We get technical

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contents

Editor's note

The manufacturing floor has the potential to be one of the most dangerous places on Earth. Without proper mitigation through safeguards and strict adherence to safety regulations workers in this environment face serious bodily harm or worse. This magazine will go over technologies and solutions that can help to reduce those dangers to your workforce. Whether you are implementing a collaborative robot or just guarding entry to a metal forming press, the products and technologies featured in this collection are just a small selection of solutions available to customers to find here at Digikey.

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Safety in manufacturing

Written by:
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As manufacturing continues to become increasingly automated, manufacturers continue to look for ways to protect their most important asset: their workforce. Robots, autonomous ground vehicles, material handling equipment, and more complex systems can create more dangerous workspaces than ever before without the proper safeguards installed on the production floor. There are many forms of safety devices available today–the below are just a couple to get you thinking about the options available to you.

E-Stops (emergency stops) are one of the most recognizable and most commonly thought of safety devices on the production floor. Think of them as the immediate interface to stop a machine. The E-Stop is typically in a normally closed position within a circuit that when pressed opens the circuit and cuts power to the device. To re-engage the circuit, the E-Stop must be pulled out or in a twist to open configuration returning the circuit to operational. According to OSHA, ANSI, NFPA79 and ISO 13850, IEC 60204-1, E-Stops are required to be installed where they are easily accessible to the operator and resetting the E-Stop should not allow operations to resume. A second redundant action is required such as an all-clear function through a circuit on the PLC (programmable logic controller).

Door interlocks are another physical safety device commonly integrated on the production floor. Safety interlocks are used on physical barriers such as gates and doors. The Safety interlock, much like the E-Stop, operate in a normally closed circuit. When the gate or door is opened, the circuit is interrupted, and all work is halted. Interlocks are required to meet ISO 14119 and ISO 13849.

Another form of safety is an operator presence trigger. These come in many shapes and sizes. For example, in a safety mat. A safety mat is activated by the presence of someone standing on the mat. This can be utilized in a few different ways. It may trigger a machine to stop, go in reverse or deactivate when presence is detected. This helps to ensure that human workers are out of the way, allowing the machine to operate.

Laser safety scanners have become very popular with the rise of cobots. The scanner uses a 360-degree beam that indicates how close a worker or an object are in relation to the robot. Usually with set zones the robot will decrease speed depending upon the closeness of the individual or object. In the orange or yellow zone, the robot is slowed to collaborative speed until the object or person have exited. If the red zone is triggered, the robot will then slow or even stop completely until safe.

Light curtains are especially effective in areas where crushing or pinching hazards exist such as hydraulic presses. The light curtain uses photoelectric beams that project from a transmitter to a receiver. If the beam is broken, all work stops immediately until the obstruction is cleared. Light curtains are particularly effective when solid gates or barricades are impractical. They come in a variety of sizes and levels of sensitivity to fit the needs of the manufacturer in meeting OSHA standards.

Safety PLCs are a way to program in safeguards in the way that they monitor the health of a line. Through redundancies, the safety PLC is designed to run diagnostics to determine if a part of the line or a component is faulty. If an event such as a broken wire or motor is running outside of spec, the safety PLC will immediately shut down the entire affected system to help prevent injury or damage. The safety PLC must adhere to a specific SIL (safety integrity level) and must meet IEC 62061, ISO 13849-1, and IEC 61058.

These are just some of the many safety devices available to manufacturers and installers today. There are many more. When automating a process, it is absolutely necessary to seek advice from a safety expert and consultant to ensure you have covered all of the possible hazards within your facility to protect your workforce and investment. These experts and consultants can help you to navigate OSHA, ANSI, and all other safety regulatory agencies.

About the author

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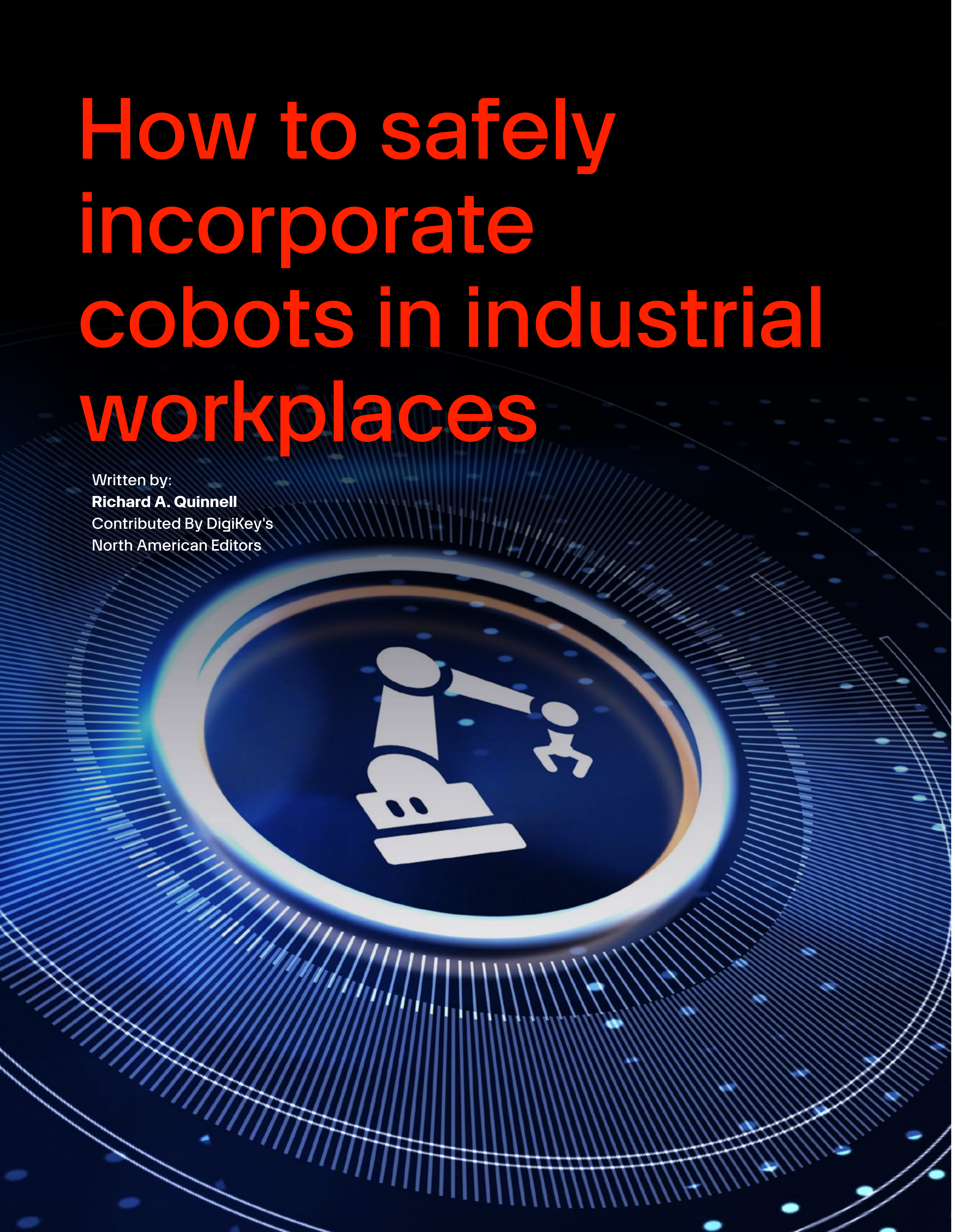
How to safely incorporate cobots in industrial workplaces



Written by:
Richard A. Quinnell
Contributed By DigiKey's North American Editors

Compact industrial robots are now available that can be cost-effectively integrated into even small production lines. Part of their appeal is that such robots can collaborate with a human operator to offload repetitive tasks that would otherwise tire the operator and lead to mistakes. The problem is that working in close proximity to a moving machine poses safety risks for humans.

The key to keeping collaborative robots (cobots) safe is to carefully consider the risks involved and configure the robot and its control system to mitigate potential hazards. Fortunately, technical specifications are now available to help guide developers along the path to safety.

This article looks at the advantages of adding cobots to a working environment and points out the safety concerns before describing the recent regulatory guidelines and presenting risk assessment and mitigation strategies. It then introduces cobots with built-in safety mechanisms that allow them to be safely added to any production or workflow environment.

Why add collaborative robots?

Industrial robots in major manufacturing facilities have long proven their worth in terms of increasing production throughput while reducing costs. Now compact, generalized industrial robots are bringing such benefits to mid and small scale production. Unlike their larger scale counterparts, however, compact robots are designed to operate in cooperation with their human operators rather than in isolation (**Figure 1**). The two share a workspace, helping to minimize the robot's use of valuable production floor space and improve its cost-effectiveness.

Figure 1: Small industrial robots are designed to operate in cooperation with humans rather than in isolation. (Image source: KraussMaffei/ KUKA Robotics)

Like all powered machinery, these cobots have the potential to cause injury if not utilized properly. Integration of a cobot into a production line, then, requires that careful consideration be given to the issue of operator safety. Factors to keep in mind include the robot's range and speed of motion, the materials it is handling, and the operator's method and frequency of interaction. Once those are understood, appropriate safety-enhancing features can be incorporated into the system design.

Regulatory requirements from organizations such as OSHA (Occupational Safety and Health Administration) in the US, CCOHS in Canada, and the European Commission mandate some elements of cobot operational safety. OSHA 29 Code of Federal Regulations (CFR) 1910, for instance, calls for systems to lock out hazardous energy sources during servicing operations (Section 147) and to prevent electrical shocks from occurring during operation (Section 333). Such regulations, however, were developed to apply to all forms of industrial machinery and have not necessarily kept pace with technology. There is relatively little regulation specific to industrial robots in general or cobots in particular.

Industry has filled the gap, however, by developing several technical standards specific to industrial robots. These include the IEC

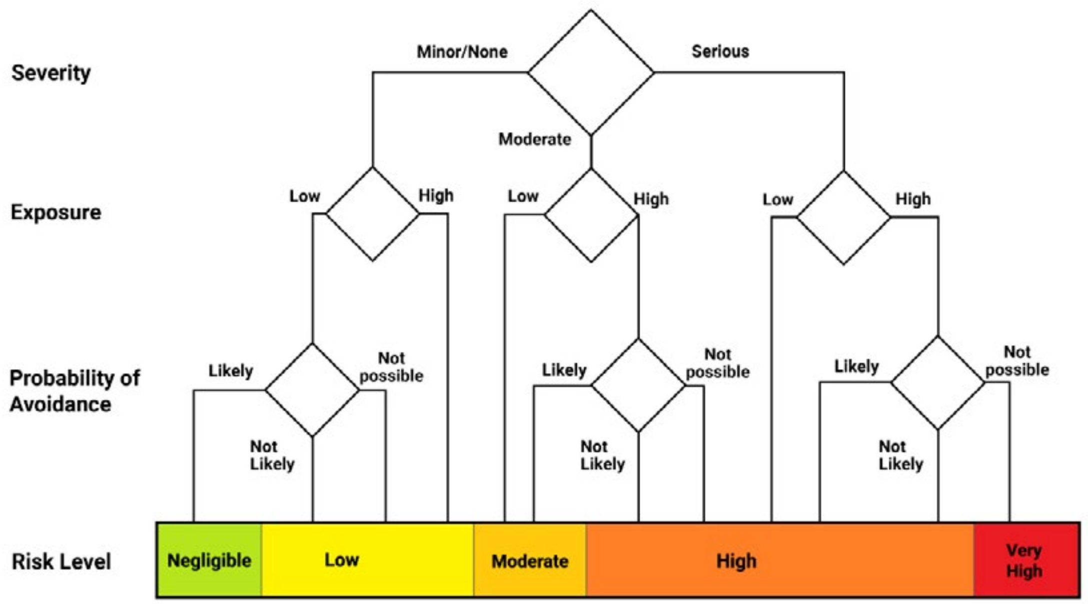


Figure 2: Risk level assessment requires examining the severity and likelihood of possible injuries. (Image source: Richard A. Quinnell)

61508 standard on functional safety, the ISO 12100 standard on design for machine safety, and the ISO 10218-1 and -2 standards on safety for industrial robots. Most recently, industry has released the ISO/TS 15066 technical standard on collaborative robot safety. Only some sections of these standards are defined as requirements for robotic system design. The rest are recommendations that provide developers and operators with detailed guidelines for ensuring safe interaction of robots and humans.

Cobot risk assessment

The road to cobot safety begins with a careful risk assessment of the intended robotic operation and usage model—not just of the robot itself, but the entire application and operating environment. A robotic system handling sharp-edged sheets of metal, for instance, creates different risks than those of a system handling cardboard boxes. Similarly, risk assessment for a robot equipped with a gripper will differ from that of a robot with a drill or soldering iron.

Thus, developers must fully understand the system's scope of operations, the robot's movement characteristics, the workspace and workflow, and other similar factors in order to identify the potential risk sources in robot operation. These sources include any possible robot-human interaction—whether intended, inadvertent, or resulting from equipment failure—that might result in an injury of some kind.

Once the risks are identified, each must be evaluated. This evaluation categorizes each such interaction as a negligible, low, medium, high, or very high risk using three key criteria:

- Severity of potential injury
- Frequency and/or duration of exposure to the hazard
- Probability of avoiding the hazard

A representative risk evaluation tree is shown in **Figure 2**. The severity of injury ranges from minor, such as cuts or bruises that completely heal in a few days, to serious, resulting in permanent damage or death. Exposure ranges from low (occasional) to high (frequent or continual), and avoidance probability ranges from likely to not possible. Evaluators can quantify these criteria in their own way to reflect their specific circumstances.

One of the insights that ISO/TS 15066 has brought to the industry, however, is a quantitative definition of physical contact between robot and human that is non-injurious. This definition is especially important in cobot applications, where physical contact is highly likely or even intended. The standard defines two types of contact: transient and quasi-static (**Figure 3**).

Situations in which the human can readily move away from contact with the robot, such as a robot part bumping against the operator's arm, are considered transient. When the human is trapped between the robot and a fixed object, such as a robotic gripper pressing the operator's hand against the tabletop, the contact is considered quasi-static.

The limits for force of contact in a cobot application are based on the human threshold of pain. Collaborative robots must be configured so that any contact, intended or otherwise, will be below the pain threshold. Force limit values vary depending on what body part is involved. Head contact has a much lower pain threshold than arm contact, for instance. Further, quasi-static contacts have lower thresholds than transient contacts.

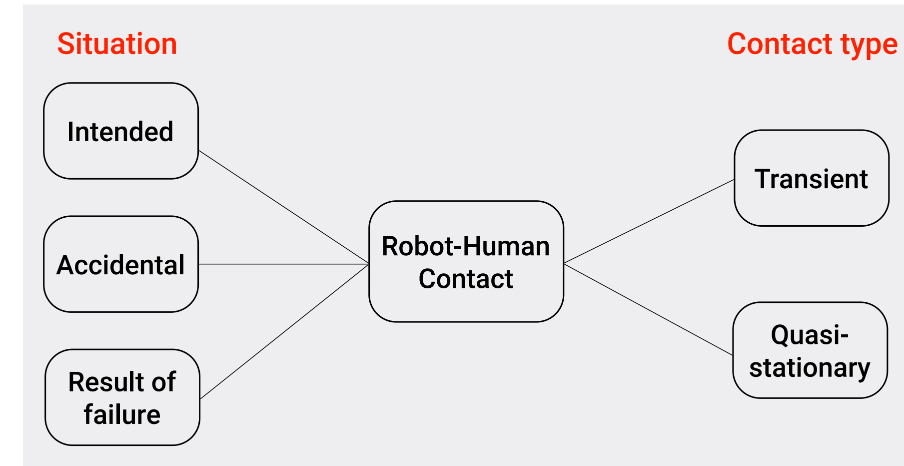


Figure 3: Robot-human contact—accidental or anticipated—falls into two categories: transient and quasi-stationary. (Image source: Richard A. Quinnell)

Once risks have been identified and evaluated, the critical question to ask for each is, "Is this an acceptable level of risk?" In most cases, a negligible or very low risk is tolerable and everything else will require one or more forms of mitigation.Choosing an appropriate form of risk mitigation followed by re-evaluation of the risk are thus the next steps along the road to robot safety, to be repeated until all risks have been reduced to acceptable levels.

Risk mitigation avenues

Some of the most preferred methods for risk mitigation include redesigning the process or layout of the robotic workspace to eliminate the hazard or to minimize exposure by limiting human interaction with the robot. Traditional industrial robot applications have limited human-robot interaction by using cages to keep humans out of the robot's workspace with interlocks to shut down the robot when a human enters the workspace. For cobot applications, where robots need to share a collaborative workspace with humans, other methods are needed.

The industry has identified four key approaches for collaborative robot-human interaction:

- Safety-rated monitored stop
- Hand-guiding
- Speed and separation monitoring
- Power and force limiting

Developers will need to determine which approach or combination of approaches best fits their application.

The safety-rated monitored stop works well in applications where the operator interacts with the robot only under specific conditions, such as loading or unloading the robot's end-effector or performing inspections on work in progress. In this type of interaction, the robot operates autonomously within a protected workspace that is monitored to detect any human presence. The human operator initiates a safety-rated stop before entering that workspace, and while the operator is within the workspace, the robot remains powered but stationary. When the operator exits the workspace, the robot automatically resumes its autonomous operation. Should someone enter the monitored workspace without initiating the safety-rated stop, the system will initiate a protective stop that will shut down system power.

In the hand guiding scenario, the operator initiates a safety-rated stop before entering the robot's workspace, then goes on to use a hand guiding mechanism to reposition the robotic arm before triggering the robot's next operation. The hand guiding mechanism may involve simply grasping the robot arm and manipulating it, or it can involve the use of a handheld control device to command the robot's motion. An application such as robotic lift assistance can utilize a hand-guided collaboration.

