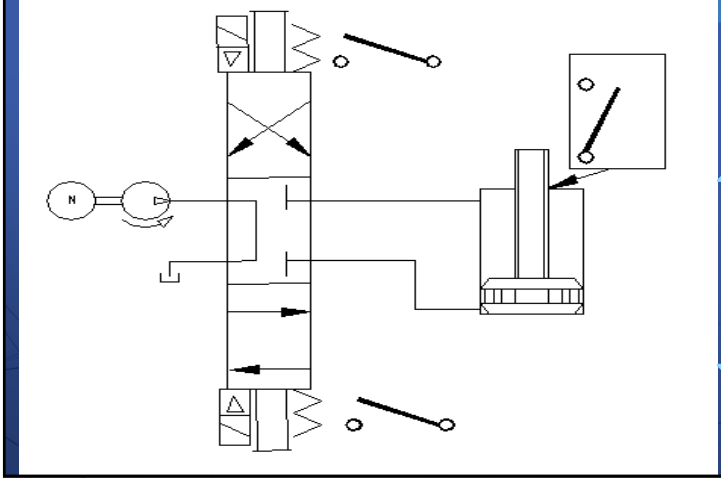
- Hydraulic circuits are very similar but we need to provide a path for the oil to flow through the system or we end up with a spill.
- With a pneumatic system we can vent the components to the atmosphere
- Oil requires a path because it cannot be compressed like the air can.

