DELPHI

Application Guideline for Presence Sensing Device Initiation (PSDI) using Light Curtains

DA-2101

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Index

1. Abstract

The intent of this document is to provide clear direction when implementing Presence Sensing Device Initiation (PSDI) using light curtains.

PSDI using light curtains is a way to initiate machine cycle. The light curtain provides two functions; first and foremost, it provides the safeguarding means. Secondly, after completing the manual interaction with the machine, when the operator is clear of the light curtain, the control system initiates the machine cycle.

This document starts by providing an overview on how light curtains operate. It then discusses the specification requirements for Control Reliable circuits, point-of-operation guarding and light curtains. The specific requirements for PSDI are then addressed. This is followed by a machine example that starts with a risk assessment and follows through the safety circuits for both electrical and fluid power to the control circuits including PLC logic.

2. Goals

It is Delphi's goal to have safe machines while minimizing cost, doing this by consistently applying the appropriate safety circuits to the application. This document has goals for the circuit design and additional goals for the overall document and process.

Goals for the circuit include:

- ✓ Meet appropriate safety specifications
- ✓ Ease to design
- ✓ Ease to adapt to different applications
- ✓ Ease to communicate / teach / and enforce
- ✓ Ease to maintain / troubleshoot

Goals for the document include:

- ✓ Document intent of safety specifications
- ✓ Document the requirements for PSDI applications
- ✓ Encourage consistent control design consideration
- ✓ Document failure mode considerations
- ✓ Document other design options which should not be used

3. Light Curtain – Theory of Operation

A light curtain is a photoelectric transmitter that projects an array of synchronized, parallel infrared light beams to a receiver unit. When an object interrupts one or more beams the control logic of the light curtain sends a stop signal[1] to the guarded machine.

The biggest difference between safety light curtains and standard photoelectric sensors is a concept known as "Control Reliability". As required by both National and International Standards, Control Reliability is defined as "The device, system or interface shall be designed, constructed and installed such that a single component failure within the device, interface or system shall not prevent normal stopping action from taking place but shall prevent a successive machine cycle".

To meet these requirements, safety light curtains use self-checking circuitry to monitor the curtain for internal faults. If

[1] Literally (FSDn) contacts open.

an internal fault is detected, the safety light curtain immediately sends a stop signal to the guarded machine. The light curtain then enters a Lockout condition. Only after replacement of the failed component and the appropriate reset will the light curtain be restored to normal operating condition.

Redundant safety outputs are another example of safety monitoring. Safety light curtains provide one of two possible types of safety outputs. The first type is a relay with positive-guided contacts; also called force-guided or captive contacts. These two sets of contacts are mechanically connected and move together. This permits monitoring of the relay contacts and guards against the danger caused by welded contacts.

Redundant relays are used for additional safeguarding. In the event one relay should fail, the second is used to send a stop signal to the guarded machine.

The second type of safety outputs are redundant, solid-state devices. These devices are electronically cross-monitored and self checking. Like the first type, should one output fail, a stop signal is immediately sent to the protected machine.

4. Specifications

It is the readers' responsibility to obtain, fully read and understand all the standards / specifications which apply to the application.

Delphi's *Design-In Health and Safety Specification* contains risk assessment and risk reduction sections[2] which detail the process to obtain the safety circuit performance level. For an operator loading to the point-of-operation (frequency is more than once per hour) where injury would be categorized as serious (OSHA recordable) whether avoidance is likely (R3C) or unlikely (R4); the associated circuit performance required is Control Reliable.

Note that keeping all other criteria the same and lowering the injury to a slight severity (non-OSHA recordable), lowers the required circuit performance to Single Channel[3]. The majority of the applications for PSDI will require a Control Reliable circuit performance and therefore this document will only address Control Reliable applications.

4.1 Control Reliable

Several national and international standards give definition to Control Reliable. Delphi's *Design-In Health and Safety Specification* establishes the rules for Control Reliable safety circuitry[4] within Delphi. Control reliable circuits are required to be hardware based, include checked redundancy to and including the final switching device(s), and take into account common modes of failure.

Electrical Control Reliable safety circuits require the use of dual-channel safety relays, two inputs with short circuit detection, and outputs with positive-guided contacts[5]. Contacts from any of these positive-guided relays are used in series to protect against a single failure, and "opposite state" contacts are used in circuitry which monitors the function

[2] DA-2006 section 3.3, 3.4, 3.5

[3] DA-2006 Table 4

[4] DA-2006 item 3.5.5.4

[5] DA-2001 item 4.1.2

of the safety circuits[6]. Positive-guided relays are sometimes added to a Control Reliable circuit to help monitor devices which do not have "positive-guided" indication that they are functioning properly[7].

Control Reliable safety circuits include checked redundancy in the fluid power controls[8]. This typically requires one or a combination of the following:

1. dual blocking valves with functional monitoring
2. dual motion valves where failure of one device is detected and does not lead to a hazard
3. use of safety-rated self-checked components
4. quick stopping / or position holding devices

4.2 Point-of-Operation Guarding

Point of operation guarding is used to protect a person who performs an interactive task such as loading, unloading or inspecting in an area of a machine where a hazard exits. When used as point-of-operation guarding, the light curtain's field is normally interrupted by the person each cycle of the machine[9]. In this case, the light curtain provides a safeguarding means while cycle initiation is provided by other means.

The point-of-operation light curtain(s) shall be installed so no one can stand between the light curtain and the hazard[10]. They must be mounted so that no one can reach over, around, or through the guarded area.[11] This may require additional hard guarding, angle mounting the light curtain, or additional light curtains.

Interruption of the light curtain shall not disable the control circuit cycle-overtime timer[12].