Speed and separation monitoring are useful in situations where the operator and robot frequently share the same workspace and the operator is able to move freely within that space. In this scenario the system monitors the human's distance from the robot, working to maintain a minimum protective separation distance at all times (**Figure 4**). When the two are at a safe separation distance—so that there is no possibility of contact—the robot is free to move at full speed. Should the separation lessen, the robot continues working but slows, serving to reduce the effort required to bring the robot to a complete stop. When the separation becomes too small, the robot comes to a safety-rated stop to ensure that there is no possibility for it to cause an injury.

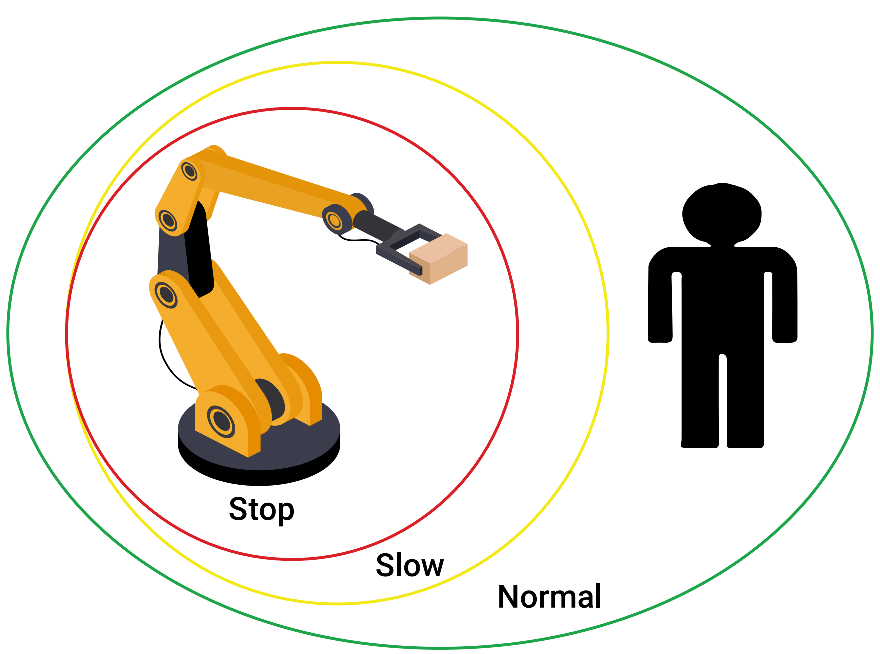


Figure 4: Speed and separation monitoring identifies zones around the robot that define its safe operation. (Image source: Richard A. Quinnell)

Defining the distances for each stage in this approach requires understanding the robotic system's movement capabilities. The system should be designed so that once the monitors detect a human moving toward the protected space, the robotic mechanisms come to a complete stop before the human can reach that space. In order to calculate suitable separation distances, developers need to know:

- How fast the robot and human move
- The system's reaction time to detect the potential intrusion
- How long it takes for the robot to stop moving after it receives a command

The workspace layout can help simplify the definition and monitoring of safety zones for the speed and separation monitoring approach. In one example, the layout creates inherent safety zones (**Figure 5**). A workbench separates the human from the robot's operating space, in which the robot

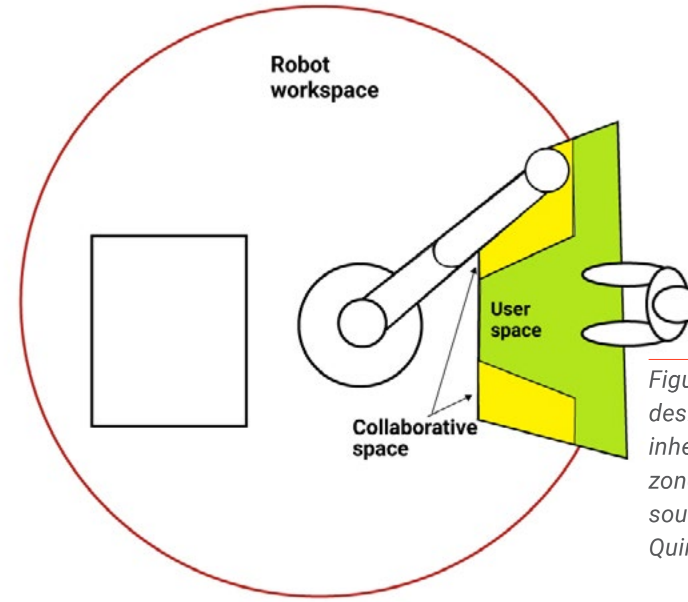


Figure 5: Workspace design can create inherent safety zones. (Image source: Richard A. Quinnell)

can freely move at full speed. The robot can automatically reduce speed when it enters the collaborative areas at the sides of the workbench, which are laid out to limit opportunities for quasi-static contact. The reduced speed minimizes risk in this area by reducing potential transient contact force and maximizing the opportunity for avoiding any hazards.

Mechanical stops can prevent the robotic mechanism from ever entering the human's operating area, eliminating risk. Such an arrangement would require only minimal monitoring of the robot's operating space for human intrusion to ensure a high degree of system safety.

The power and force limiting approach is especially useful in applications where human-robot contact is highly likely. To use the approach, the robot must be capable of sensing when unusual forces have been applied to the mechanism so that it can detect and react to contact. The robot should also be designed to minimize potential contact force, such as by avoiding sharp edges and pinch points, incorporating surface padding, and limiting movement speed.

The application should be designed so that contact is infrequent and avoidable, with care taken to evaluate what types of contact (transient or quasi-static) might occur and what body parts might be involved. The application design should also aim to minimize the opportunities for quasi-static contact and prevent contact with head, neck, or throat altogether.

Robotic system safety features

Developers selecting a robot for a collaborative application should keep in mind how they might implement one or more of these mitigation methods. The robot's physical design as well as the systems that control it are all factors to evaluate in determining how readily safety measures can be implemented. Typically, however, robot vendors have worked to make their systems safety ready.

For example, the Agilus robot kit family from KUKA, includes a smartPAD touch operator panel for hand-guided control and the KR C4 system controller with integrated safety features. The optional KUKA.SafeOperation software completes the package. The kits' arms come with various reach lengths, including 540 millimeters (mm) (KR 3 R540), 900 mm (KR 6 R900-2), and 1100 mm (KR 10 R1100-2) (**Figure 6**).

Figure 6: Compact industrial robots such as the KUKA Agilus KR 3 are designed with safety as a major consideration and can safely share workspace and collaborate with human operators if industry standards are followed during setup. (Image source: Kuka Robotics)

Figure 7: The KUKA robot kits include a smartPad touch operator panel to enable hand-guided control where appropriate. (Image source: KUKA Robotics)

All three robots are designed with rounded surfaces under energy absorbing padding to minimize the pressure of contact. Joints are covered to eliminate any pinching hazards. The robots also offer adjustable mechanical stops for key movement axes so that developers can physically restrict the robot's operating space.

The included smartPAD helps address applications where hand-guided operation is required (**Figure 7**).

The KR C4 controller comes with integrated safety software that includes routines for implementing safety-rated and emergency stops as well as an ability to monitor industry standard external sensors, establishing a safety fence. In addition, the software can internally monitor the robot's position and movement around any of its motion axes.

KUKA.SafeOperation software enhances this internal monitoring by allowing developers to define a fixed operating cell: a convex polygon with three to ten corners outside of which the robot should never move (**Figure 7**). In addition, developers can define up to 16 monitoring spaces within that cell using either Cartesian or axis-specific coordinates.

To further refine position-related safety monitoring, the SafeOperation software allows users to model the end-effector tool on the robot's mounting flange as a collection of up to six user-defined spheres. These spheres move with the robot arm. If the arm or the tool spheres move into or out of the monitoring spaces during operation, the software will respond. Possible responses include signaling an alarm, slowing the robot's motion, or implementing a safety stop. Developers can thus readily control how the robot behaves anywhere within its range of motion.

Such features simplify the implementation of risk mitigation schemes, but do not in themselves ensure safe human-robot interaction. Developers seeking to integrate a robotic system into their production workflow, especially in a cooperative application, must do the work of risk assessment and mitigation, much of which will be specific to their application. This effort includes following all manufacturer guidelines and restrictions, properly training users, and implementing monitoring systems and barriers as needed.

Conclusion

Robots and cobots are an increasingly welcome part of manufacturing and other workflows but do present potential hazards that industrial automation developers must take into account. While newly developed standards for robot safety do help, the availability of robotic systems that have been built from the ground up with safety as a prime consideration makes the integration of robots into a workflow much easier, and safer.

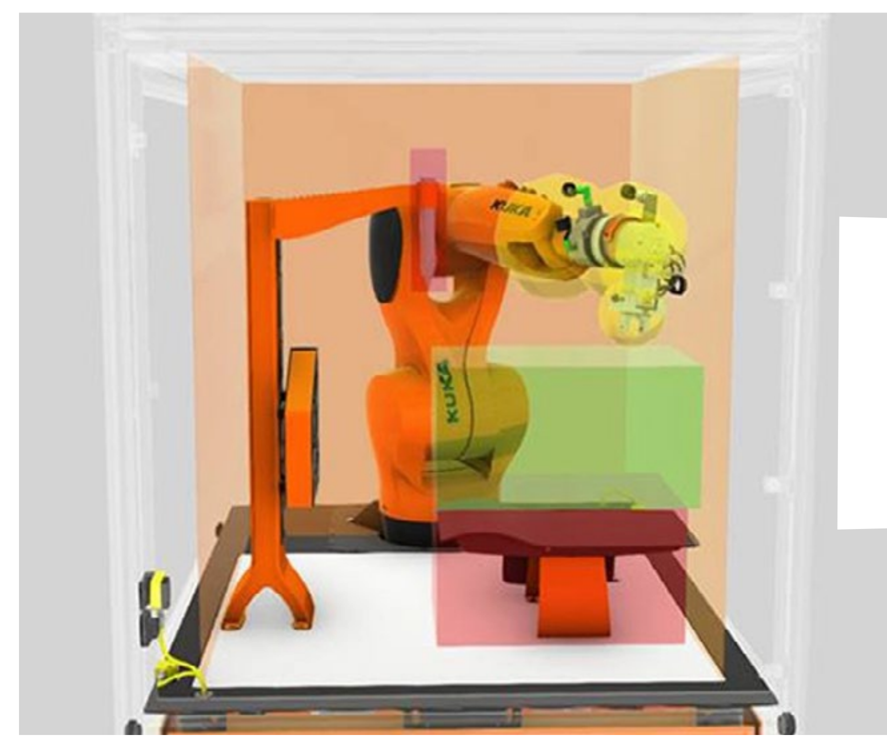


Figure 8: Developers can refine position related safety monitoring using KUKA. SafeOperation software with which they can define an operating area and model end-effector tools. (Image source: KUKA Robotics)

Basic understanding of safety circuits

By Lisa Eitel
Contributed By DigiKey's
North American Editors

This article reviews the basics of safety circuits for automated machinery. The discussion will touch on standards that dictate required features; common setups; mechanisms for addressing faults and preventing tampering; and the functions of components often found in safety-circuit installations.

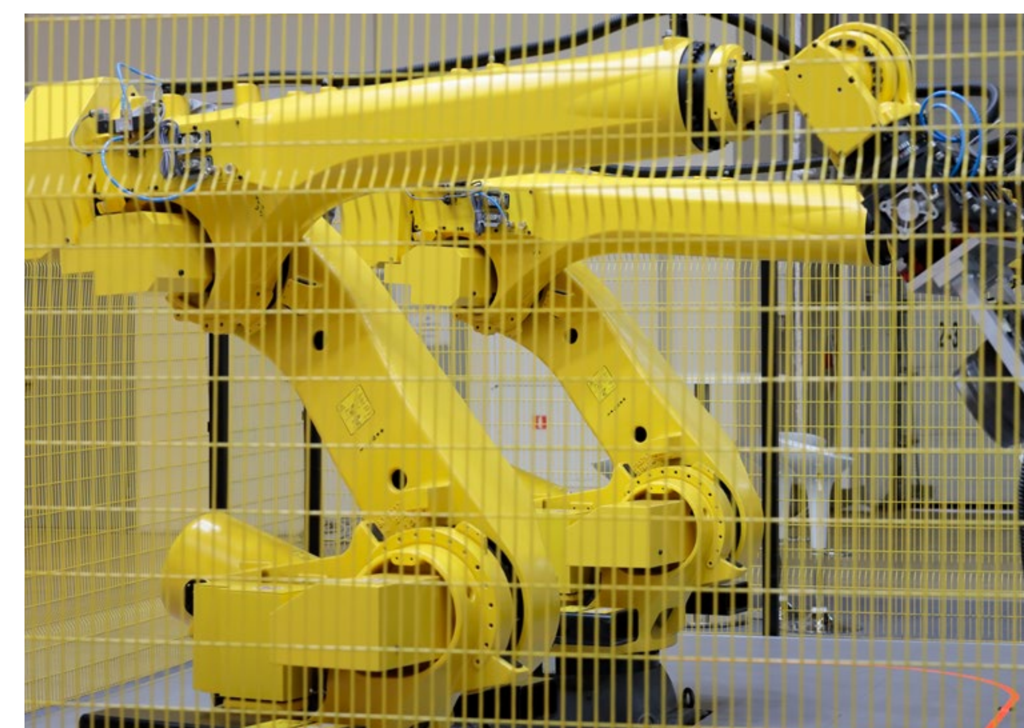
History and function of safety circuits

In the early industrial period, machinery was extremely dangerous. It was common for both factory and agricultural workers to lose fingers, limbs, and even their lives through entrapment in moving machinery. This led to the development of systems of guarding and other safety devices.

Interlocks — which make the state of two or more machine functions interdependent — are core to the function of today's safety systems. These prevent machines from injuring operators or damaging their own components. For example, an interlock may prevent a machine from starting if its guard is open and stop the machine if a guard is opened during operation.

Many simple interlock systems are purely mechanical. For example, in some machine designs, the guard pivots about an axis with an interlock cam attached. When the guard is open, the cam engages with a matching cam on the machine's drive shaft to prevent operation of the axis. That means it's only possible for the machine to operate when the guard is closed.

Most modern machines use electronic safety circuits or even microprocessor control to implement interlock safety



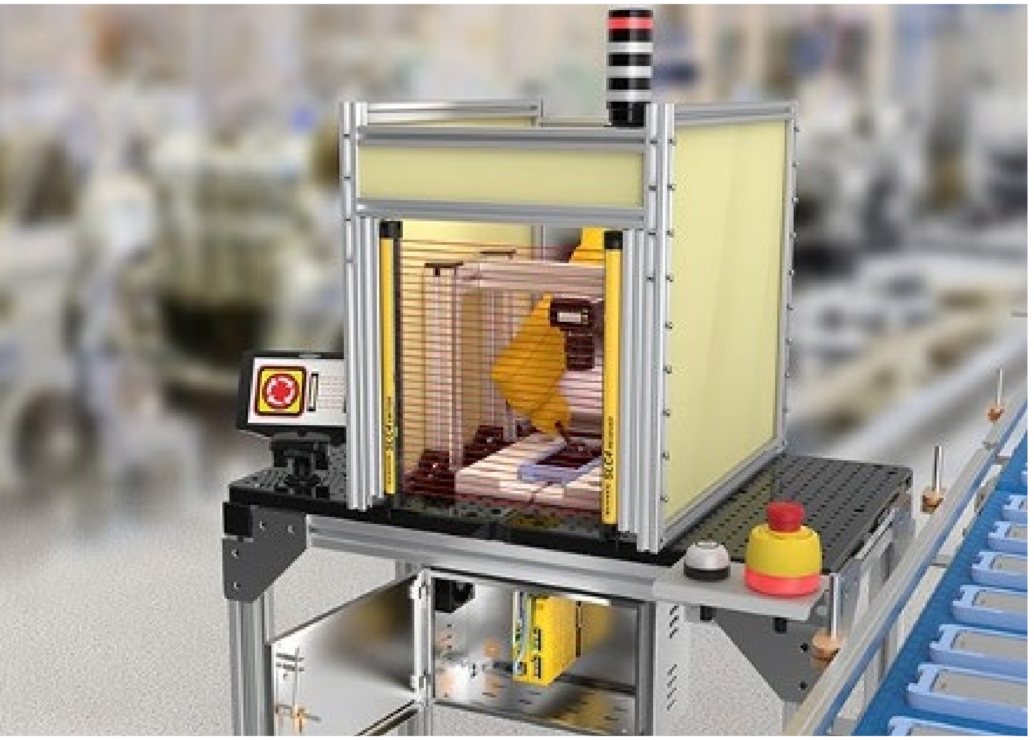


Figure 1: Shown here is a Banner Engineering SC10 Series safety controller designed to deliver the functionality of three safety relay modules. (Image source: Banner Engineering)

systems. Electronics give far greater flexibility in the arrangement of guards and the complexity of safety procedures than mechanical solutions.

Typical electronic safety circuits only allow the machine to operate if the circuit is closed — a structure called *normally closed* (NC) operation. They also wire safety components in series to maximize effectiveness and minimize complexity and cost.

Consider a typical safety installation with a number of position switches that are NC when the corresponding section of guard is closed. These position switches are wired into the installation in series so that if any section of the guard is not closed properly, the whole circuit will be open, and the machine will not run. In fact, controls in a safety circuit also require series wiring to ensure safe conditions in the event of any loosening of connections or sudden breaks in (such as severing of) the safety-component wiring.

One caveat related to the series wiring of safety circuits: when a circuit contains more than four safety switches or includes frequently used switches or gates, there's a decrease in the design's performance level (PL_r — which is detailed in the next article section) as well as an increased risk of *fault masking*. The latter is when the emergence and resolution of one open switch or fault obscures the presence of another open switch or fault. Fault masking is most likely to occur where an installation includes volt-free contacts such as relays having no other power connections beyond that for the switch connection. Where such risk is unacceptable, more sophisticated wiring systems and methodologies may be necessary.