Category 1 Hydraulic Circuit



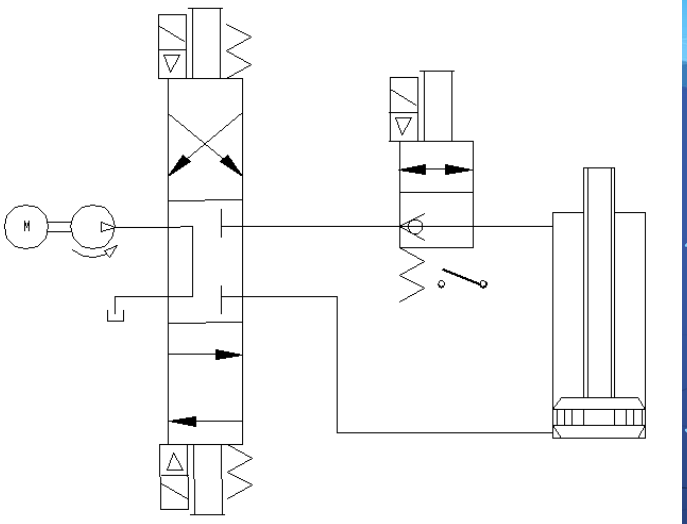
Hazardous motion

Add some monitoring and it increases to Category 2



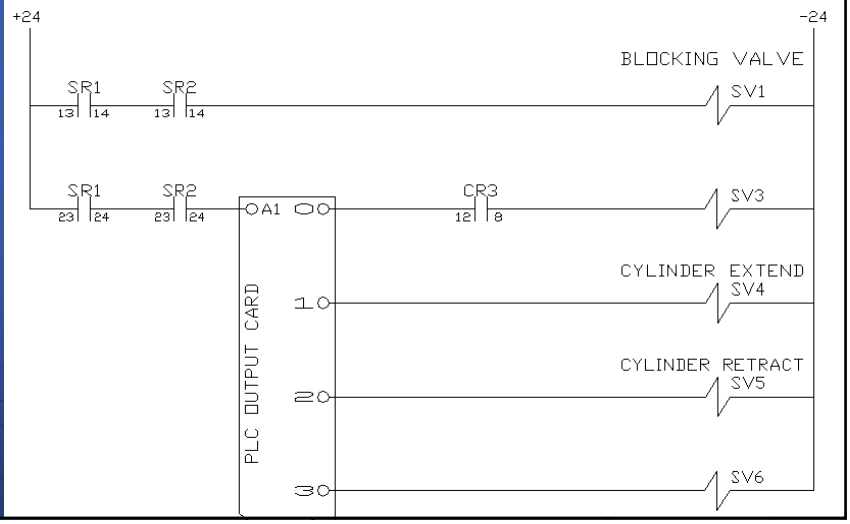
Hazardous motion

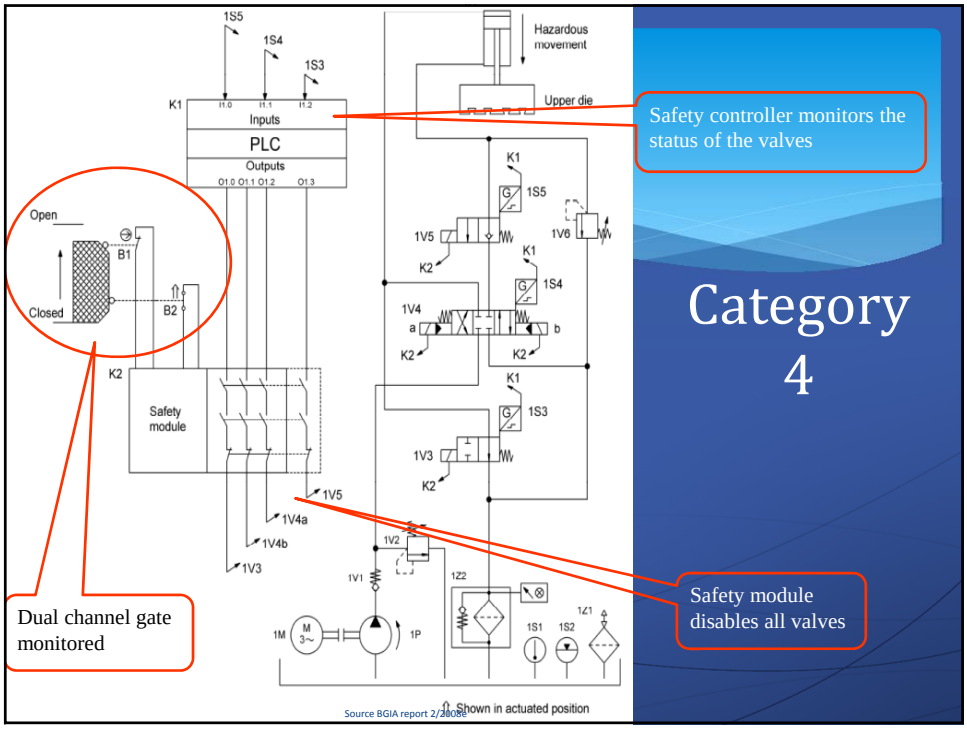
Add a blocking valve (Category 3)