If the light curtain is interrupted during the hazardous portion of the cycle, the appropriate safety circuit shall remove power (including fluid power) from hazardous devices[13].

4.3 Light Curtain Requirements

Light curtains shall be certified in compliance with IEC-61496-1 part 1 and IEC-61496-2 part 2. For Control Reliable applications, a type 4 ESPE is to be used[14].

Type 4 ESPE devices: Electro-sensitive protective equipment (sensing devices such as light curtains) that contain at least two output contacts which go to an Off-state when the sensing device is actuated, or when power is removed. A type 4 ESPE device protects against single internal faults. This can be accomplished by either going to the Off-state immediately upon detection of the fault, or by guaranteeing that further faults will not cause a failure to danger.[15]

[6] DA-2001 section 5.4
[7] DA-2001 item 5.4.5.2
[8] DA-2001 section 8
[9] DA-2001 section 6.1
[10] DA-2006 section 4.1.1
[11] DA-2006 section 10.1.4
[12] DA-2004 section 6.4.1
[13] DA-2001 section 6.3.3
[14] DA-2001 section 4.6.1
[15] IEC-61496-1 items 3.1, 4.2.2.5

Light curtain applications shall meet all of the requirements in ANSI B11.19 for presence-sensing devices[16].

Light curtains shall be mounted in accordance with the safe distance formula[17]. Reference Annex A.

5. Presence Sensing Device Initiation

Presence sensing device initiation (PSDI) applications shall meet all "Point-of-Operation Guarding" requirements as detailed above. Additionally, the light curtain shall provide cycle initiation. The following shall apply:

1. PSDI shall not be used on full revolution mechanical power presses.

2. Light curtain cycle initiation shall be enabled when the control system is placed in auto mode.
   - A PSDI cycle enable timer should be added to limit the amount of time PSDI is enabled.

     Note this would require that the operator re-initiate auto after this timer times out. The appropriate time setting will depend on the application.

   - Auto mode shall be disarmed if an E-stop, cycle overtime fault, light curtain field interrupted prior to end of cycle or some other abnormal stop has occurred.

3. Sensors shall be provided to detect that all parts are properly loaded before cycle initiation.

4. Machine initiation **shall not** occur based only on cycling of the light curtain one or more times. Machine initiation shall occur only as the result of a specific sequence of events, such as parts present sensors released, followed by parts detected as loaded in position (anti-repeat) and the light curtain's field interrupted and cleared.

5. When light curtains are used for PSDI, they shall be implemented only in a straight-line configuration. The use of any device (mirrors, reflectors, etc) to go around corners shall not be used.
6. The use of Blanking which allows the light curtain to ignore certain objects located within the defined area are not allowed in PSDI applications.
7. Beam spacing, which is the distance between the center of one beam to the center of an adjacent beam is not to exceed 1.25 inches.
8. Each machine incorporating PSDI must have a sign that is clearly visible and indicating that PSDI is being used. A sample is shown below.

CAUTION!

THIS MACHINE IS DESIGNED TO OPERATE USING

(PSDI)

PRESENCE SENSING DEVICE INITIATION

BY

ENTERING AND EXITING THE LIGHT CURTAIN

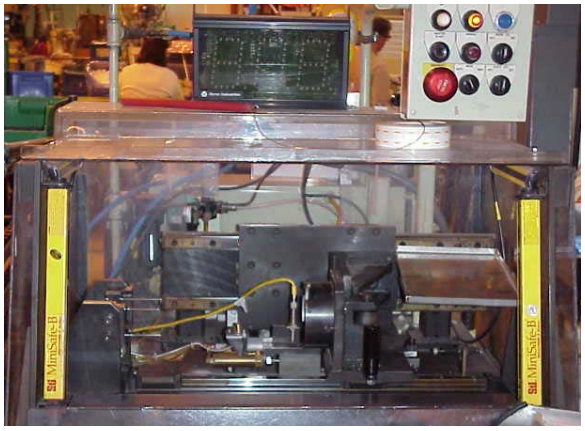
[16] DA-2001 section 4.6.2
[17] DA-2001 item 5.9.2

6. Design-In Safety Process

Delphi's *Design-In Health and Safety Specification,* Design-In Safety Process, shall be followed when implementing PSDI applications[18].

- The manufacturing engineer (ME) is to assemble a team and conduct a risk assessment.
- When the PSDI detailed design is complete, the controls engineer (CE) completes a safety design review using the "Safety Circuit Design Verification Checklist" in Annex A.
- When the equipment build is complete, the CE completes a safety design review using the "Safety Circuit Construction Verification Checklist" in Annex A.
- With equipment installed and prior to release for production, the CE and plant Electrician are to verify the implementation using the "Initial Operation Verification Checklist" in Annex A.

7. Machine Overview



Application: The machine is a manually loaded lean assembly station, which presses four individual rods into the lower and upper half of a Fuel Level sending unit.

The light curtain provides both point of operation guarding as well as PSDI. The cycle is initiated automatically upon detection of both a part present and the exit of the operator from the hazardous area. The part present sensor is checked[19] in the logic to verify that it changes state each time the light curtain is blocked.

Description: The operator manually insets the rods part of the way into both half's of the unit and then places the lower half into a stationary fixture. While holding the assembly in a horizontal plane, the operator then slides the movable fixture over the upper half of the unit until it engages a detent along with making a part present switch. With the part present switch made and the operator clearing the light curtain, the pressing cycle is initiated. A pneumatic cylinder moves the entire fixture away from the operator and while doing so, a cam roller on the movable slide makes contact with a cam angle compressing the fixture and inserting the four rods. Once the slide-advanced switch is made, a full depth timer times out and then returns the fixture back to its start position completing the cycle.