Trapped-key interlocks are often used to ensure that all guards are locked shut before operating a machine. In these systems, locks on each safety guard have keys which can only be removed when the guard is barred shut. The keys can then be taken to the control or power unit and used to activate the machinery. Similarly, the keys are held captive while the machine is activated and can only be removed from the power unit after the machine has been shut down. The keys can then be used to open the guards again.

Risk assessments and the requirements of governing standards

ISO 14119 covers the safety of machinery with interlocking devices associated with guards and outlines design and selection principles to ensure machinery safety. It refers to other standards for general principles of risk assessment and risk reduction in the design of machinery.

The basic function of an interlocking guard is to prevent the execution of hazardous operations it covers until that guard closes. So, if something or someone forces the guard open during operation, the guarded operation should stop. In some cases, a guard-locking device may be fitted to prevent opening of the guard during machine operation.

It should be noted that although machines can operate when the guards are closed, the closure of a guard shouldn't trigger the beginning of a hazardous operation. Instead, such operations should require a separate start command. One exception is something called a control guard — a special type of interlocking guard with a start function capable of starting a hazardous operation when the guard is closed, without a separate start command.

Also covered in ISO 14119 is the concept of a safety-system defeat. This is an action that bypasses a machine's interlocks. For example, an operator may accidentally or deliberately rest a heavy object on a position switch while the guard is open, which in turn may grant access to workspaces that become dangerous when the machine is in operation. Properly designed safety systems make it impossible to defeat interlocks in any reasonably foreseeable manner — either manually or with readily available objects nearby. This includes the removal of switches or actuators using tools that are used to operate the machine or are readily available such as screw drivers, hex tools, adhesive tape or wire. This also means that spare keys should not be accessible for trapped key systems.

ISO 14119 puts interlocking devices into four categories:

- **Type 1** interlocking devices have mechanically actuated position switches with uncoded actuators such as a rotary cam, linear cam, or hinge. These are relatively easy to defeat by resting an object on the switch or holding it in position in some other way.

All design work on a machine incorporating safety should start with a risk assessment according to ISO 12100 to identify hazards and estimate risks.

- **Type 2** interlocking devices have mechanically actuated position switches with coded actuators such as a shaped actuator (tongue) or trapped-key. These are considerably more difficult to defeat.
- **Type 3** interlocking devices have non-contact position switches with uncoded actuators such as proximity switches. The difficulty involved in defeating Type 3 interlocks depends on the actuation principle involved. Capacitive, ultrasonic and optic actuators can be defeated by a wide range of objects. Inductive actuators may be defeated by any ferric metal object. Magnetic actuators require a magnet to defeat them.
- **Type 4** interlocking devices have non-contact position switches with coded actuators, such as RFID tags, coded magnets or coded optical tags. These are extremely difficult to defeat if properly constructed so that the coded actuator cannot be removed.

When designing a safety circuit, interlocking devices should be selected to minimize the possibility of a defeat. Consideration should also be given to:

- The *overall system stopping performance*, which is the amount of time required for the machine to become safe after a stop command is issued.
- The *access time*, which is the time it takes a person to reach the hazard after the stop command has been initiated.

The overall system stopping performance must be significantly more rapid than the access time. There should also be consideration of whether guards require emergency release, to allow manual opening from outside, or escape release to allow manual release from inside.

ISO 13849 is referenced by ISO 14119, it is in two parts, covering the principles of designing and validating the safety-related part of a control system (SRP/CS). According to this standard, the SRP/CS can be classified according to its:

- Resistance to faults
- Behavior if a fault does occur

All design work on a machine incorporating safety should start with a risk assessment according to ISO 12100 to identify hazards and estimate risks. The risk-reduction process then involves first applying inherently safe design, then safeguards, and finally information for use. Any protective measures that depend on the control system must then be evaluated using a special iterative process. This involves determining the required performance level (PL_r) for each safety function and its mean time to dangerous failure ($MTTF_D$) to determine the reliability of the SRP/CS. Each part may be assigned a performance level from a through to *e* — with PL_a having the highest probability of a dangerous fault and PL_e having the lowest probability. The specific way that the failures may occur involves the considerations set out above for ISO 14119.

Variations on safety-circuits — and some example arrangements

For large enclosures such as gated robotic cells, safety arrangements are a little different. This is because guards are often closed with the operator inside the active workspace. So, in many instances,

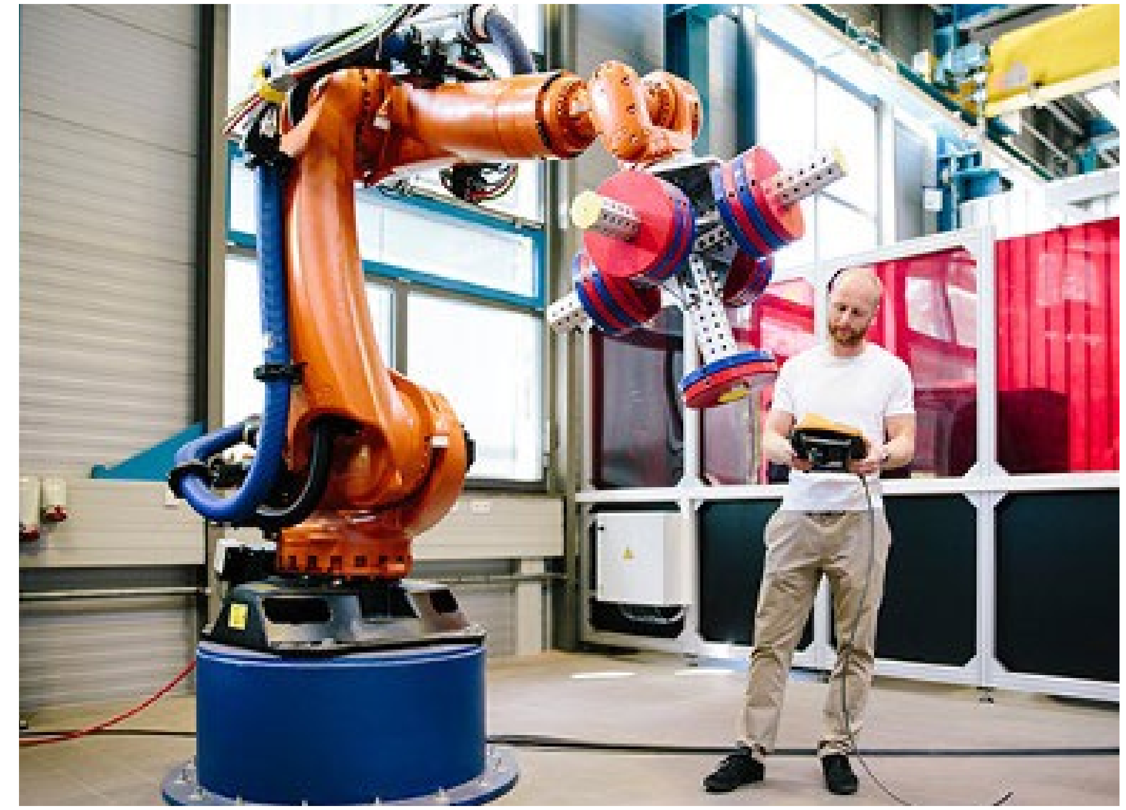


Figure 2: Particularly unique are safety circuits associated with robotics — especially for robotics that employ teach pendants (as shown here) as well as collaborative robots.

trapped-key systems are used to ensure that operators are outside the workspace upon the closing of gates; and only then can the robot begin its full-speed operation.

Of course, traditional robots can typically be operated in a low-speed teach mode with the operator in the cell, but when operating at full speed (unlike collaborative robots) they must not come into close proximity to humans. Even in teach mode, unless the robot is fitted with a force feedback system, there is still the danger of the operator being crushed. The handheld control unit is therefore normally fitted with a *dead man's switch* which will shut down the robot if the operator becomes incapacitated.

Another automation situation requiring specialized safety is personnel-tended conveyor systems. Here, it may be necessary for personnel to work alongside conveyors operating rather quickly. This has a significant risk of entrapment resulting in serious injury, and so should be avoided wherever possible. But where such workspaces are essential to an operation's productivity — as in Amazon Fulfillment Centers, for example — distributed stop switches in the form of pull-cords and stop strips must be installed. These give personnel a reliable means to stop the conveyor along its entire length. Such stops should be arranged so that an operator can easily grab or press them without having to hunt for them during an emergency.

The safety devices should also be positioned so that an injured or unconscious person falling or being pulled into the conveyor automatically triggers a stop. Multiple stop devices and redundant circuits may be required, and where conveyors are accessible from both sides, such safety devices must be present on both sides as well.

Common safety-circuit components

Mechanical switches include position switches, used to detect gate and guarding positions, and manually activated stop switches such as e-stop palm buttons and pull-cords. Non-contact switches, such as light and inductive sensors, may be also used in a similar

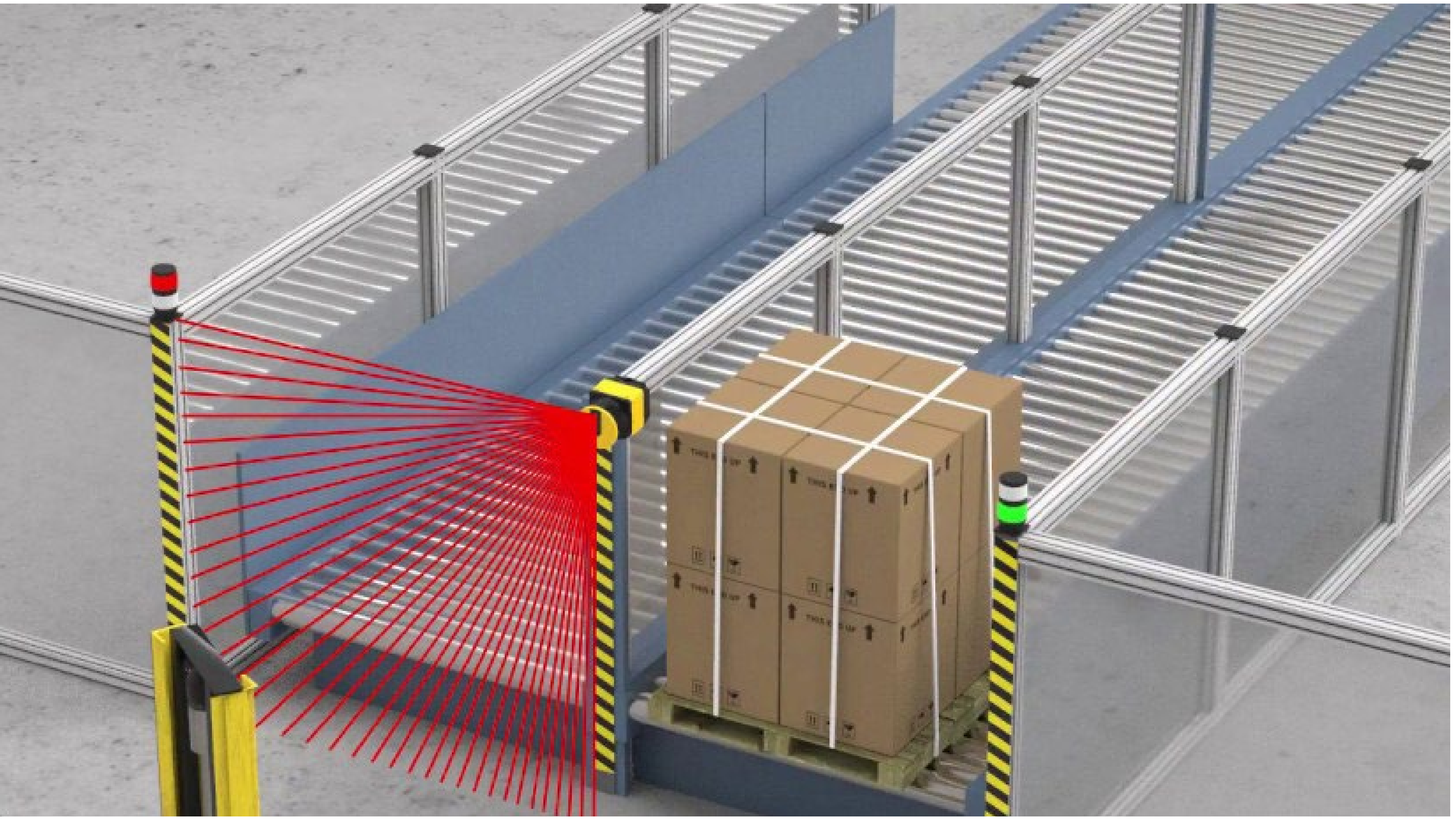


Figure 3: SX Series safety laser scanners from Banner Engineering can safeguard access points and areas in industrial applications. The device continuously scans 275° to protect personnel and machinery with warnings and safety zones customizable with free configuration software. Muting functions are also configurable in this software that, along with muting sensors networked to the SX Series scanner, eliminate the need for an additional module or controller. (Image source: Banner Engineering)

way. These types of interlock components tend to be used with physical guards and gates. They are covered well by the standards discussed above. Other types of safety components that may be used within safety circuits include light curtains, laser scanners, and safety mats.

Safety mats use pressure sensors embedded in a rubber platform to provide a simple way of detecting when a person steps into a guarded area. These have, in recent years, been largely replaced by optical systems such as light curtains and laser scanners.

Light curtains can remove the need for physical guarding by creating a virtual guard to stop a machine axis if any of the curtain's beams are broken. The light curtain consists of two parts — a transmitter and a receiver. The transmitter projects an array of parallel light beams. The receiver detects these beams and if any of them is broken, it triggers a machine stop. Benefits of light curtains include clear visibility of the working area as well as unrestricted access and rapid movement in and out of the protected area.

Laser scanners function much like light curtains. However, instead of having a separate transmitter and receiver to maintain a barrier, laser scanners can monitor gateways as well as portal areas from a single piece of hardware. In other words, light curtains provide perimeter guarding whereas laser scanners provide protection for larger portals into areas such as conveyor and robotic cells. As with all safety components, use of laser scanners requires calculation of the minimum safety distance. This value depends on the overall system stopping performance and the access time. However, the overall system stopping performance is likely to be considerably longer for laser scanners than that for light curtains due to the additional processing involved.

The electronic safety circuits and safety components of today afford plant and OEM design engineers flexible options for protecting personnel and equipment. Software and other supplier resources help simplify the specification of safety systems for traditional interlock arrangements, workspaces protected by trapped-key designs, and even flexible areas that require plant personnel or machine operators to work in close proximity to conveyors, robotics, and other moving equipment associated with industrial automation.

Component designs to satisfy functional safety standards

Written by:
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Contributed By DigiKey's
North American Editors

Functional safety systems include electronics in the form of sensors, I/O, controls, switches, electromechanical components, fluid-power components, and software that detect dangerous conditions and change the machine state to prevent dangerous situations from arising.

Safety is a top priority in industrial applications to protect employees and equipment from injury and damage. Welding, cutting, and pressing operations as well as high-speed axes and those handling dangerous workpieces or substances pose the most threat. In the U.S., plant operators must satisfy Occupational Safety and Health Administration (OSHA) regulations with safe equipment, operational procedures, and training protocols. Complementing these systems should be plant-specific analyses to identify pragmatic ways to enhance worker well-being and equipment longevity. In addition, automated machinery must satisfy *functional safety requirements* via automatic machine actions or corrections to potentially or certainly unsafe conditions or failures.

Functional safety systems include electronics in the form of sensors, I/O, controls, switches, electromechanical components, fluid-power components, and software that detect dangerous conditions and change the machine state to prevent dangerous situations from arising. First originating in the European Union, today functional-safety design and regulations apply to suppliers, machine builders, and end users around the world. The harmonized European Norm (EN) and International Electrotechnical Commission (IEC) EN/IEC 62061 standard — listed in EU Machinery Directive 2006/42/EC — and the International Organization for Standardization (ISO) EN/ISO 13849-1 standard are the most applied.

ISO 13849-1 and IEC 62061 can be cross-referenced, and OEMs and end users are free to use either. The only caveat is that functional safety relates to machines and controls and not devices or components … though the latter may offer functionalities supporting the satisfaction of a given safety rating.

EN/IEC 62061 details requirements and recommendations as safety integrity levels for the design, integration, and validation of permanently installed (nonportable) machine or plant-installation SRECS — consisting of **s**afety-**r**elated **e**lectrical, electronic, and programmable controls. EN/IEC 62061 safety integrity levels (SILs) grade a system's functional safety from 1 (most rudimentary) to 4 (most integrated and sophisticated) with SIL3 the highest possible for machines. Risks dictating the required SIL include the regularity of risk exposure, severity of the potential injury, incidence probability, and likelihood that a machine operator's evasive maneuvers can help avoid harm.

Figure 1: Light towers today use LEDs for efficiency and visibility. Some enhance safety with built-in buzzers to emit a siren to 100 dB during safety breaches. (Image source: Menics)

SIL	Probability of failure on demand	Risk reduction factor
1	0.1 to 0.01	10 to 100
2	0.01 to 0.001	100 to 1000
3	0.001 to 0.0001	1000 to 10,000
4	0.0001 to 0.00001	10,000 to 100,000

Table 1: Required SIL levels depend on the severity of injury should a given unsafe condition occur as well as the likelihood of that condition occurring. (Table source: IEC)

In contrast, EN/ISO 13849-1:2005 details requirements and recommendations based on SRP/CSs — **s**afety-**r**elated **p**arts of **c**ontrol **s**ystems. SRP/CS performance levels allow for quantification of machine safety capabilities no matter the subcomponents. The standard employs well-known performance level (PL) ratings of functional safety — ranging from "a" (most rudimentary) to "e" (most integrated and sophisticated). Risks dictating the required PL include those applicable to SILs as well as the frequencies and durations of repeated exposures to the machine hazard. In addition, a complete PL rating includes a Category number (to indicate the overall system architecture) and the mean time to dangerous failure or *MTTFd*.