Hazardous motion

Safety Control



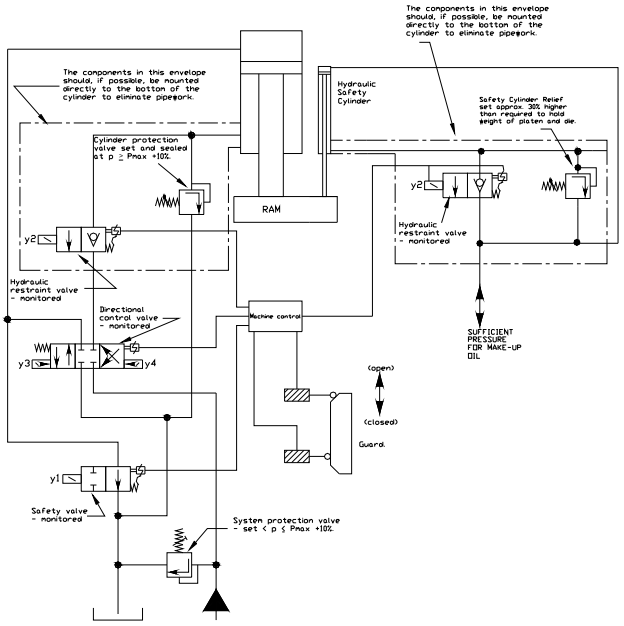


Category 4

Gravity fall

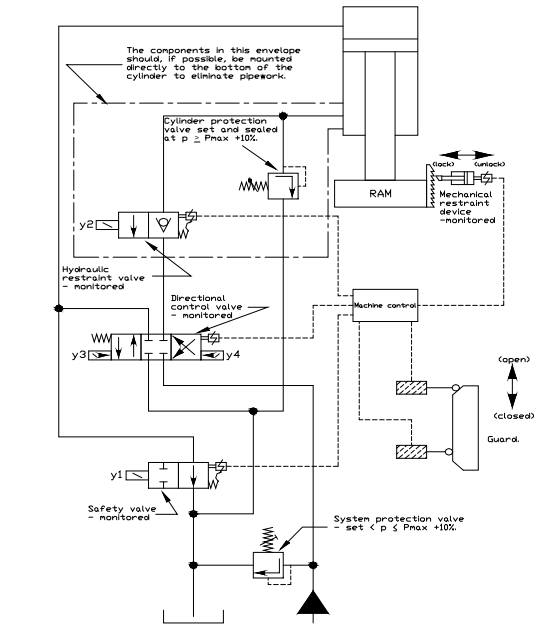
- A cylinder could have a seal failure
- the rod or its connection could break
- A hose or fitting ruptures

- and the platen or attached hardware will fall



Example of single cylinder system using a hydraulic safety cylinder.

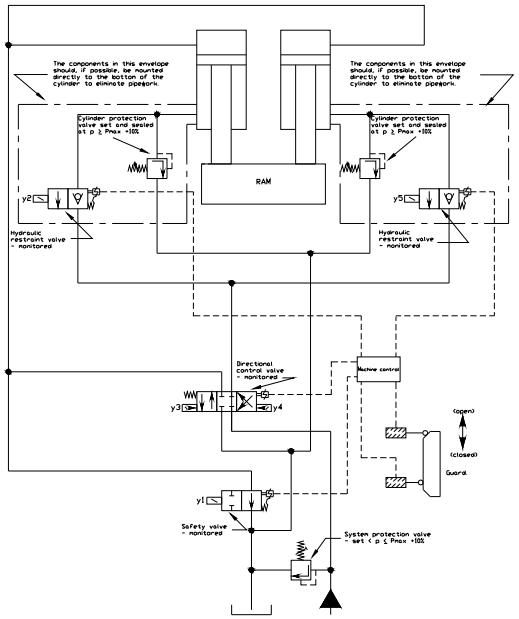
Single Cylinder C/W Counter Balance System



Example of single cylinder system using a mechanical restraint device.

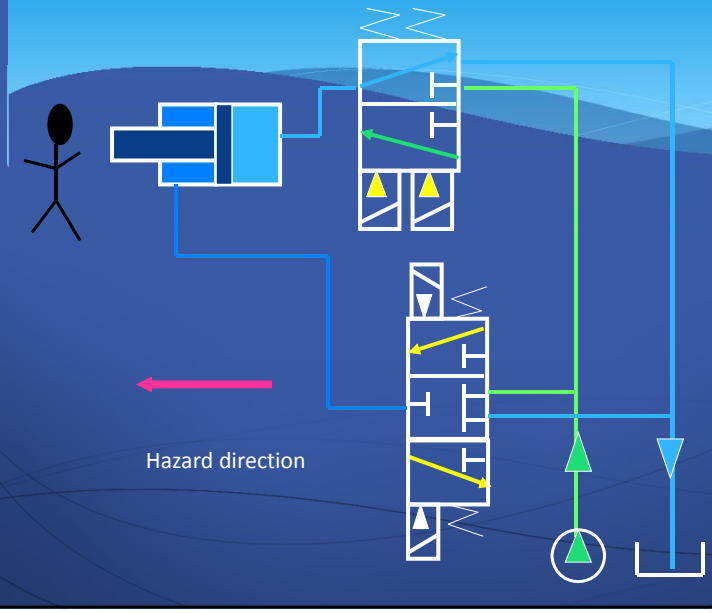
Single Cylinder C/W Mechanical Restraint

Multiple Cylinders



Example of multiiple cylinder system.

4 way circuit



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

Questions?

Roberta Shea Nelson RobertaNelson@Shea.us

Jim Van Kessel: 566 Fishermills Road
Cambridge, Ont. N3C 2V3

* 519-651-3371; Cell: 519-573-3371; Fax: 519-651-0791
* Email jimv@sympatico.ca

Tom Eastwood Machine Safeguarding Specialist
Thomas.eastwood@wsps.ca