[18] DA-2001 section 1.6.4

[19] DA-2004 section 21.2

8. Risk Assessment

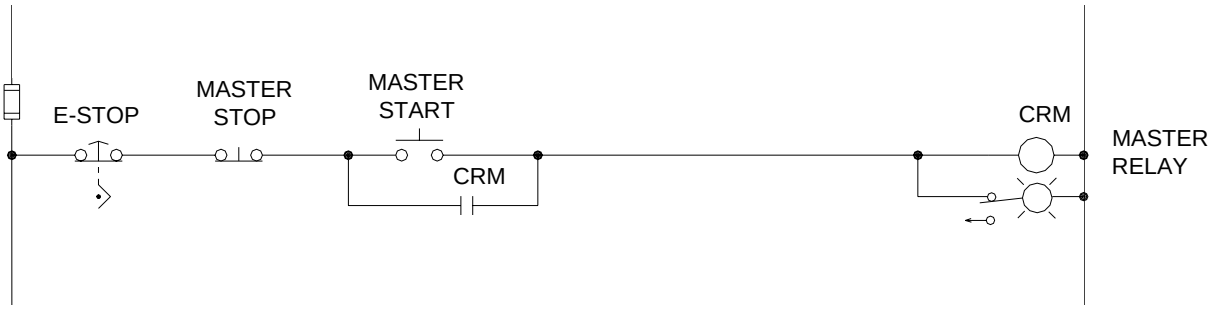
The following risk assessment sample is for the example machine in this paper. It has indicated that the worst-case hazard for the machine is an R4 category. In most cases, a machine that uses a light curtain for PSDI will be an R4 category because of the frequency of hazard exposure.

User	Task	Hazard / Failure Mode	S	E	A	Category	Solution	Risk Reduction Methods
Operator	Load rods into tooling	unexpected advance motion of shuttle bumps hand	S1	F2	P1	R2B	Engr Ctrls	Light curtain with fixed barrier guards to prevent reaching over, under, or around light curtain.
Operator	Load fuel level sender body	unexpected advance motion of shuttle bumps hand	S1	F2	P1	R2B	Engr Ctrls	Light curtain with fixed barrier guards to prevent reaching over, under, or around light curtain.
Operator	Manual pull slide over to engage body over rods (slide latches)	pinch point during engagement/manual operation	S1	F2	P1	R2B	Other Safety Measures	Train operator on safe operation of equipment per job instructions
Operator	Manual pull slide over to engage body over rods (slide latches)	unexpected advance motion of shuttle bumps hand	S1	F2	P1	R2B	Engr Ctrls	Light curtain with fixed barrier guards to prevent reaching over, under, or around light curtain.
Operator	Initiate Cycle	expected advance motion of shuttle causes pinch point between shuttle wheel and cam bar	S2	F2	P2	R4	Engr Ctrls	Light curtain with fixed barrier guards to prevent reaching over, under, or around light curtain. Light curtain implemented in a control reliable manner using redundant spring return valves for shuttle motion.
Operator	Initiate Cycle	expected retract motion of shuttle bumps hand/ no pinch points	S1	F2	P1	R2B	Other Safety Measures	Train operator on safe operation of equipment per job instructions
Operator	Initiate Cycle	expected advance motion of cylinder to release part slide - no hazard	S1	F2	P2	R3A	Elim / Sub	Exposure to cylinder motion has been designed out
Operator	Initiate Cycle	expected retract motion of part slide under no power bumps hand	S1	F2	P1	R2B	Other Safety Measures	Train operator on safe operation of equipment per job instructions
Operator	Unload finished assembly	unexpected advance motion of shuttle bumps hand	S1	F2	P1	R2B	Engr Ctrls	Light curtain with fixed barrier guards to prevent reaching over, under, or around light curtain.
Operator	Cleaning machine						Lockout	Follow lockout and hazardous energy control procedure
Skilled Trades	Major Repair						Lockout	Follow lockout and hazardous energy control procedure
Skilled Trades	Switch Adjustments with power on	unexpected advance motion of shuttle bumps hand	S1	F2	P1	R2B	Engr Ctrls	Light curtain with fixed barrier guard to prevent reaching over under around light curtain.

9. Hardwire Control Circuit Design

The hardwire control circuit design is for a Control Reliable implementation and has been broken down into individual circuit steps for clarity purposes.