IEC 61508 and IEC 62061 satisfaction involves testing safety controls (and validating machine modes, status criteria, and corrections) to confirm the machine's functional safety rating. EN ISO 13849-1 and 2 also demand documented testing (static and dynamic) for confirmation of seamless safety control integration.

Operator-triggered safety components

Many safety-related components are designed to accept input from plant personnel and not through some intermediate section or axis of a machine or guard. These include tactile safety mats,

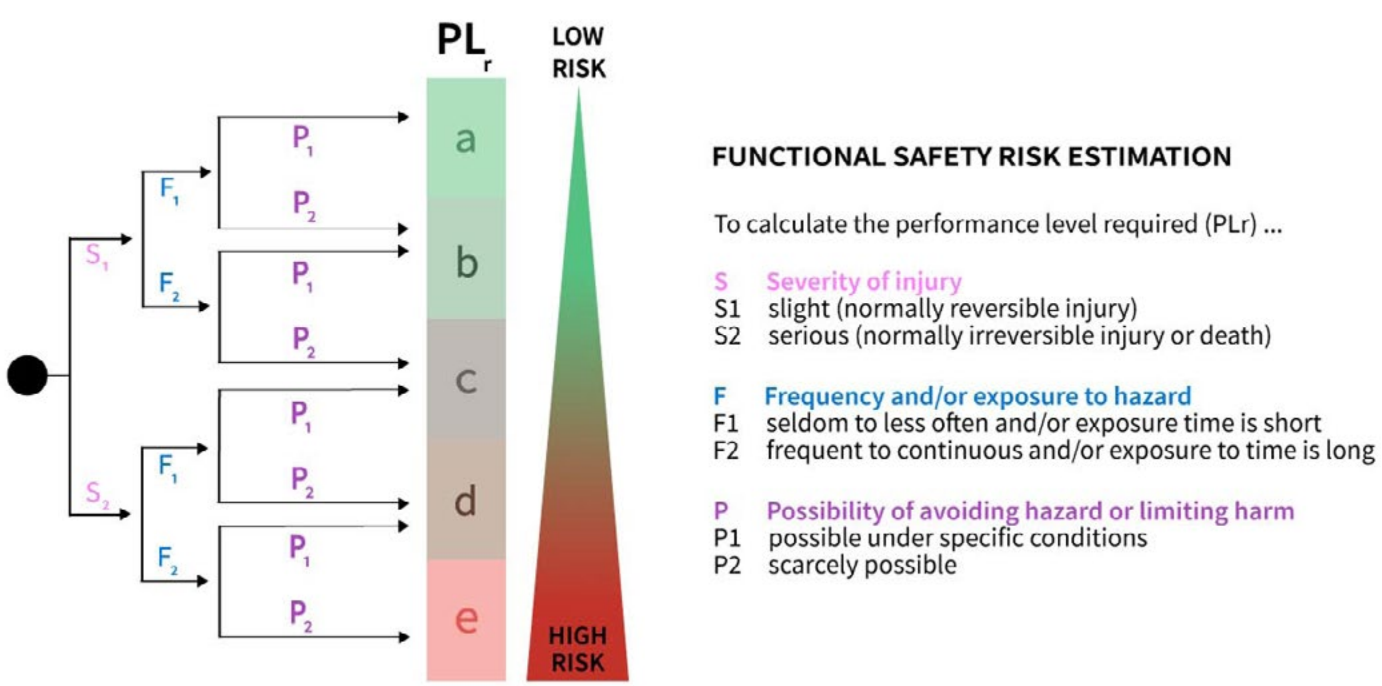


Figure 2: The appropriate functional safety level for a given installation depends on qualitative variables, quantitative values, and the results of software-based analysis. (Image source: Design World)

light curtains, consoles as well as human-machine interfaces (HMIs), touchable machinery locks, and (for emergencies only) bright red mushroom-head stop buttons. Personnel-facing safety components also include enclosures (protecting housed components according to NEMA ratings) as well as machine shields and wire ducts — simple yet reliable machine safety elements to protect personnel who must work near (and sometimes in) machines and their power and control panels.

Cable-pull switches encircling hazardous machine sections let operators trigger emergency stops (e-stops) with a quick tug. Especially common around open-faced machines (impossible to guard) as well as unguarded conveyors, these safety elements differ from disconnect switches that de-energize circuits and secure dangerous work cells to keep personnel out. Other offerings include safety edges (strips) that install around machine-tool openings (especially those that execute cutting or pressing tasks) and floor safety mats that trigger (via specialized safety relays) safety responses upon detection of an operator stepping or standing on their surfaces.

Somewhat more sophisticated are the aforementioned light curtains. These include an emitter of photoelectric beams that, if broken in the plane of detection

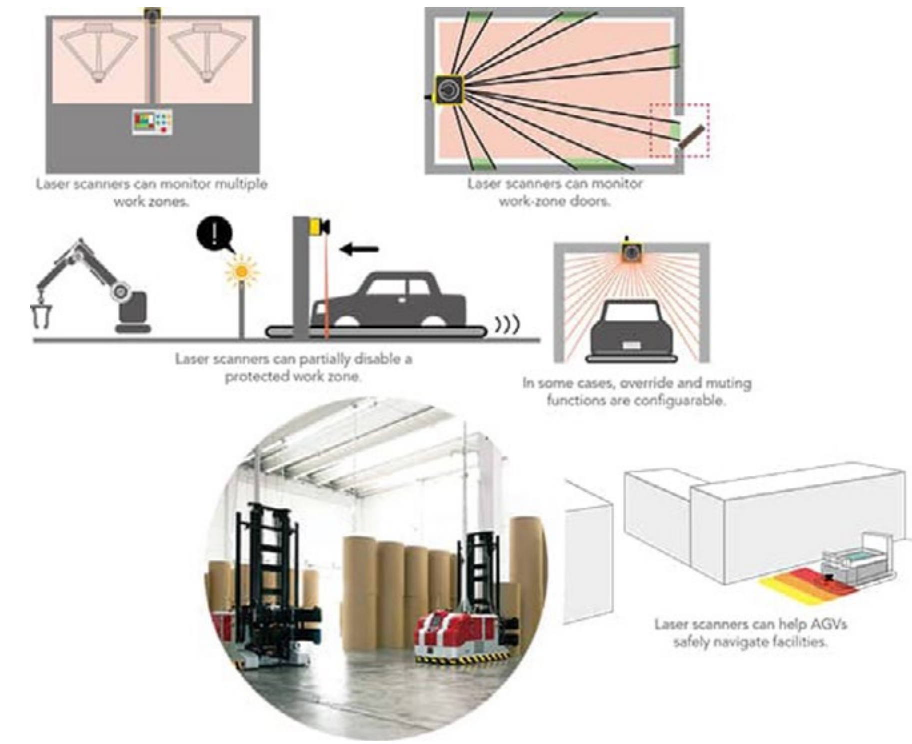


Figure 3: Laser scanners are a type of noncontact safety-feedback component best known for their helping AGVs navigate facilities. However, their applications abound — and they can sometimes offer an alternative to light curtains. (Image source: IDEC)

on their way to a receiver, quickly halt dangerous processes. They're costlier than other options but justified where machine operators frequently interact with a machine section. Yet another sophisticated safety component is the two-hand safety console. These typically require simultaneous activation of separate switches to start or maintain machine operation.

Before they're trusted to protect plant personnel and equipment, all operator-triggered safety components (and the safety logic or controls into which they integrate) must be verified. For example, IEC 61508 and IEC 62061 testing standards require that an e-stop using redundant relays should work if an operator trips the first channel between the logic and field devices … and should also work on the second channel between them. Such redundant e-stop functions are separately validated during machine commissioning.

Automatic safety switches, sensors, and guards

Separate from personnel-triggered safety-related components are those for automatic machine functions.

Built-in lockouts with latches and switches

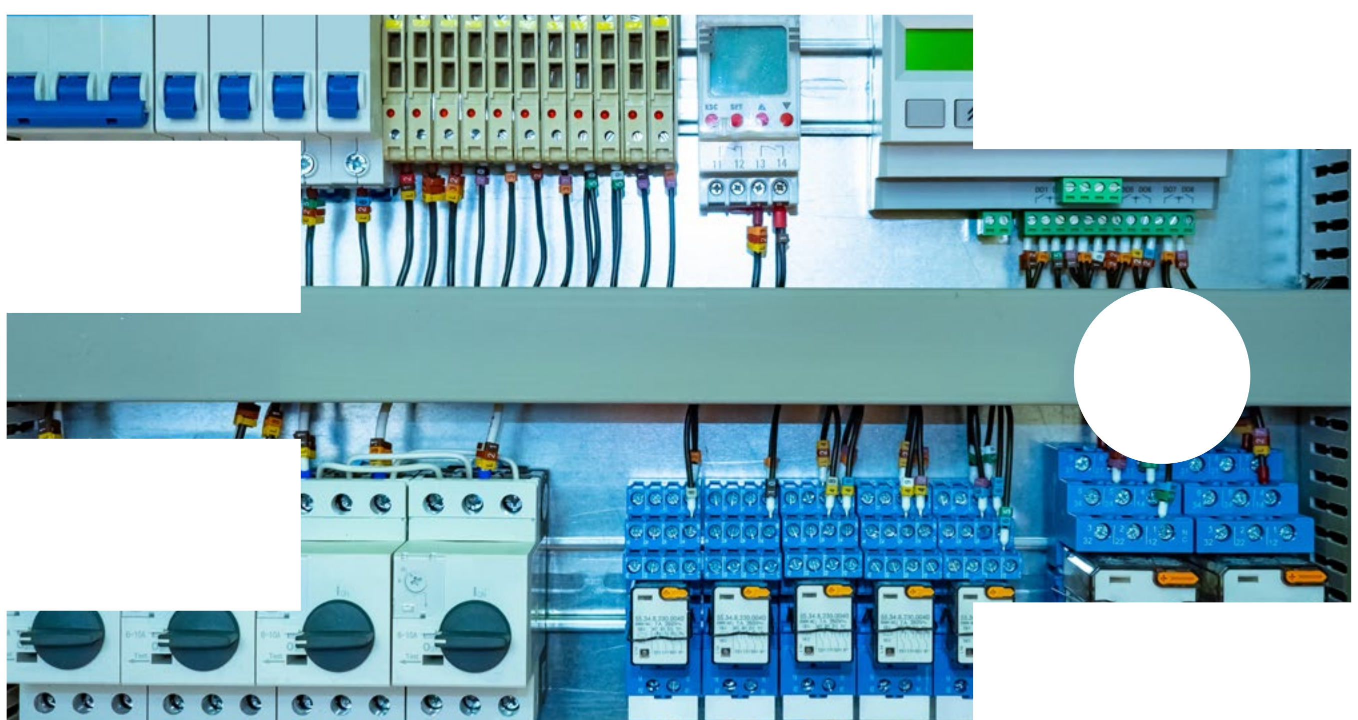
Switches and interlocks are essential elements on the outer perimeters of machine work cells. Safety limit switches have contacts that serve to automatically verify machine element positions or motions. In contrast, safety switches with higher functions — those called interlock safety switches — use tongue or hinge interlock mechanisms as tamper-resistant machine guards having positively driven (double-verifying NO and NC) switching contacts. Trapped-key interlock switches with mechanical keys and locks keep doors into machine workspaces closed until access is safe. Increasingly common though are noncontact RFID and magnetic safety switches that monitor the position (open or closed) of work-zone doors and disallow operator access during hazardous processes.

Built-in safety with electrical breakers and isolators

Safety components triggered by machine status also include those to ensure electrical safety. Circuit breakers (much like fuses) protect against the detrimental and dangerous effects of overload currents on mains, power branch, and signal circuits. Some installations include isolators for galvanic separation between field devices and controls to ensure intrinsically safe operation. Complementing all designs for electrical safety are surge-protective components to prevent voltage spikes from damaging electrical and electronic automation components involved in mains and drive power and/or feedback and control-signal distribution.

Built-in mechanical safety with brakes

Brakes that qualify as safety brakes are also called failsafe brakes. These default to a stopped state (typically to lock or hold a motion axis) even if electrical or fluid power fails or is removed. All rely on spring-loaded or other mechanical action for this failsafe operation.



Another option for safety that qualifies as failsafe is the integration of dedicated safety controllers.

Case in point: Spring-set friction brakes that are pneumatically released often serve as failsafe brakes in servomotor-driven automation applications. All must carry a rating that certifies compliance with ISO 13849-1 — typically from the international product-testing organization Intertek Group. Thanks to their mechanical locking, these consume no electrical power while holding … which provides maximum reliability for safety-grade performance and avoids overheating associated with other electrically based modes of stopping. Life is rated in millions of cycles before common cause (predictable) failure to some percent of all components in the series. Where IIoT functionality is useful, failsafe brakes can also include onboard diagnostics and sensor feedback to track operational status.

Brakes having the highest functional safety ratings incorporate multiple springs that mechanically lock machine axes via friction surfaces that interact with stationary elements inside the brake housing. Safety standards also require inclusion of sensors to confirm brake status.

Safety relays and other safety controls

Supporting the functions of safety switches, sensors, and guards are safety relays and other controls. All share a common ability to (when needed) take the machine to a safe state through the removal of electrical or fluid power — or slow or lock a still-powered machine into a safe condition.

Figure 4: Simple equipment needing just a handful of safety I/O can economically employ electromechanical safety relays such as this one. (Image source: Omron Automation)

Relays for hardwired safety

One option for failsafe control is safety relay modules. These employ electronics with short-circuit and overvoltage protection as well as complementary relays. Hardwired electromechanical relays have been used for decades; they simply wire into automated controls and (in conjunction with emergency stop or light curtains) electrically disconnect machine subsections as needed. Drawbacks include the need for extensive wiring onsite and a lack of reconfigurability. More advanced safety relays sport I/O and a modular design to facilitate flexible integration with sensors, machine controls, and automation networks.

Safety controllers for programmable safety

Another option for safety that qualifies as failsafe is the integration of dedicated safety controllers. Such controllers are more suitable than relays for complex automation systems because they can serve larger I/O arrays as well as PLC functions. The one caveat is that these standalone safety controllers necessitate additional

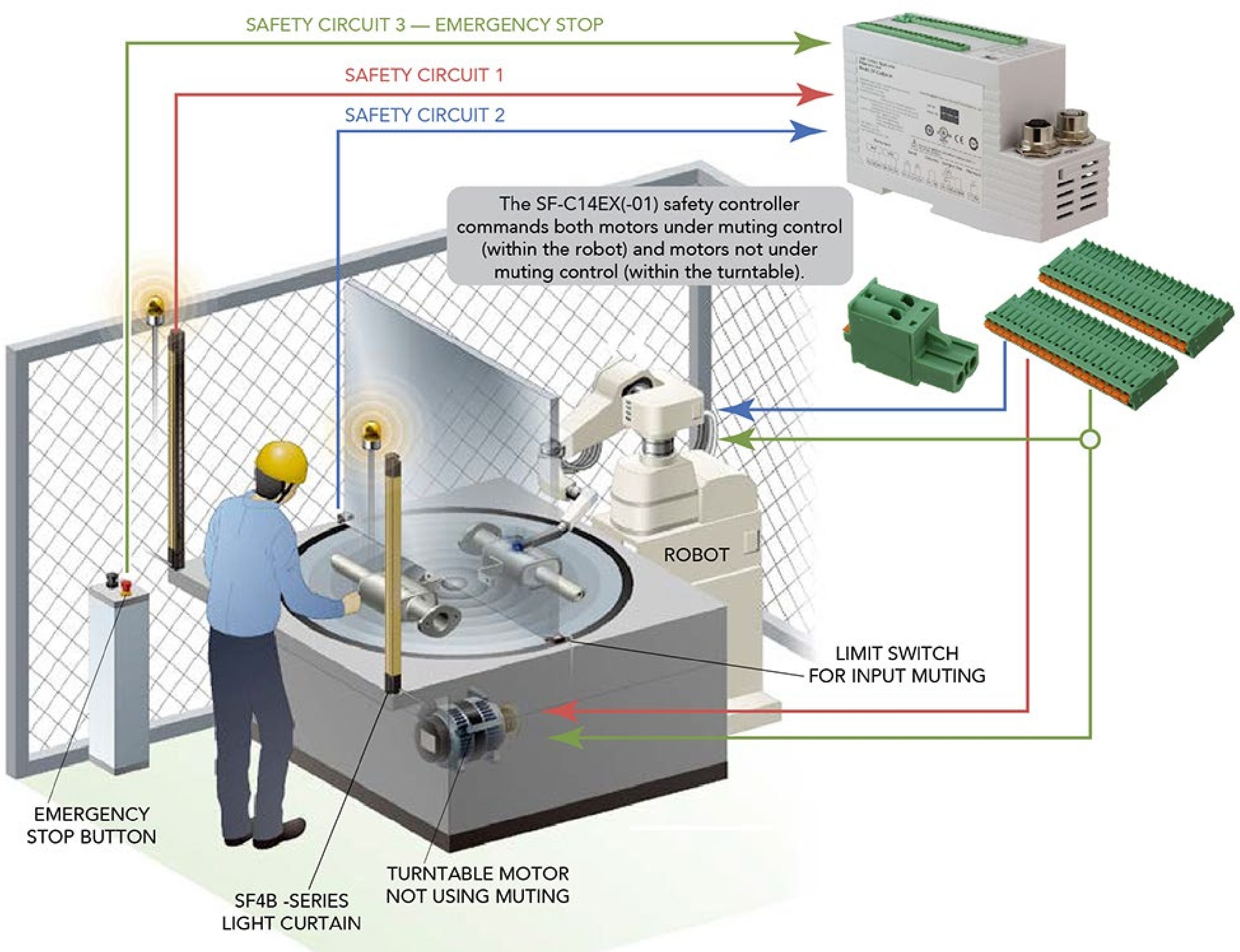


Figure 5: Safety controllers can unify multiple safety functions for flexible and reconfigurable safety installations. In the workcell illustrated here, the first safety circuit includes a light curtain that (upon reporting an interrupted status) opens a circuit switch to stop the turntable. The second safety circuit integrates muting controls that let the robot operate normally if a workpiece enters the workcell when the turntable is stopped. Otherwise, this circuit opens a switch to disable the robot. The third safety circuit includes an emergency stop that opens all switches and stops both turntable and robot. (Image source: Panasonic Industrial Automation Sales)

programming and personnel training. However, their digital electronics allow for automation functions that are fully configurable via software.