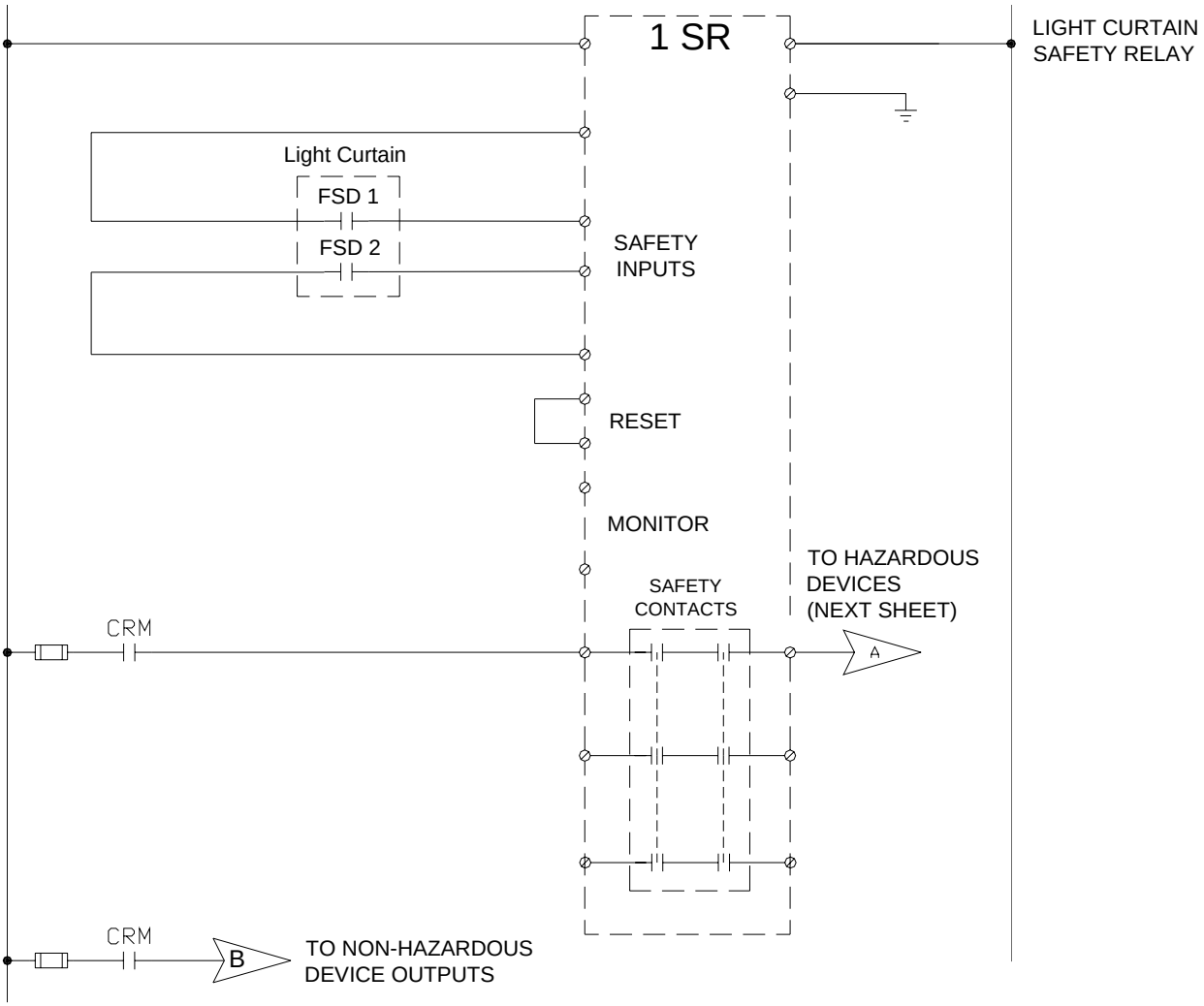
Step #1: E-stop circuit design



NOTES:

1. The risk assessment has determined that the light curtain connected to the safety relay has addressed all hazards, therefore e-stop needs to be a minimum single channel circuit performance.
2. The master relay (CRM) performs a safety function at a single channel level.

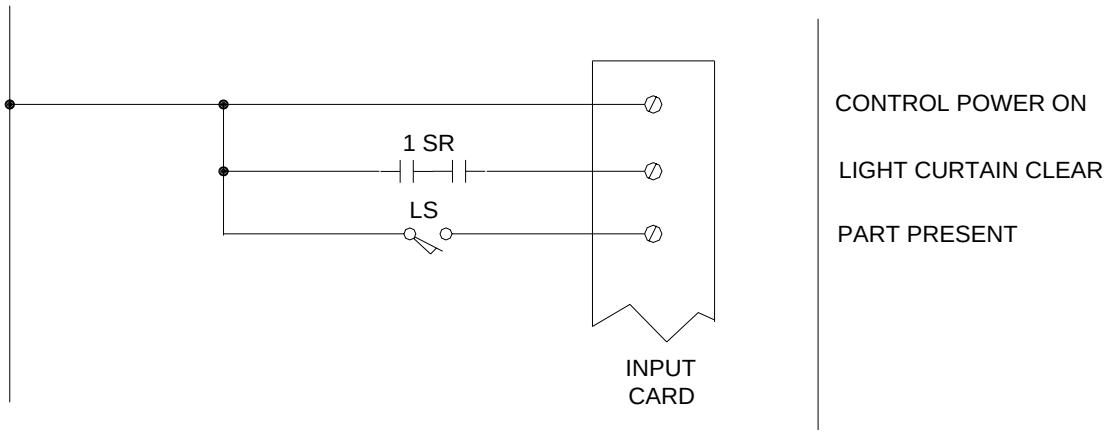
Step #2: Light Curtain Safety Relay:



NOTES:

1. The outputs are divided into those that potentially could harm an operator (e.g. hazardous devices) and those that are assessed as being non-hazardous.
2. The programmable device controls the state of the outputs, however supply power is disconnected based on the state of the light curtain safety relay.
3. An auxiliary output from the light curtain could be connected to the input card for state annunciation.
4. Once the light beam is interrupted, the safety relay shall require that both of the light curtain FSD contacts transition to off and then back on prior to automatic reset of the safety relay. For point of operation guarding, reset is automatic.