Engineers can define zones needing safety coverage and modify their settings without the need to rewire the entire workcell. (That in turn trims wiring hardware and labor costs.) Usually, safety-controller-based installations also support network expansion and IIoT connectivity as operations evolve.

Integrated safety on safety-rated industrial controls

A third option for failsafe safety control that's increasingly common in sophisticated machinery is integrated safety PLCs, programmable automation controllers (PACs), and other PC-based controls. Some such electronics hardware can assume safety functions in addition to everyday machine functions. The result is programmable and therefore flexible control over both automated machine equipment and the safety functions their operations require.

Conclusion

Sufficient machine safety relies on feedback and control components rated to provide protections commensurate with a given application's hazards. Machine safety also requires proper component integration, documentation, and validation. The latter ensures safety circuits work correctly for all machine operation modes, even during faults.

IEC 61508 and 62061 safety-lifecycle standards define how safety integration is correctly executed — from initial risk assessment and design to real-world verification of an installed system's performance by the OEM and again by or for the end user once the machine is installed. The latter puts machines "through the paces" with tests of normal operation sequences, slowdowns, stops, and reset routines.

Figure 1: On each of this machine's doors, limit switches verify closure before allowing the machine to startup. (Image source: Getty Images)

Basics of safety interlocks

Written by:
By Lisa Eitel
Contributed By DigiKey's North American Editors

Keeping plant personnel safe requires that they be protected from mechanical threats to bodily harm. This field of safety engineering is called *industrial risk* reduction. Local laws and industry standards legally require that automated equipment include various mechanical safety features to prevent dangerous machine startups and trigger safe shutdowns should a new risk of personnel harm arise. The foundation of these safety systems are well-defined boundaries around the machine — and *safeguarding* or machine-guarding components.

Though safeguarding is a term casually used in some literature, standards from the International Organization for Standardization (ISO) and an increasing number of automation component suppliers assign it a very specific definition. These authoritative industry sources generally limit *guarding* to mean components and subsystems surrounding possibly dangerous segments of equipment with:

- Sheet-metal housings and chain-link or glass fencing
- Sliding glass panels, doors, and swinging gates
- Sensors and light curtains
- Specialty barrier components of other electronic or physical design
- Safety interlocks — the focus of this article

Though guarded machine perimeters mostly consist of immovable elements, the movable or penetrable sections mentioned (including window shields, curtains, and doors) can allow operator access at strategic locations for machine tending, adjusting, or servicing. A convenient way to categorize these safety components is to group them by whether machine operator or other plant personnel make direct physical contact with that safety component (as with light curtains, for example) or whether some intermediate machine subsection contacts the component. The latter include an array of machine-activated safety switches and sensors as well as interlocks.

So, what exactly are interlocks? They are mechanical, electrical, or electromechanical safety components that are at their core a proximity or position switch. They always install on machine confines at moveable (penetrable) gates. Unlike safety curtains or operator switches, interlocks are those that are triggered through the movement of either movable machine or perimeter sections. To be clear though, safety interlocks can be triggered by actuated perimeter sections or those that are manually opened. Their name derives from the way they inter-lock (and render interdependent) allowed safety-controller conditions and perimeter-gate positions … whether open or closed or something else. In other words, interlocks provide feedback to safety controllers that in turn elicit the correct machine status for a given set of machine-guard positions.

Standards governing the inclusion of interlocks

Currently, the design and integration of interlocks of industrial-automation applications must satisfy five full standards — including Conformitè Europëenne (CE) Machinery Directive 2006/42/EC. ISO 12100 (and adopted ISO 14119 passages) define interlocks as devices that prevent hazardous machine operations when gates into the guarded area are open. The interlocks called *guard locks* or *locking gate switches* that go a step further to latch gates closed are subject to their own requirements — including the requirement that they feature an escape latch for technicians who find themselves locked inside a dangerous work cell.

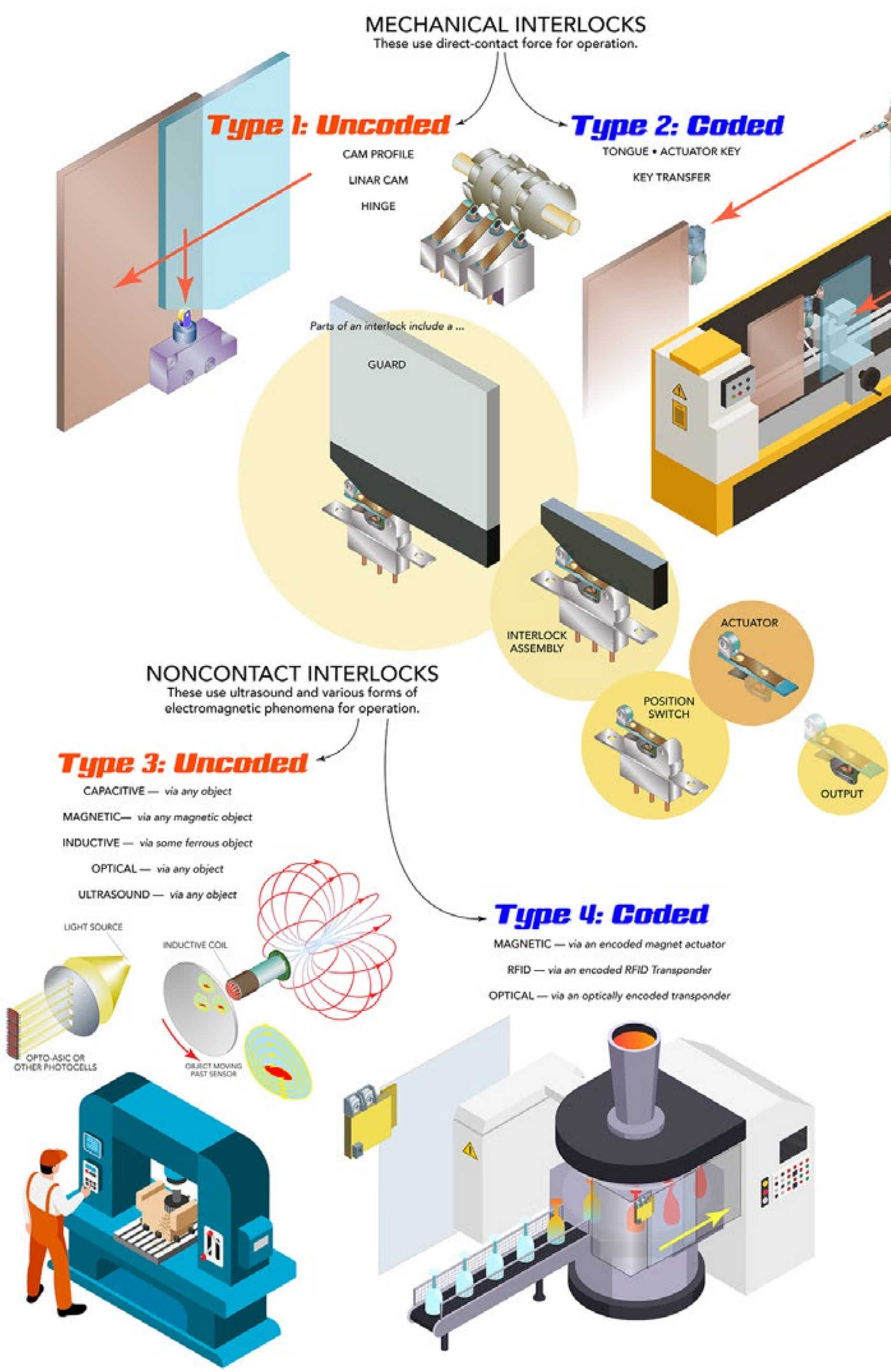


Figure 2: Interlock switches can accommodate various orientations. International safety standards define the classifications of such interlock variations. (Image source: Design World)

Some of the standards reference the core position switch or proximity-switch technology at the core of every interlock. They also outline the requirements of how electronically actuated workcell guard sections network with equipment controls — typically to command any potentially dangerous motions to slow or even cease.

Accommodating time for machine to stop

The most dependable interlocks satisfy specific axis-stop intervals — defined as the time a machine requires to slow to a safe state after issuance of a stop command. In fact, interlock systems accommodate for these stop intervals as well as the time in which it's feasible that a machine operator could reach hazardous axes after issuance of a stop command. Optimized interlock installations:

- Ensure a safe state is achieved long before an operator could ever possibly touch or approach dangerous machine axes.
- Support efficient machine use by avoiding excessively long lockdown states.

In fact, ISO 12100 details how interlock-guarded doors and panels can (with their closing) immediately trigger resumption of machine operation. That's in contrast with emergency stops that necessitate more involved machine-restart sequences. The logic of such standards is that the use of interlocks is routine (so shouldn't hinder every day operations) but that of e-stops is not.

Core interlock technology and defeatability

Automated machines must satisfy Type A, B, and sometimes C international safety requirements. The functional-safety ISO 12100-1 standard and other foundational Type A standards apply to all automation equipment. Electronic controls satisfying ISO 12100 can address situations involving any unavoidable maintenance of some energy source — namely by preventing any unexpected machine restart. For this purpose, e-stops are never acceptable solutions … but key interlocks can be.

Type B midrange standards include B1 safety-approach standards (including ISO 13849-1 and 62061) as well as specific B2 safe-system requirements (including ISO 13850 and 13851). In contrast, Type C standards are very specific to machine types, so are particularly stringent and most employed by OEMs for new equipment design.

Standards specific to interlocks are ISO 14118 and 14119.

ISO 4118 details ways to prevent unexpected machine startups (by dissipating mechanical power and cutting electrical power) upon an operator's entry into a hazardous machine workspace. Such systems can disconnect power supplies, stop motors, release fluid power actuators, and allow the spending of any remaining kinematic energy of the machine's moving segments.

In contrast with other standards mentioned in this article, ISO 14119 covers the required specifics of guard interlocks by:

- Referencing the risk-analysis techniques of other safety standards.
- Defining interlock features that prevent accidental and intentional safety defeats.

ISO 14119 defines Type 1 interlocks as position switches using easily defeatable mechanical hinge or cam actuation. Actuating contact occurs between interchangeable (uncoded) halves. Benefits of Type 1 interlocks are low cost and high configurability.

Type 2 interlocks (as first defined by DIN EN 1088) include less circumventable position switches based on mechanical actuation. Halves are coded (mated) tongues or (for safety guard locks) trapped keys. The latter force operators to lock all guards before controls allow machine startup … and key removal is only possible when the guards are latched. Fully integrated perimeter controls go even further to force operators to use those same keys in keyed HMI start switches that hold the key captive during machine operation.

ISO 14119 classifies all noncontact safety switches sans coded actuation as Type 3 interlocks. The most easily defeated are those employing optical, ultrasonic, or capacitive actuation; slightly less defeatable are induction and magnetism-based interlocks. Where defeatability is unacceptable, Type 4 interlocks which use matched or coded actuator halves in noncontact operation whether based on RFID, magnetic, or optical technology) are warranted.

Comparing interlocks with safety sensors and perimeter switches

Interlocks share similarities with other safety-rated feedback and sensing components based on the same core technologies. But to be clear, none of these other components are associated with machine perimeters like interlocks. In addition, today's safety standards require that interlocks won't greenlight resumption of action sans some corrective reversal process.

Components supplied as industrial safety sensors verify (often via noncontact inductive or photoelectric means) machine element or workpiece positions for controllers to command responses suitable for the reported conditions. In contrast, industrial safety switches turn power supplies off and on upon detection of machine element or workpiece positions. Upon verification of the trigger positions, such switches either prompt disconnection or resumption of power to the related machine section. No more is it sufficient to use an ordinary proximity switch as an interlock. Demanding IEC 60947 requirements now demand that components used as interlocks have very specific safety-related features to prevent defeats and other failures.

Also found in safety systems are relays that directly make or break electrical contacts — in the most common arrangements, essentially communicating a small command voltage onward to ultimately spur a larger current through the power contacts it commands. Consider two common functions that interlocks render interdependent: the opening of a guard door and a motor-driven spindle on a machine

Figure 4: Some doubly capable interlocks have actuators to function as guard locks. These are position switches with deadbolts or electromagnetic assemblies that can keep doors barred until the guarded robotic arm or machine ceases its hazardous motion. Unfortunately, some engineers mistakenly believe that all interlocks are of the guard-lock variety. (Image source: Omron)

tool. Mutuality between these renders the milling station unlikely to damage its own subsystems or injure the operator. In this regard, interlocks function as switches in an operational sequence.

Most rare are mechanically cammed interlocks with arms that pivot on an axis to lock dangerous machine axes. Far more common are electromechanical and electronic interlocks employing circuits and microprocessors for cost-effective reliability and even

reconfigurability. For example, electromechanical hinged interlocks on perimeter doors include a mechanical elbow or lever arm that opens with the hinged guard; beyond the set switching angle, it triggers commands to stop the perimetered machine. Upon door reclosing, the door force ultimately prompts the interlock's solenoid to reclose the circuit.

Typical wiring and solenoid types in interlocks

Interlocks are most commonly wired for normally closed or NC logic to only let machines run if the circuit is closed. Most safety standards require that safety-circuit components wire in series for maximally reliable error and event detection (up to an allowable sensor

Figure 3: The mere closing of guard interlocks doesn't trigger the restart hazardous machine processes; instead, those honors go to a separate double-duty control interlock or start switch like the soft-touch capacitive finger switch shown here. (Image source: Getty Images)

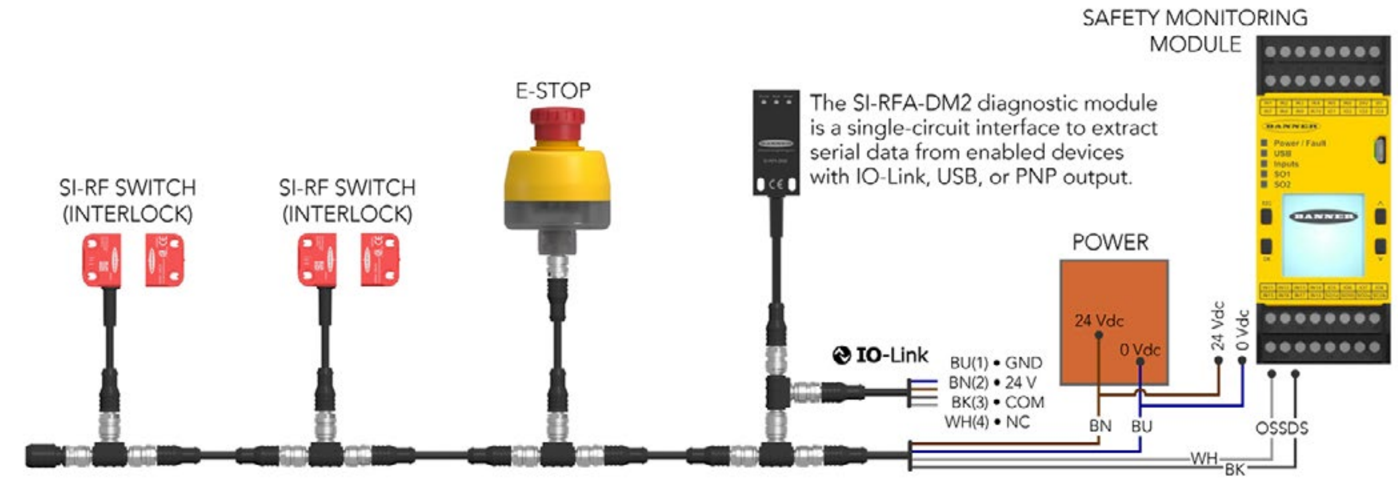


Figure 5: Innovative connectivity options have only increased the reliability of multi-guard installations in recent years. Here, an interface module is connected via T-adapter networks to other safety components. (Image source: Banner Engineering)

total). Exceeding that number of sensors can degrade a design's performance level (PL) and increase the likelihood of fault masking.

Safety interlocks employing one spring-actuated NC switch (whether position or limit) typically deliver positive breaking — so that opening the guard presses against the interlock's spring to spread its electrical contacts apart. In contrast, more reliable twin-switch interlocks use one switch to actuate upon guard opening and another switch with electrical contacts spread apart upon guard closing. Electronic self-reporting of shorts (usually by monitoring the potential difference between two input channels) is a complementary feature to detect severing of wires due to shearing, corrosion, or overheating.

The reliability of plunger-and-coil solenoid operation renders solenoid-based safety components suitable for critical interlock applications. Electrical input typically causes linear plunger output (with a spring-set return upon power off). When integrated into guarding and deadbolting interlocks, solenoids are the input source for the latching mechanisms. Other such solenoid-based designs can also ensure correct mechanical operation — for example, to ensure consistent conveyor travel even when tending equipment handle or process workpieces riding its belt. Solenoid-based redundancies (with series-wired and double-pole switches for verifying position) can minimize faulty interlock signaling.

Conclusion

Interlocks render machine perimeter status interdependent with safety controls. In fact, today's interlock feedback to such controllers can spur exceptionally sophisticated machine responses to various machine-gating positions. The most advanced interlocks can assume failsafe edge computing, IIoT, and reliability tasks beyond the capabilities of traditional industrial switches and sensors. The main caveat is that guard interlocks mustn't be cumbersome to machine operators. Automatic functions and conditional unlocking on the most frequently accessed guard doors can improve functionality with minimizing undetected faults.

Danger – keep out

Written by:
European Editors
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Rigorous attention to safety at work has become ingrained in the industrial culture of developed economies. Safety is viewed as important not only for workers but also for employers, who understand the financial and reputational benefits of a good safety record.

Safety-oriented regulations cover numerous aspects from the working environment and practices to the design of equipment used in the workplace. Machinery must meet essential health and safety requirements (EHSRs), such as those listed in the European Machinery Directive 2006/42/EC, to ensure the health and safety of machine users and others who may be affected.

Safety standards and the machinery directive

Machine design is subject to a system of standards that extends to cover a wide range of risk reduction and safety-protection mechanisms. At the highest level, type A standards include ISO12100, which sets out basic concepts and design principles that are applicable to all types of machines and also makes reference to risk assessment and risk reduction. At a lower level, type B1 standards set out general requirements for safeguards and type B2 standards apply to particular safety devices.

Among the type B standards, those set by the International Standards Organization (ISO) tend to focus on machinery and management, while International Electrotechnical Commission (IEC) standards are concerned with electrical and electronic safety systems. ISO standards include ISO13849-1 covering safety-related parts of control systems. IEC standards, on the other hand, include IEC60204 concerning electrical equipment in general, IEC61496 for electro-sensitive protective equipment, and IEC62046 for equipment designed to detect the presence of persons.

Equipment marketed in Europe must be shown to comply with the Machinery Directive 2006/42/EC, which aims to establish common minimum standards for the health and safety of new products. These common standards are expected to facilitate trade and the free movement of goods between member states. The Directive references ISO12100 and the ISO and IEC Type A and Type B standards, as well as Type C standards that cover particular types of equipment such as forming machinery or industrial sewing machines. Meeting the specifications of the ISO and IEC standards helps machine designers demonstrate compliance with the Machinery Directive.

As far as design principles are concerned, the expected approach is to design out hazards where possible and implement protective systems where necessary to minimize risks. These protective systems may take the form of physical guards that prevent personnel entering hazardous areas or placing fingers, hands or limbs in harm's way. By preventing such intrusions, which can result in personal injury, physical guards can enable machinery to operate continuously for long periods without interruptions from emergency stop signals. This can help maximize productivity.

On the other hand, sensor-based systems that detect intrusion and trigger an alarm or stop the machine can allow greater flexibility and permit easier access for replenishing consumables or carrying out routine maintenance. Some applications may call for a combination of physical guarding where frequent access is not required, and intrusion detection where easier access is desirable or a barrier is not practicable.

Safety systems

Physical barriers must incorporate safeguards that can either prevent any access doors or hatches from being opened while the machine is operating, or stop the machine in the event the door is opened. These safeguards can be implemented using limit switches that can detect when the door is opened or closed, or by using a safety-door switch such as the Omron D4BS.

The D4BS switch has up to two normally closed (NC) contacts and incorporates a direct-acting mechanism that opens the contacts if the safety barrier is opened. A number of built-in features prevent malfunctions or incorrect operation, such as a special operation key for activating the switch. This key is designed exclusively for use with the D4BS and will not work with any other switch type. In addition, a built-in shearing-force mechanism ensures reliable separation of the contacts as soon as the switch is actuated by forcibly pulling apart the NC contacts. This ensures that any abnormalities such as contact welding will not prevent correct operation of the switch.

As far as intrusion detection is concerned, light curtains are commonly used to protect operators by causing the machine to stop. A combination of transmitters and receivers set up an array of light beams, and generate an alert if one or more of the beams are interrupted. The Panasonic SF4D series of light curtains has three variants comprising the SF4D-F, which is optimized for detecting intrusion by human fingers, the SF4D-H for hand detection, and the SF4D-A for arm/foot detection. The SF4D-F can detect objects as small as 14 mm in diameter, which gives designers extra flexibility to use light curtains in compact machines in accordance with the standard ISO13855 governing the positioning of protective equipment. Other important selection criteria for light curtains include the protected height and protected width. Light curtains such as the SF4D series, which features a small distance from the edge of the assembly to the center of the first beam, can be connected together to extend the protected area without introducing dead zones.

When designing a light curtain into machinery, muting capability may be needed to allow the machine to operate normally without stopping when a workpiece enters the machine, for example on a conveyor. This ensures the light curtain will only generate a stop signal when human intrusion is detected. Proximity sensors placed near the conveyor, as shown in Figure 1, enable the system to detect the presence of a workpiece and mute the associated light beams for the duration the workpiece is passing. If non-muted light beams are interrupted the system assumes an intrusion has occurred. Some types of light curtain may require a separate controller to interpret signals from the proximity sensors. The SF4D series has muting control built in, which allows proximity sensors to be connected directly to the light curtain with no need for an external muting controller.

An inductive proximity sensor such as the Panasonic GX-F12B can be used for muting control. It provides the benefit of a long sensing distance and a stable temperature characteristic that ensures consistent performance independent of the time of day or the season.

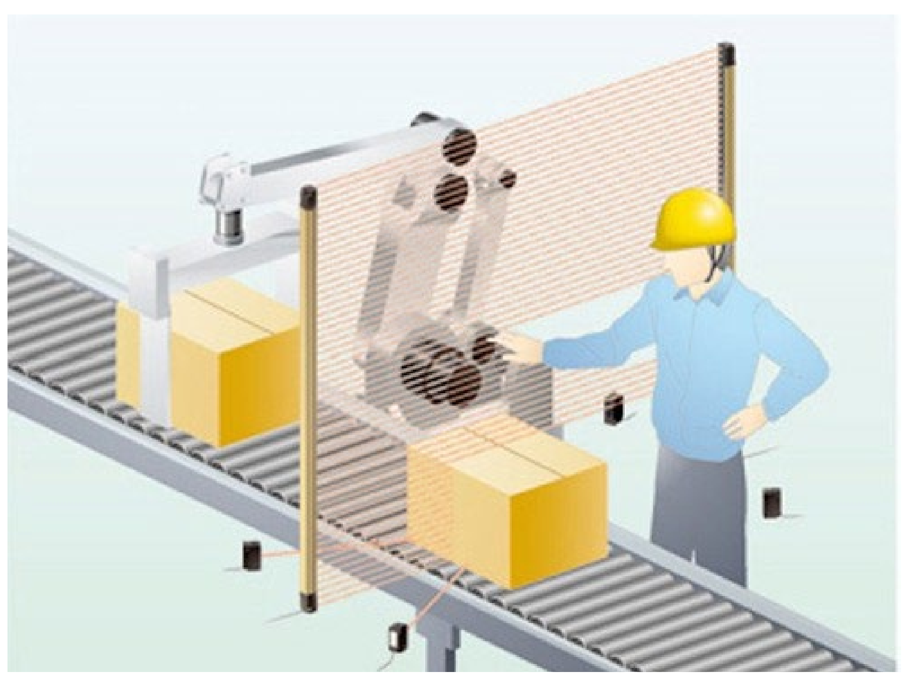


Figure 1: Proximity sensors help discriminate between a passing workpiece and intrusion by a human operator.

Safety-system control

In a basic machine-safety system, detectors such as door switches and light curtains are typically connected to the inputs of a reliable safety relay such as the Omron G7S. The relay responds to the switch or sensor signal by signaling a contactor to turn off the applicable motor drive in order to stop the machine. Figure 2 illustrates a simple safety system built around a safety relay.

A critical difference between a safety relay and a standard relay is that the safety relay has forcibly guided contacts. These ensure enhanced reliability, and allow abnormal relay operation to be detected in the event that one set of contacts becomes stuck, for example due to welding. If a normally-open (NO) contact becomes welded while the relay is energized, normally-closed (NC) contacts on the same relay will not close when the coil is de-energized. Conversely, if an NC contact becomes welded, NO contacts on the same relay will not close when the relay is energized. The ISO 13849-1 functional safety standard requires that safety relays should comply with EN 50205. EN 50205-compliant relays such as the G7S are designed to ensure an air gap of at least 5 mm between open contacts.

If the safety system requires a large number of safety relays, to handle inputs from multiple sensors, a safety PLC may be needed. Alternatively, a software-configurable safety module such as the Phoenix Contact 2986012 can allow a compact and economical solution. The 2986012 has twenty safe inputs and four safe outputs, as well as additional alarm, clock and ground-switching outputs. Using a configurable safety module, it is possible to monitor several safety functions with a single device. The monitoring system can also be extended if required by adding extra safe I/O modules, as shown in Figure 3.

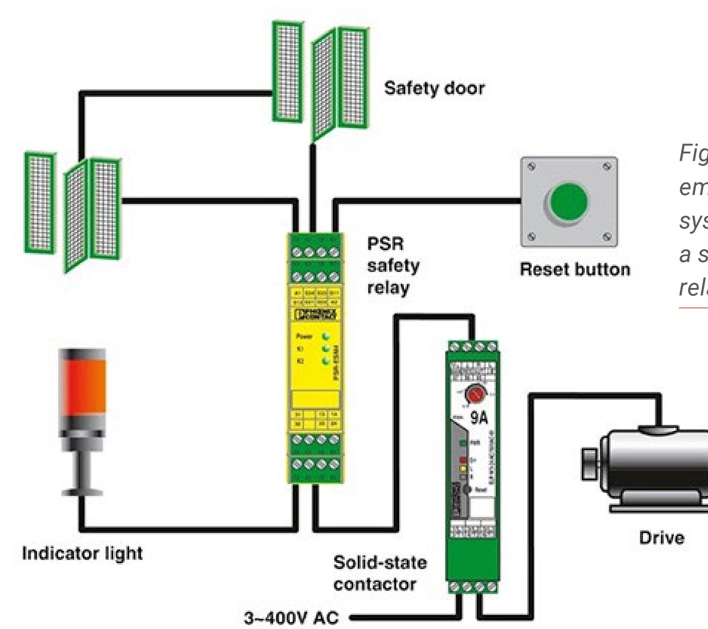


Figure 2: Simple emergency stop system using a single safety relay.

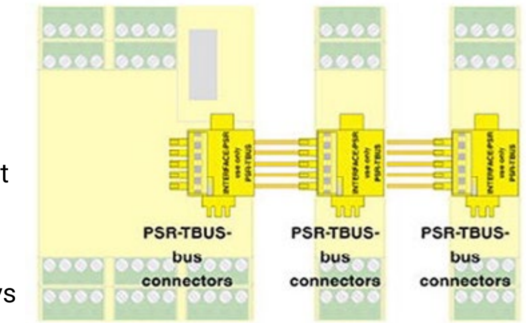


Figure 3: Adding safe I/O modules to extend the safety-monitoring system.

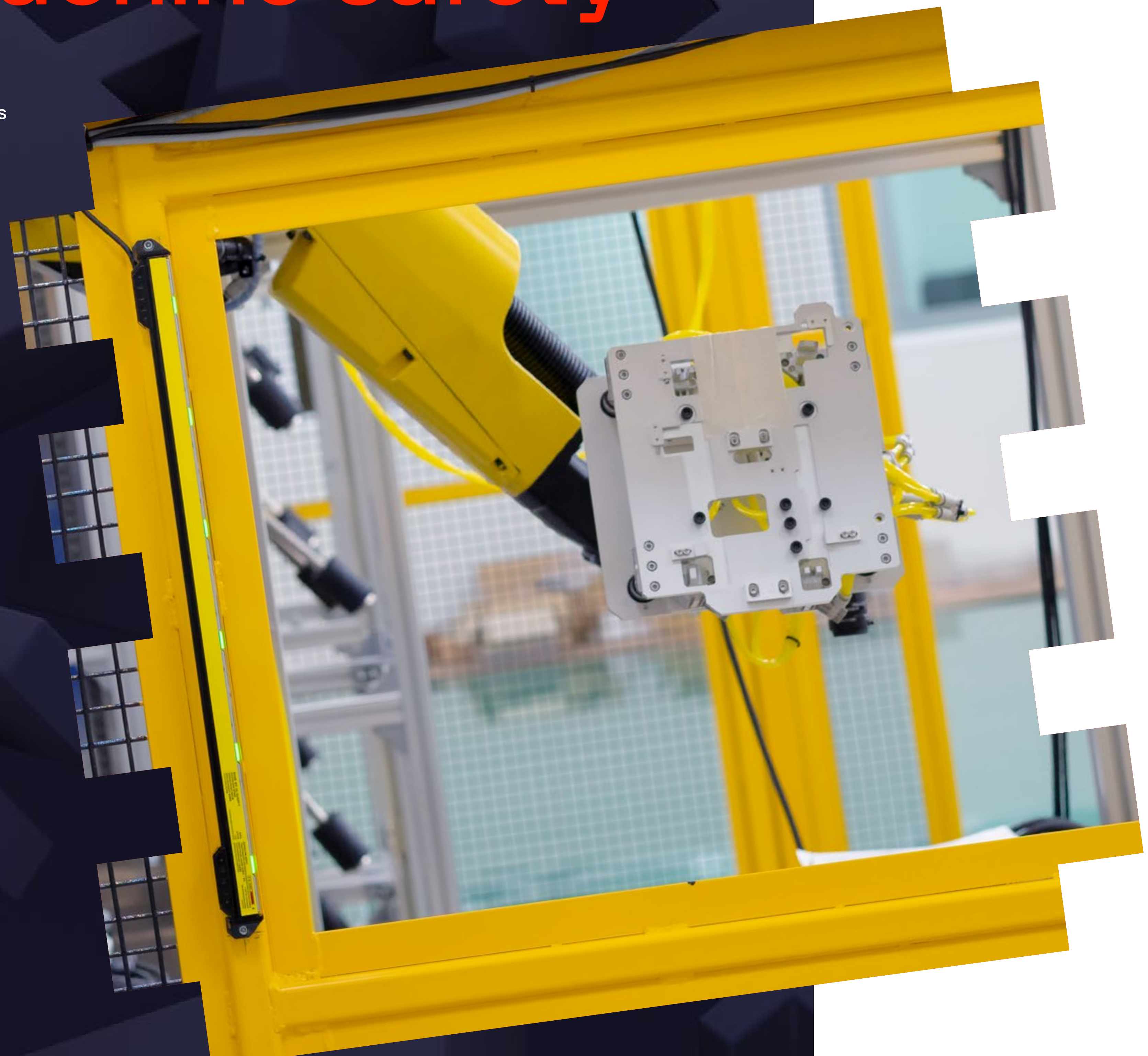
Conclusion

As well as protecting the health and safety of operators, complying with machine-safety standards can help equipment producers win the confidence of customers and strengthen their position in the marketplace.

An effective yet relatively simple safety system can be built around one or a small number of safety relays, which provide a highly reliable mechanism for stopping the machine in the event of a safety breach. A variety of mechanical and optical sensors are available, such as open/close switches, proximity sensors and light curtains, to inform the relay instantaneously when safety is put at risk. If extra inputs are needed, calling for a large number of safety relays, a software-configurable safety controller can provide a cost-effective alternative.

Making light work of machine safety

Written by:
European Editors
Contributed By DigiKey's
European Editors



Increasing global competitiveness drives the continuing efforts to reduce the production cost of manufactured goods through techniques such as 'Just in Time' and 'Lean Manufacturing'. But, however plants and factories are organized and however often they are re-organized, safety cannot be compromised.

Protecting personnel from machine hazards need not be a costly affair, but it does require highly reliable equipment. With the advent of powerful and low cost LEDs, together with easily programmable control electronics, safety light curtains can be conveniently configured to match a wide variety of machines, and efficiently reconfigured when necessary.

This article will outline recent technological advances in safety light curtains. Higher light intensity, smaller packaging and easy control are important aspects, but variable range/resolution, long life, high reliability, and especially low cost, are making safety light curtains a more compelling choice in many applications.

Specific reference will be made to models in the F3SG range from Omron Automation and the SF4D range from Panasonic Industrial Automation Sales.

Invisible light

On its website, Omron has provided informative and technical data on the operation and application of safety light curtain products1. In its simplest form, the industrial safety light curtain consists of optical transmitters and receivers used to detect swiftly any object that breaks the light barrier. A signal is sent to stop any hazardous machine movement instantly within the protected area.

The light curtains typically incorporate photoelectric transmitters in the form of infrared LEDs, which project an array of synchronized, parallel invisible (infrared) light beams to the receiver unit. The light beams are sequenced and modulated to pulse at a specific frequency. The receivers are programmed to detect only the pulses emitted at the designated frequency, thereby avoiding interference from other light sources.

Safety light curtains can be configured to meet a wide variety of applications, providing different levels of protection across different distances and resolutions. There are three broad categories: point of operation or pinch point (guarding a specific machine or operating area of a machine); perimeter guards (protecting a robot work cell, for example); and area guards (effectively an optical fence).

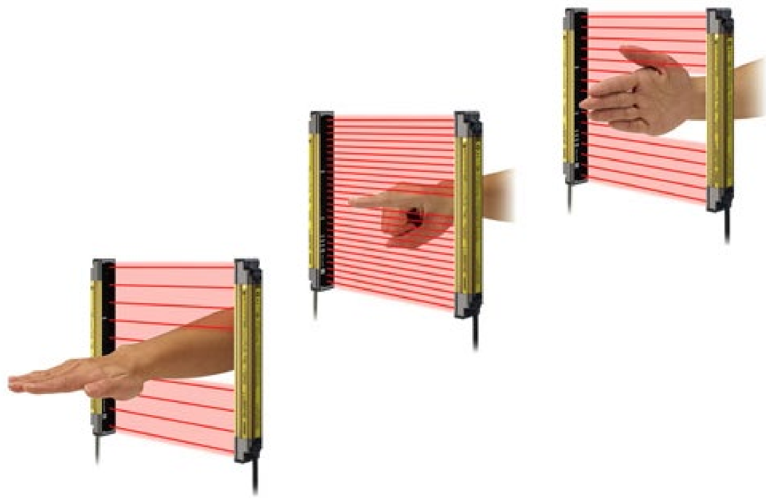


Figure 1: Safety light curtains control access to potentially hazardous areas in an industrial environment. The highest resolution (center) will detect the presence of a finger. Medium resolution (right) will sense a hand, while still lower resolution can be set to sense an arm or a whole person. (Photo credit: Omron Automation)

Safety light screens for industrial machinery are typically constructed to meet IEC61496-1 or -2 international standards requirements, and described as Type 2 or Type 4. Type 2 is for lower risk applications where an accident would result in a slight injury. These include the guarding of small assembly equipment, automated production equipment such as pick and place machines, table-top robotic workstations and small packaging machines.