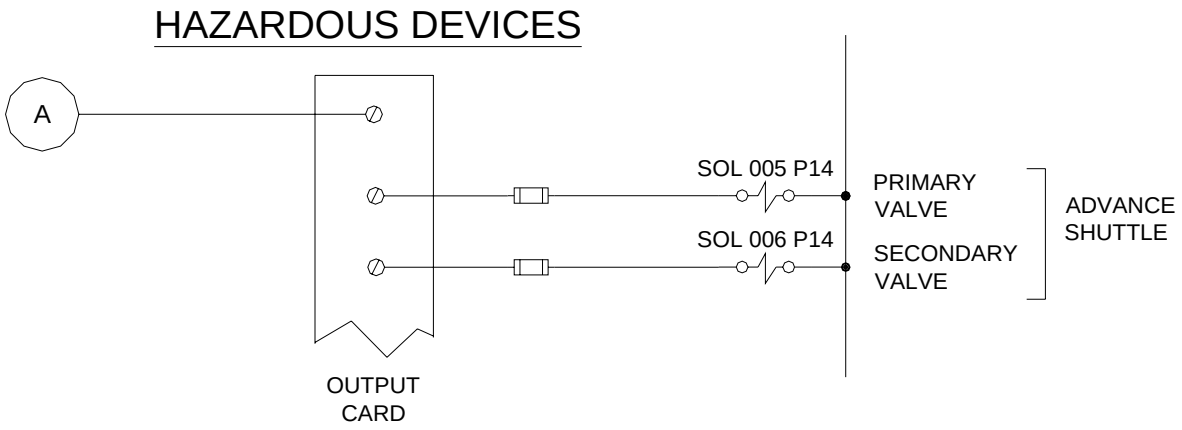
Step #3: Programmable Electronic System Inputs:



NOTES:

1. A redundant contact from the light curtain safety relay is connected to the input card for state annunciation.
2. The part present input provides status such that the programmable device can ensure that the parts have been removed and a new part is in position while the light curtain is open.

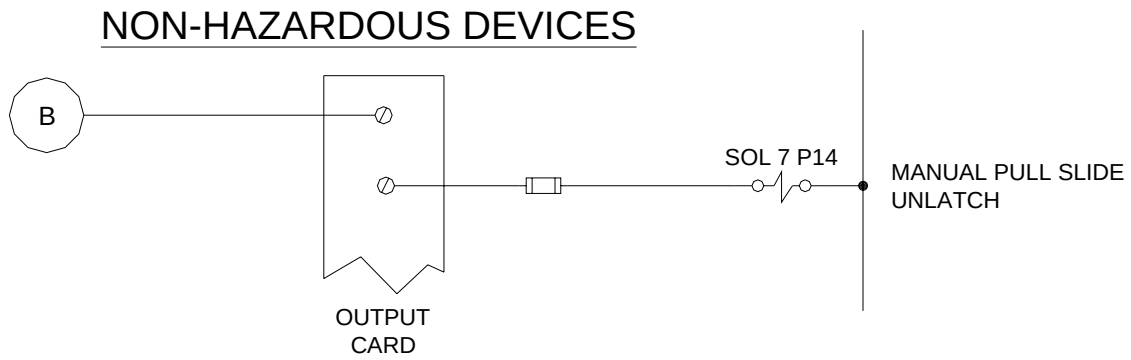
Step #4: Hazardous Devices Output Wiring:



NOTES:

1. The state of the contactors and/or spool position monitoring are monitored through normally closed contacts (i.e., for contactors, auxiliary). In this example, monitoring of the hazardous devices is not required. The failure of either valve would not allow the shuttle to return to home.

Step #5: Non-Hazardous Devices Output Wiring:

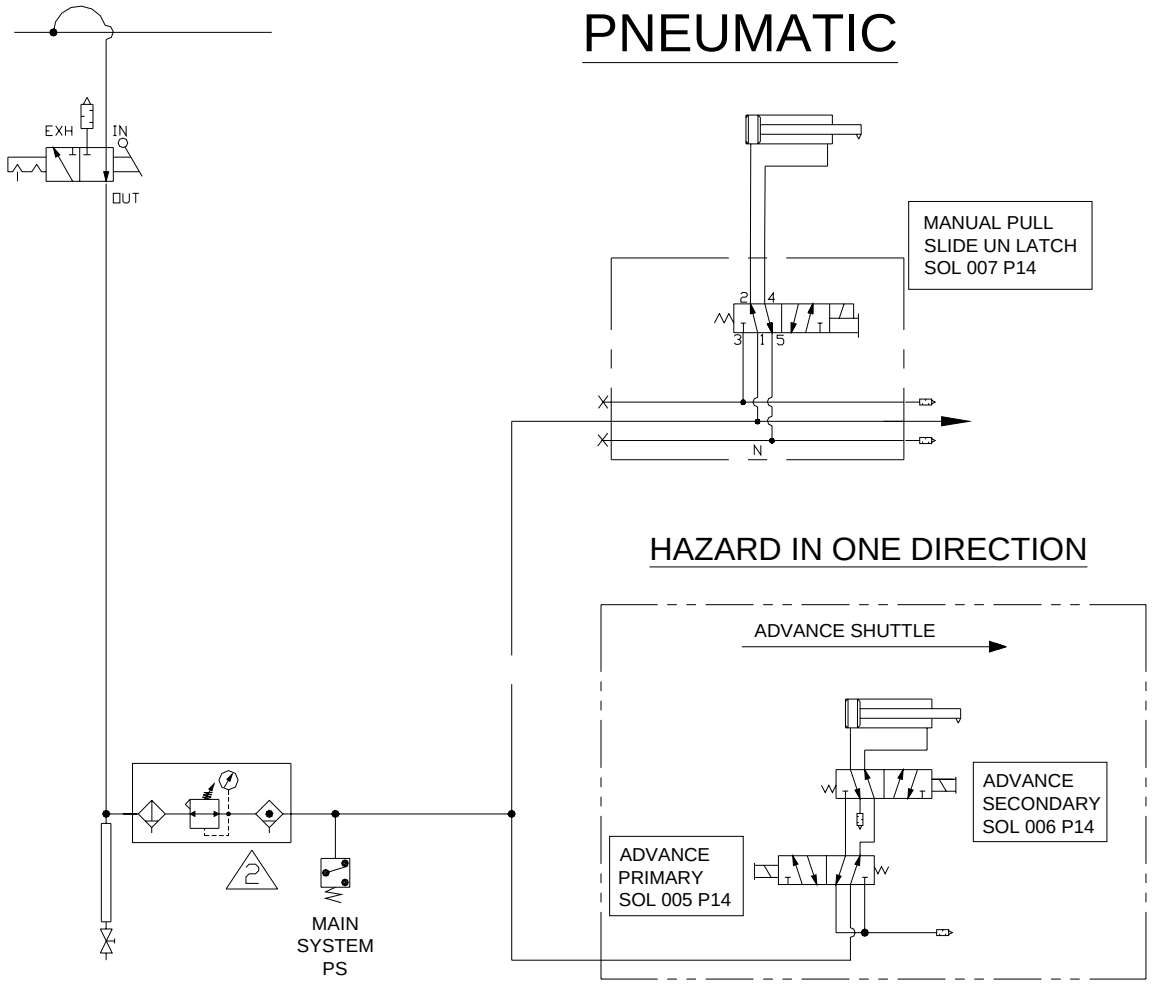


NOTES:

1. The programmable device controls the state of the non-hazardous outputs and is independent of the light curtain safety relay. In this example, the programmable device logic should not allow the valve to energize when the light curtain is open.

10. Fluid Power Circuit Design and Requirements

Sample Circuit: Control Reliable Circuit Performance



NOTES:

1. The valves used in the fluid power circuit **MUST** be direct acting (solenoid driven) valves and **NOT** pilot operated. Direct acting valves are not susceptible to shifting of the valve spool when not under power.
2. The valves **MUST** be mounted in a horizontal plane.

11. Failure Mode Considerations

Control Reliable circuit applications are by definition to be implemented in hardware and not controlled by a PLC[20]. The machine discussed in this document uses a light curtain to provide both the safeguarding function and cycle initiation function (PSDI). This PSDI function requires an interface to the PLC for determination of *when* to initiate the cycle, yet it keeps the safety portion of the circuit as hardwire component based.

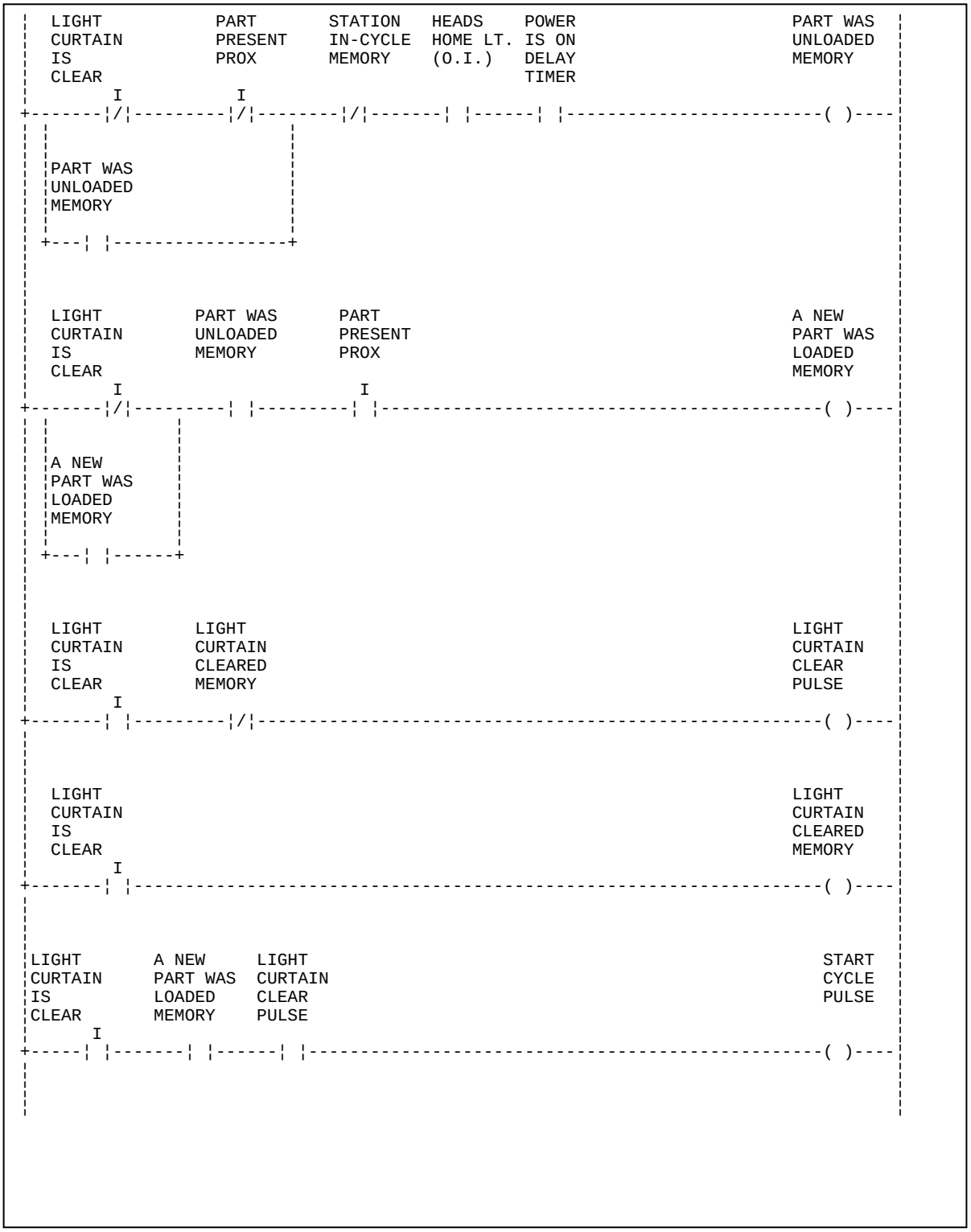
Normal Mode of operation: The operator places a part in the nest by reaching through the light curtain. When the light curtain is clear (operator exits) and there is a part present, the PLC initiates a cycle. Upon cycle complete, the operator reaches in and removes the assembly. When the light curtain is clear again (operator and part exits), the PLC remembers the state change of the part present sensor and is ready for new parts to be loaded.

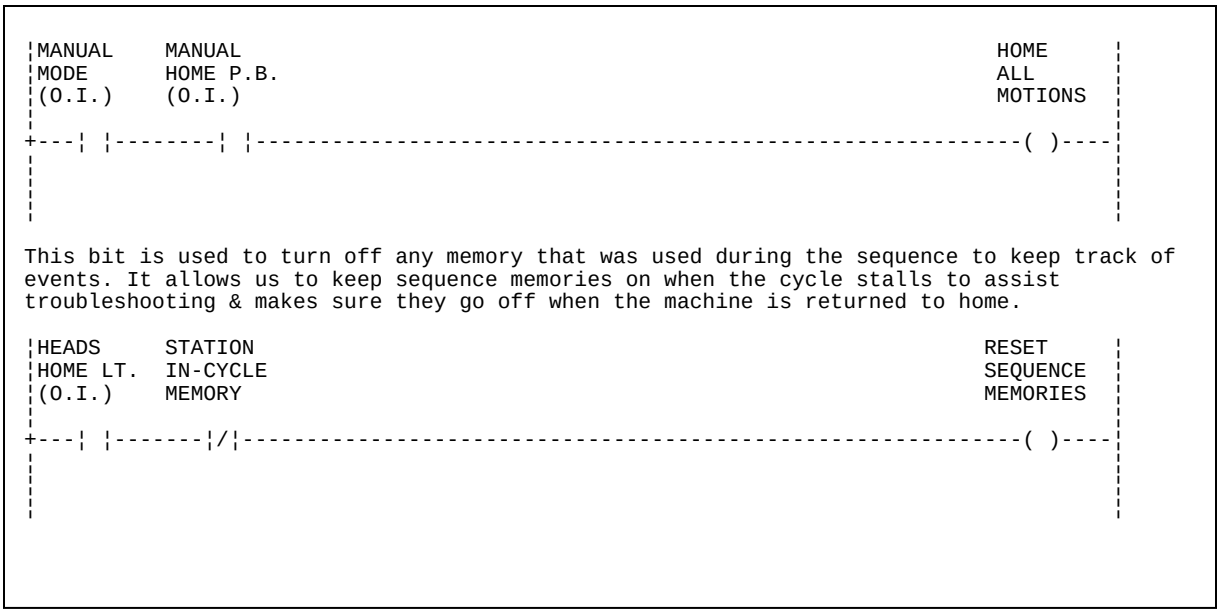
Failure Modes: If the part present sensor should fail in the "***Always Off***" state (wire detachment, general device failure, misalignment, etc.), the machine will simply not cycle. However, it may fail in the "***Always On***" state due to reasons that are device-specific; one example would be ferrous debris stuck to a greasy proximity sensor. In this case, self-checking[21] logic must be implemented that looks for a change of state in the sensor each time the light curtain input cycles. If detected, the PLC logic will not initiate a cycle and may annunciate the 'fault' to the operator. This will also inhibit automatically double cycling (anti-repeat) on a part that has not been removed from the machine.

[20] DA-2001 item 5.1.4
[21] DA-2004 section 21.2

12. Logic Design Considerations

This example incorporates part present sensor error proofing. The sensor must change state each cycle in order for another one to begin.





This bit is used to turn off any memory that was used during the sequence to keep track of events. It allows us to keep sequence memories on when the cycle stalls to assist troubleshooting & makes sure they go off when the machine is returned to home.

Annex A Design Verification of Safety Circuit

1. Safety Circuit Design Verification Checklist

			Is type and design of components compatible with operational and safety requirements?
Y	N	NA	• Light Curtain per Section 4.3?
Y	N	NA	• Safety Relay (Refer to *Specification for the Application of Safety Circuits*, section 4.1)
Y	N	NA	Are components applied consistent with manufacturers' recommendation?
Y	N	NA	Has the supplier calculated or tested the stop time?
Y	N	NA	Are safety circuits consistent with circuit performance - risk assessment (i.e. control reliable)?
			Are safety circuit designs consistent with the *Specification for the Application of Safety Circuits* requirements?
Y	N	NA	• Control reliable safety circuit, electrical section 5.1.4 and fluid power 8.1.4?
Y	N	NA	• General requirements, electrical section 5.2 and fluid power 8.2?
Y	N	NA	• Safety relay output, section 5.4?
Y	N	NA	• Emergency stop, section 5.6?
Y	N	NA	• Light curtain, section 5.9
Y	N	NA	• Pneumatic, annex C, sheet C9?
Y	N	NA	• Hydraulic, annex D, sheet D5-D7?