Type 4 light curtains are required for higher risk applications that could result in serious injury or death. These light screens have high levels of fault tolerance through redundancy and constant monitoring, plus many other safety features, and are generally constructed in more robust housings. Typical applications include mechanical and hydraulic power presses, molding presses, stamping, forming, riveting, and other automated assembly machinery.

Once the appropriate standard has been determined, a number of other factors must be considered. For example, the minimum separation distance from the sensing field to the hazard is determined by the hand/body speed, machine response time, safety light curtain detection capability and response time.

The size of the object to be detected will determine the resolution of the optical system, which is a function of the beam diameter and spacing of adjacent beams (Figure 1). High-resolution systems can be specified to reliably detect a finger, for example, while medium resolution screens can be set to signal an arm or foot/ankle. Low-resolution systems would be used for perimeter and access guarding applications, detecting when someone has stepped right through the curtain. While high and medium resolution curtains can be oriented in any direction, low-resolution systems are usually only configured in a vertical orientation.

Features and flexibility

Early light curtain designs had drawbacks. They could be difficult to install effectively for certain types of equipment. Today's designs are more flexible in terms of mounting options. Smaller curtains, configured vertically and horizontally, can be made to fit into tighter spaces within a machine framework. This not only helps avoid blind spots and dead zones, but can also allow operators easier access to the equipment while still being protected from hazards.

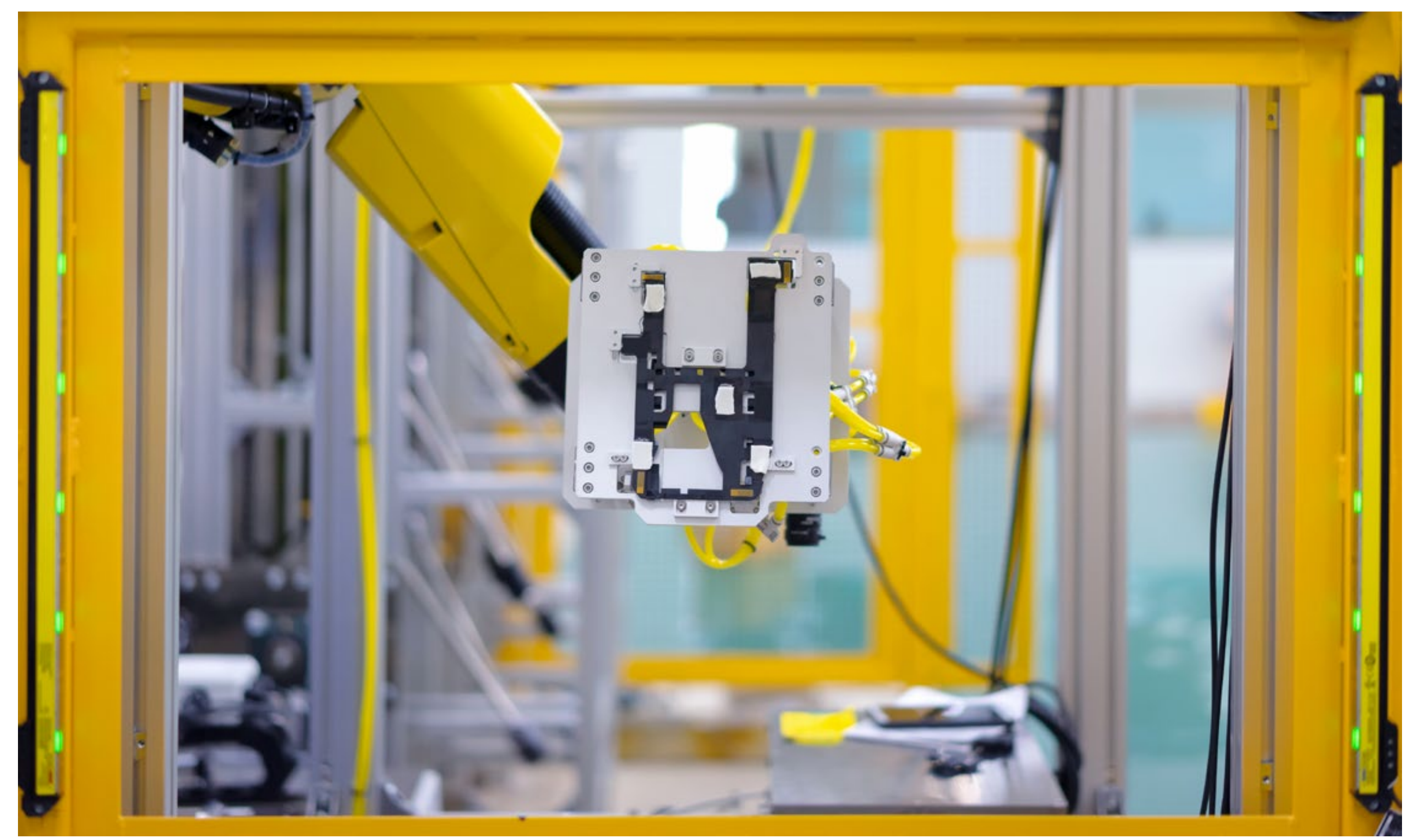
Some machines require intermittent access by the operator, either in certain areas, or at certain times. A muting function is available on many systems that allow the light curtain, or sections of the screen, to be bypassed or the sensor unit disabled while the machine is in a non-hazardous part of the cycle, such as an upstroke.

The use of advanced electronic controls together with facilities such as a smart muting actuator, allows the system to be easily configured and reconfigured to suit different production lines and/or work pieces.

In certain medium resolution applications, material or tooling may need to be fed into the machine through the light curtain without stopping the machine. A blanking feature can allow the light curtain to be programmed to ignore objects of a predetermined size, or permanent stationary objects such as tooling or conveyors that obstruct a part of the field.

Importantly, today's infrared LEDs are more reliable, and thermal issues are better understood, extending the lifetime of the components. Microprocessor control and the ease by which LEDs can be programmed enable many more safety features to be incorporated as part of the curtain system. These include built-in redundancy, self-test and restart interlock, thereby improving failsafe operation while providing greater flexibility and lower cost.

Omron Automation offers a wide range of models in its F3SG-R series of safety light curtains, meeting both Type 4 and Type 2 specifications. Finger protection models range from 15 beams and a protective height of 160 mm up to 207 beams and a protective height of 2.08 m. With a beam gap of 10 mm, object resolution is 14 mm



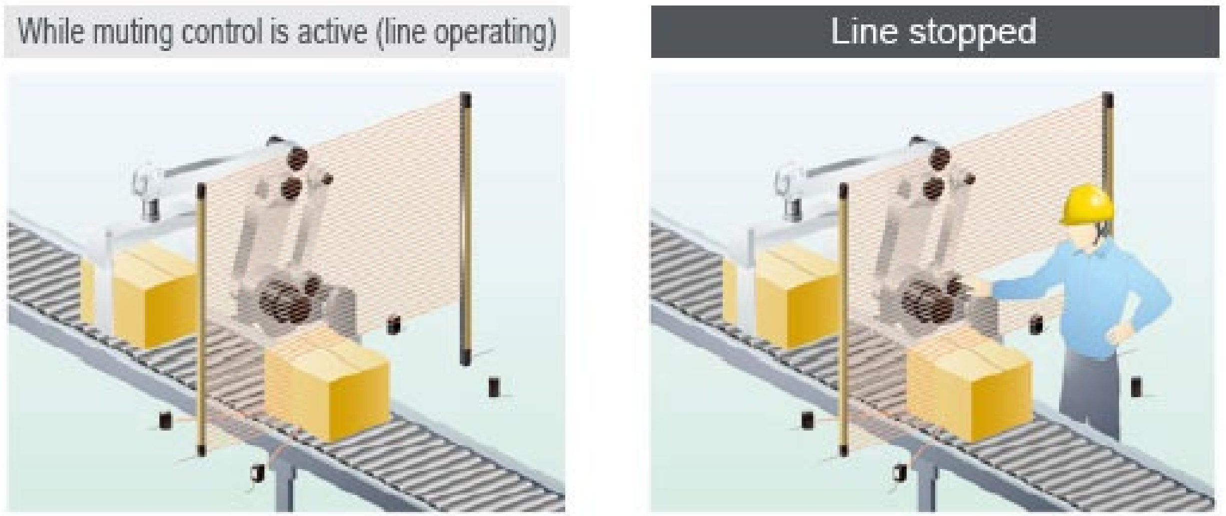


Figure 2: With a muting control function, the Panasonic Industrial light curtain will allow specific size objects through, but will detect a hand, for example, and the machine will stop instantly.

diameter. Operation range is from 30 cm to 10 m (long) and 30 cm to 3 m (short).

The medium resolution hand/arm protection units range from 8 beams at 190 mm to 124 beams at 2.51 m protective height. With a beam gap of 20 mm, object resolution is 30 mm diameter. Operating range is from 30 cm to 20 m (long) and from 30 cm to 7 m (short).

Response time from on to off is 8 to 18 ms maximum normally, depending on the model, or it can be set to a slow mode at 16 to 36 ms. Off to on response time is 40 to 90 ms. The effective aperture angle of Type 4 units is +/-1.5o with emitter and receiver operating range of 3 m or greater, and +/-5o for Type 2 units.

Compared to earlier versions, these units are installed in a more robust housing for long-term use in harsh conditions and withstanding shocks from impacts from tools or material. The housing is more compact, yet torsion resistant. Quick connect cables and connectors reduce the time required for wiring and set up. Optical synchronization between emitters and receivers now requires only a single cable. The use of advanced electronic controls together with facilities such as a smart muting actuator, allows the system to be easily configured and reconfigured to suit different production lines and/or work pieces.

An advanced muting function detects the zone where work pieces pass on a conveyor, for example, and tolerating vibration, will disable only the relevant beams until the object has passed. Where different sized objects pass on the same line, partial muting can be automatically performed.

Additional features aim to reduce the number of accidental machine stops while maintaining safety. The reset switch, for example, can be programmed only to operate when certain conditions are met (i.e. all detected objects are removed). A reduced resolution function allows the system to differentiate between objects, such as an automated transport vehicle, and the potentially dangerous ingress of a human foot.

Typical models include the F3SG-4RA0240-14, a finger protection unit with 23 beams and a protective height of 240 mm; and the F3SG-4RA0910-30 hand/arm protection system with 44 beams and a protective height of 910 mm.

Three resolutions

[Panasonic Industrial Automation Sales]() has also recently upgraded its ranges of light curtains. The Type 4 SF4D models, for example, feature new housings with a seamless structure and minimal joints, providing improved environmental resistance and easier installation and operation. Improved self-checking circuitry enables the system to constantly check for correct operation and to identify fault conditions, such as cable wiring disconnects, short circuits and interference.

Response time is 14 ms irrespective of the number of beam channels, axis pitches or the number of units connected in parallel. Additional features include an easy to set up muting control function with handheld controller to control specific beam axes. Thus, the unit can be programmed to allow objects through a line but not people. Fixed and floating blanking is also achievable.

Safety mechanisms include an override for smooth restart and built-in external device monitoring. Potential light interference is minimized with automatic scan timing shifts and a double scan/retry function.

Safety mechanisms include an override for smooth restart and built-in external device monitoring.

The company offers a wide range of units in three resolutions for finger, hand and arm/foot detection. The SF4D-F79 high resolution model, features a sensing distance of 14 mm to detect fingers, with 79 beams on a 10 mm beam pitch and a protective height of 790 mm. For hand protection, the medium resolution SF4D-H12 is a compact unit with just 12 beam channels on a 20 mm beam pitch, providing a protective height of 230 mm. Units up to 1.9 m protective height are available.

Finally, for hand/foot detection, the SF4D-C range provides from 16 to 48 beams on a 40 mm beam pitch, sensing objects of 45 mm diameter, for protective heights from 630 mm to 1.9 m. The SF4D-A24 is a typical example.

Summary

Advances in microprocessor control, high reliability infrared LEDs and compact yet robust mounting design are giving industrial light curtains a new lease on life in the modern manufacturing plant. Easier installation on complex machinery and better choice in terms of protective height and resolution, make this safety system more widely applicable. Programmable functions such as muting and blanking ensure that the light curtain can be adapted to most production lines and machine guard applications, as well as to changing production requirements driven by the need for responsive, flexible automation systems in a more competitive market.

Reducing robot risk: how to design a safe industrial environment

Contributed By DigiKey's North American Editors

The increase in industrial automation (IA), and particularly the use of industrial robots, is increasing the chance of an unexpected interaction between a human operator and a piece of other mobile equipment or moving machine. The onus is on designers to implement appropriate and often overlapping safety precautions to avoid consequences ranging from interruptions in production to injury or even death.

While safety is paramount, designers must still design and keep an eye on both initial costs and total cost of ownership.

This article will discuss best practices in plant safety and review some of the techniques and products used to establish and maintain a safe industrial environment and their applications.

Factory safety affects everyone in the organization

Safety in an industrial plant is a multi-faceted topic that requires involvement from all levels of the organization, from the shop floor to the executive suite. Ideally, a safe factory is designed from the ground up, but many plant buildings predate the widespread adoption of automation, the use of industrial robots, and the rise of the Industrial Internet of Things (IIoT) technologies.

Numerous national and international safety standards apply to different types of industrial machinery, safety equipment, and production processes. Among these are:

- ANSI/RIA 15.06 (Robot and Robot System Safety)
- ISO 13856-1:2013 (Safety of machinery: Pressure sensitive protective devices)
- ISO 13849-1 (Safety of machinery: Safety related parts of control systems)
- ANSI B11.19-2003 (Safeguarding Equipment and Protecting Employees from Amputations)
- CSA Z432-16 (Safeguarding of Machinery)

Designers must take time to familiarize themselves with the applicable specifications before they begin.

The preferred approach in developing a safe factory environment has several layers. The process begins with a comprehensive identification, evaluation, and analysis of the hazards, and an assessment of their relative importance.

There are several ways to reduce the risk posed by the hazards thus identified. Examples include:

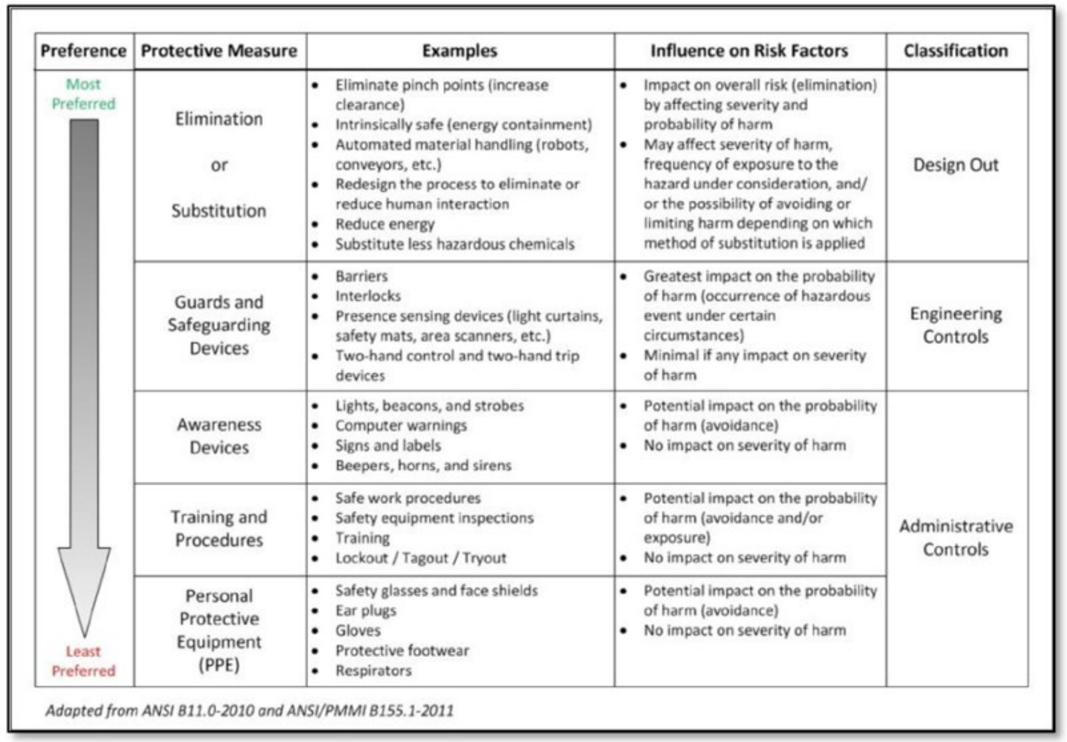
- Decreasing the potential severity of harm
- Improving the possibility that the harm can be avoided
- Reducing the number of personnel with access to the hazardous area, or their duration of exposure

After the initial analysis, the next stage is to develop a Hazard Control Hierarchy that ranks these measures in order of effectiveness and preference for each risk. ISO 12100:2010 (Safety of machinery – General principles for design) is the primary standard addressing the concept and methodology of tiered risk reduction.

The preferred solution is to eliminate the risk completely or substitute a safer alternative that minimizes the opportunity for unexpected human-machine interactions (Figure 1). An example is installing an automated material handling system to replace a manual loading operation.

If that is not feasible, the next most desirable course of action is to add safeguarding devices that prevent a hazardous event from occurring. If such a device is activated, it typically initiates an automatic operation without human input; a machine is shut down, or a robot is disabled until an operator performs a manual reset. Examples of such devices include light curtains, interlocks, and pressure mats.

Other options are less desirable because they require human action as part of hazard avoidance: these options include visual or audio alarms, enhanced safety training, and protective equipment such as face shields, ear plugs, or gloves.