2. Safety Circuit Construction Verification Checklist

Y	N	NA	Were manufacturers' recommendation for mounting and alignment followed?
Y	N	NA	Are all connections between safety devices and safety circuits wired per the approved prints?
Y	N	NA	Does the barrier guarding prevent reaching over, under, around or through a barrier into the point of hazardous motion?
Y	N	NA	Where fixed guarding is used in conjunction with the light curtain, does it require a tool be used to install/remove the guard?
Y	N	NA	Is light curtain installed to prohibit a person from placing their body between light curtain and hazard?
Y	N	NA	Is light curtain implemented in straight-line configuration?

3. Initial Operation Verification Checklist

Y	N	NA	Has a test tool been made available and the operator given instructions for it's use?
Y	N	NA	With the machine at rest and using the specified test piece, follow the light curtain manufacturer's recommended test procedure and verify that the light curtain is operational throughout the physical ranges of the transmitter and receiver. Banner for example, recommends that this test be performed at every power-up, shift change and machine set-up change.
Y	N	NA	Remove power to the light curtain and verify that the light curtain goes to a lockout state (all outputs immediately de-energize). Verify that the light curtain outputs do not re-energize until the light curtain's reset is performed.
Y	N	NA	With the machine in motion, does the hazardous motion(s) stop if the light curtain is interrupted?
Y	N	NA	Has a stop-time measurement device, such as the Gemco model 1999 Semelex SE-3-E Safetimer test set, been used to verify machine stopping performance?
			With the machine at rest, the associated hazardous motion(s) cannot be re-initiated with:
Y	N	NA	• the light curtain interrupted?
Y	N	NA	• a rest button being tied down?
			Verify Presence Sensing Device Initiation (PSDI) control:
Y	N	NA	• cycle initiates only in auto mode
Y	N	NA	• PSDI cycle initiation timer functional with correct time
Y	N	NA	• auto mode disarmed with E-stop, cycle overtime fault and light curtain interrupted prior to end of cycle
Y	N	NA	• sequence of events with part presence sensors and light curtain interruption function consistent with design
Y	N	NA	• anti-repeat circuit captures part presence sensor failure
			Verify that output monitoring, via safety relay, is functional:
Y	N	NA	• with redundant starters, interrupt light curtain while manually overriding one, then the other
Y	N	NA	• With redundant hydraulic valves, interrupt light curtain while manually overriding one of the valves, then the other

Gemco Series 1999 Semelex II Safetimer

"The Series 1999 Semelex II Safetimeter is a self-contained, portable electronic stop time meter capable of measuring elapsed time, stop time (Ts) from 1-9999 milliseconds. It also calculates the minimum safety distance (Ds) based on the OSHA formula, as understood by the factory, and will display up to 999.9 inches to the nearest 0.1 inches"

Annex B Safety distance formula

1. Light Curtain formula

The following safety distance formula is suggested in ANSI B11.19-1990 and should be used to calculate the minimum safe distance to mount the light curtain from the hazardous motions:

$$D_S = K \times (T_S + T_C + T_r + T_{bm}) + D_{pf}$$

D_S = Minimum safety distance between the device and the nearest point of operation hazard in inches.

K = Hand speed constant of 63 inches per second

T_S = Stopping time of the equipment at the final control element (seconds).

T_C = Response time of the control system (seconds).

Note: T_S and T_C are usually measured by a stop-time measurement device such as the Gemco model 1999 Semelex SE-3-E Safetimeter test set .

T_r = Response time of the safeguarding device (seconds). This response time is available from the manufacturer of the device.

T_{bm} = Additional time required in press applications for the brake monitoring to compensate for variations in normal stopping time. Refer to ANSI B11.1-1988 for information on press brake monitors.

D_{pf} = Added distance due to the penetration factor as shown on chart 1. The minimum object sensitivity is stated by the light curtain manufacturer. When beam blank outs or floating-window features are used, these figures should be added to the object sensitivity figure before using chart 1.

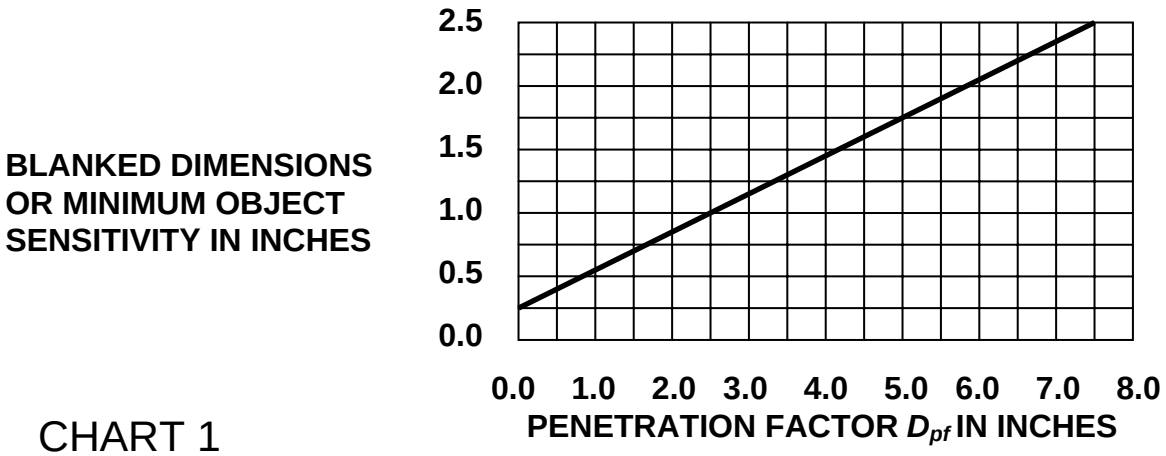


CHART 1

Annex C Bibliography

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IEC-61496, *Safety of Machinery – Electro-Sensitive Protective Equipment*