Preference	Protective Measure	Examples	Influence on Risk Factors	Classification
Most Preferred	Elimination or Substitution	• Eliminate pinch points (increase clearance) • Intrinsically safe (energy containment) • Automated material handling (robots, conveyors, etc.) • Redesign the process to eliminate or reduce human interaction • Reduce energy • Substitute less hazardous chemicals	• Impact on overall risk (elimination) by affecting severity and probability of harm • May affect severity of harm, frequency of exposure to the hazard under consideration, and/or the possibility of avoiding or limiting harm depending on which method of substitution is applied	Design Out
	Guards and Safeguarding Devices	• Barriers • Interlocks • Presence sensing devices (light curtains, safety mats, area scanners, etc.) • Two-hand control and two-hand trip devices	• Greatest impact on the probability of harm (occurrence of hazardous event under certain circumstances) • Minimal if any impact on severity of harm	Engineering Controls
	Awareness Devices	• Lights, beacons, and strobes • Computer warnings • Signs and labels • Beepers, horns, and sirens	• Potential impact on the probability of harm (avoidance) • No impact on severity of harm	Administrative Controls
	Training and Procedures	• Safe work procedures • Safety equipment inspections • Training • Lockout / Tagout / Tryout	• Potential impact on the probability of harm (avoidance and/or exposure) • No impact on severity of harm	
Least Preferred	Personal Protective Equipment (PPE)	• Safety glasses and face shields • Ear plugs • Gloves • Protective footwear • Respirators	• Potential impact on the probability of harm (avoidance) • No impact on severity of harm	

Adapted from ANSI B11.0-2010 and ANSI/PMMI B155.1-2011

Figure 1: A hazard control hierarchy ranks protective measures by their impact and implementation. (Image source: SICK)

For retrofitting existing work areas, active safeguarding devices have another advantage: speed of installation. They can be added without redesigning the work flow or training personnel in new safety procedures, both of which can take months to implement.

Design a multi-layer approach to work-cell safety

The modern industrial work cell uses a multilayer approach to safety: designers must combine active measures such as safety mats, light curtains, and lasers with visual and audible warning indicators (Figure 2). The desired result is that an operator receives warning of a potentially unsafe situation; if they then venture into harm's way, several independent devices shut down operations before disaster can strike.

Increasingly, an industrial network links these devices; the data is used to track and log incidents, as well as identify areas for future improvement. A discussion of some of the main safety devices and their application follows.

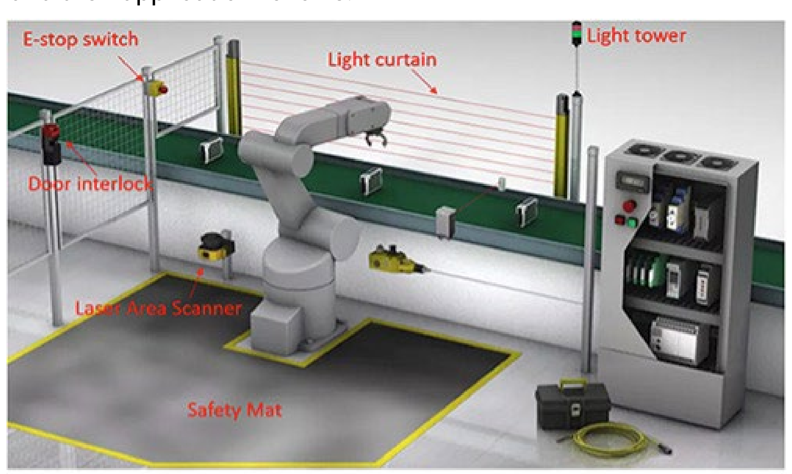


Figure 2: A variety of safety devices is used in an automated work cell so that if someone ventures into harm's way, several independent devices can shut down operations. (Image source: DigiKey)

Safety mats: a traditional, but still effective solution

A safety mat is a cost-effective means of preventing a human or wheeled machine from entering an unsafe area. Typically, a safety mat uses an open switch that closes when a specified minimum weight presses on the mat. The switch closure results in a signal to the mat controller that initiates a stop signal to the machine being guarded.

Figure 3: the Omron UM5 series safety mat system includes the mat, controller, and a variety of trim pieces to secure the mat to the floor. (Image source: Omron)

Omron Automation's UMY5S-48X37.4 is a good example: it employs two conductive plates made of 24 gauge steel that together form the switch (Figure 3). An activation force of 30 kilograms (66 lbs) closes the switch. The mat includes an integrated four-wire cable that allows a controller to monitor for fault conditions such as a permanently open connection or physical damage.

Multiple mats can be wired in series to form a safety zone around a machine. The safety zone combines with a mat safety controller such as Omron's MC4.

Dating back to the 1950s, safety mats have long been the standard form of area protection in the factory. Be aware, however, that as an electro-mechanical technology, safety mats are subject to physical, environmental, and operational abuse, and the contacts can wear out with long-term repeated use. Still, safety mats are widely used in modern highly automated factories.

A light curtain prevents access to hazardous areas

A safety light curtain is a suitable choice if the designer needs to isolate a hazardous machine or cordon off an area behind an "invisible wall" (Figure 4). A light curtain consists of a set of photoelectric transmitters that project an array of synchronized, parallel infrared light beams to a matching receiver unit. When an opaque object interrupts one or more beams in the sensing field, the receiver detects the event, and the light curtain sends a stop signal to the guarded machine.

The transmitter module contains LEDs that emit sequenced pulses of infrared (IR) light. The pulses are modulated – pulsed at a specific frequency – and the corresponding phototransistors in the receiver are designed to detect only the designated pulse and frequency. This technique improves the rejection of external light sources.

In an application such as a conveyor belt, the light curtain incorporates a muting function that causes the line to stop only when an unexpected object passes through it, but not when a product passes through.

If the muting transmitter/receiver pair detects the presence of a product on the conveyor belt (Figure 4a), it can disable a defined number of channels to prevent a

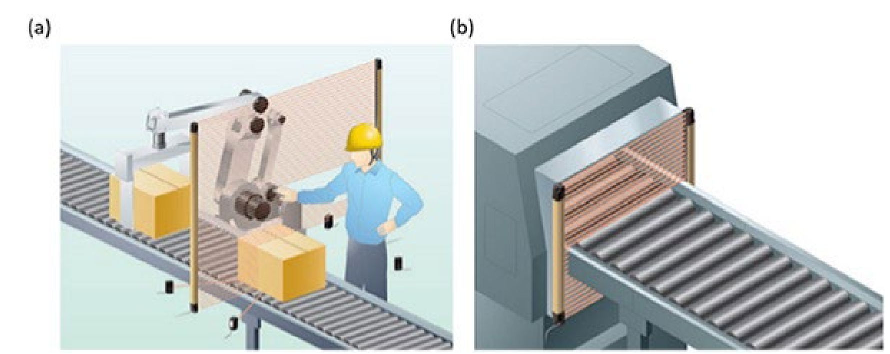


Figure 4: A light curtain can discriminate between a workpiece and a human operator (a) by performing muting control for each beam axis. It can also include a blanking action (b), so permanent obstacles are ignored. (Image source: Panasonic Industrial Automation)

false trigger. A human operator, however, can still interrupt one of the active channels and cause an alarm. When the muting system detects that the product has passed, it reenables the muted channels.

Additionally, a blanking function can disable channels (Figure 4b) that are always blocked, by a piece of equipment, for example.

The SF4D series of light curtains from Panasonic Industrial Automation includes multiple products optimized for different applications. The "H" series devices are intended to detect hand-sized objects, with a vertical spacing between beams of 20 mm (0.8"). For example, the SF4D-H28 has 28 transmit/receive channels that form a curtain 550 millimeters (mm), or 21.7 inches (") high. This product has an operating range from 0.2 meters (m) to 9 m.

With a 20 mm (0.787") spacing, "F" series products protect against smaller objects such as fingers. The SF4D-F79 features 79 transmit/receive pairs for a protective height of 790 mm (31.1") and has a range of 0.2 m to 12 m.

The SICK C4C-SA03030A10000 transmitter and its matching C4C-EA03030A10000 receiver combine to form a 300 mm (11.8") light curtain with a maximum range of 15 m (49 feet). The company also offers a range of transmitter/receiver pairs with protective heights up to 900 mm (35.4").

A laser scanner allows design flexibility in area protection

In the last couple of decades, laser technology has also begun to help improve safety on the factory floor. A safety laser scanner can provide three-dimensional protection of an area, and offers the designer increased flexibility to tailor the system response by specifying different warning and safety bands, also known as zones, around the hazard (Figure 5).

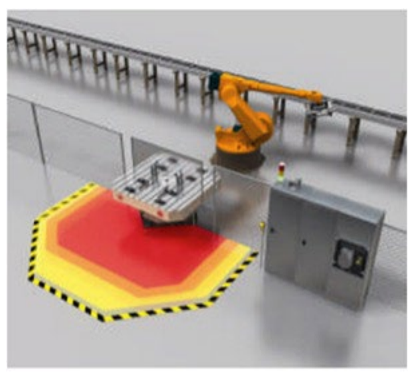


Figure 5: A laser scanner allows the designer to set up multiple safety zones with different response levels. (Image source: SICK)

Once an object or person is detected in the outer warning zone, the scanner sends a warning signal to an audible or visible indicator that notifies them of a potential hazard. When the person or object enters the inner safety field, the laser scanner sends a signal to stop the hazardous motion of the robot or machine. The zones are programmable and can be changed dynamically by an input to the safety scanner.

Safety laser scanners use time-of-flight technology. The transmitter emits a pulsed laser beam that is reflected by an intruding object and detected by the receiver. The time between transmission and reception is proportional to the distance between the scanner and the object.

An integrated rotating mirror deflects the pulsed laser beam and enables the unit to perform a fan shaped scan of the surrounding area. The real-time measurement data can be transmitted over a networked interface for further analysis if needed.

SICK's S32B-2011BA safety laser scanner, for example, uses a laser diode to produce a near-infrared pulse with a wavelength of 905 nanometers (nm). This device is part of SICK's S300 family and features a protective range of 2 m and a warning range of 8 m. Another S300 device, the S32B-3011BA, features an expanded protective range of 3 m.

The OS32C Area Scanner from Omron Automation and Safety features a monitoring field of up to 270° and includes two separate warning zones, plus a safety zone (Figure 6). The OS32C can communicate via the industrial EtherNet/IP protocol: it can be monitored by ODVA EtherNet/IP-compliant products such as programmable logic controllers (PLCs) or industrial human-machine interface (HMI) modules.

Figure 6: Omron's OS32C family of area scanners features multiple programmable zones (Image source: Omron Automation)

A variety of data including system status, zone status, and measurement details can be transmitted.

Until recently, laser scanners have been considerably more expensive than safety mats. But lower cost laser safety scanners are becoming available, and the return on investment (ROI) for safety scanners compares well to older technologies from a total-cost-of-ownership (TCO) perspective. The TCO analysis particularly favors a laser scanner in a high traffic area where a safety mat might have to be periodically replaced.

Other safety components help to "connect the dots".

The main safety devices discussed above are used in conjunction with other safety components that might not be as technologically sophisticated, but play a vital role in plant safety. Among these are items such as emergency switches, door interlocks, light towers, and cable-pull actuators. Designers can find out more about these products on DigiKey's Safety Components page.

Conclusion

Designing a safe industrial environment requires a multi-layer approach which employs multiple strategies to guard against unwanted human-machine interactions.

The key is to first prevent personnel and equipment from entering potentially dangerous areas. Safety mats, light curtains, and safety laser scanners play an important role in detecting intrusions and shutting down machines automatically without the necessity of human interaction.

Using laser scanners to safeguard your workforce

Written by:
Bill Giovino
Contributed By DigiKey's North American Editors

Most industrial automation facilities are hazardous workplaces. There are areas of the floor where automated or semi-automated equipment is operational, and often—while the equipment is in use—such areas are extremely hazardous for humans to enter. Hazardous areas can include equipment such as high voltage generators, industrial welding machines, heavy-duty pick and place machines, robots, and other exposed machinery where an unauthorized access can result in serious human injury. Often these areas also require quick and easy access during times the machinery is not operational, making fences and gates cumbersome or impractical. Colored reflective strips on the floor can be used to indicate a hazardous area, but a more effective means would be an active detection system for the floor that could take action if a human enters the hazardous zone.

This article explains how safety laser scanners can be used to monitor dangerous industrial work areas by scanning the target area with laser beams. It examines the advantages of safety laser scanners in busy industrial facilities while keeping human operators safe when approaching hazardous equipment. It then shows how industrial laser scanners from Banner Engineering and IDEC can easily monitor an area of the floor to detect human operators and take safety actions such as sound an alarm, slow the machine, or shut down the equipment.

Keeping hazardous work areas safe

Industrial facilities can have high voltage equipment capable of inflicting serious damage on operators. While the equipment can be kept isolated or enclosed in cages, the human technicians tasked with operating the equipment must be protected. Manufacturing facilities can also have industrial robotic equipment that can easily knock an operator off their feet without warning. If the robot is on an automated assembly line it can usually be fenced off, but if it is an operator-attended workstation for handling and processing materials, it might need to be easily accessible to anyone on a busy factory floor. Pick and place machinery is also usually accessible but safe from passers-by; still, it must be kept safe from curious visitors that might want to stick their hands and arms where they don't belong.

With these types of industrial equipment on the floor it's important when planning an industrial facility to ensure human operators are kept safe. Rather than making these safety decisions when the equipment floor plan has already been laid out, it's best to make safety preparations during the initial stages of planning the

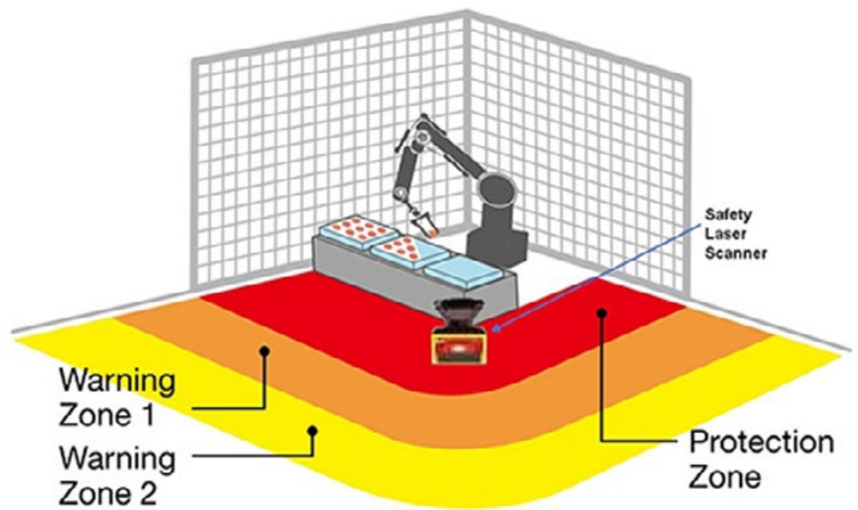


Figure 1: A typical safety laser scanner setup consists of two warning zones that issue alerts during an intrusion, and a protection zone that puts the equipment in a safe or non-operational condition during an intrusion. (Image source: IDEC)

facility. This is especially true when using safety laser scanners. These scanners flood a selected area with multiple focused lasers, and the laser light is reflected back to receivers on the scanner. The scanner uses this reflected light to create a two-dimensional line-of-sight map of the floor area in the scanner's detection region. If a laser beam in the scanned area is broken, the safety laser scanner can detect the event a nd be programmed to set off warning lights and alarms, or even disable automated equipment. This keeps human operators safe while increasing machine uptime, improving the productivity of the facility.

The entire area to be scanned must have a clear line of sight to the safety laser scanner (Figure 1). If the work area is not planned for a safety laser scanner from the beginning, the scanned area might contain objects in the path of the beam creating blind spots for the scanner beams. Worse, the scanned area might contain large and non-movable obstructions like a load-bearing pillar. These obstacles can be avoided if the industrial facility is designed from the start with safety laser scanners in mind.

The work area should be set up for a safety laser scanner in mind from the beginning. A technician programs the scan zones into the scanner using the visual planning software that comes with the scanner. As seen in Figure 1, the area is usually programmed with one or more warning zones and a final protection zone. Each warning zone can be set using configuration software to set off an alarm or alert. Trespassing into the protection zone can be set to shut down the equipment.

Safety laser scanner operation

Safety laser scanners have a built-in detection algorithm that uses a programmable laser sampling rate to verify intrusions. Most scanners are set at the default sampling rate of 2x to verify an object—that is, the object must be detected twice in a row to trigger an action. Multiple sampling prevents foreign particles such as metal shards or insects from triggering a false alert. Increasing the number of samples decreases false positives but also increases detection time. If the detection time is increased, safety can be maintained by increasing the detection distance, allowing more time to provide an alert.

A rugged safety laser scanner designed for large industrial environments is the Banner Engineering SX5-B safety laser scanner (Figure 2). The SX5-B has a maximum range for safety and warning zones of 5.5 meters (m) and 40 m, respectively, and connects to the facility's wired Ethernet using an M12 connector. It is IP65 rated, making it immune to dust and water sprays. The laser receptors filter out visible light, making it immune to ambient light interference. The SX5-B can be configured for up to six zone sets—for example, five warning zones and one protection zone.

The SX5-B has a color LCD display to indicate the status of the safety laser scanner. The display can

Figure 2: The Banner Engineering SX5-B safety laser scanner has a maximum range for safety and warning zones of 5.5 m and 40 m, respectively. It can provide 275 degrees of coverage and is immune to ambient light and dust. (Image source: Banner Engineering)

indicate up to 27 different status, diagnostic, and error conditions including a warning or protection violation, or indicate if the laser detectors need to be cleaned.

The SX5-B has a 275-degree protection field and can continuously scan the protection area for intrusions in the monitored area. The scanner can filter out false positives from dust, dirt, or small debris. It is 152 millimeters (mm) high, making it easy to position in a busy area without interfering with factory operations. The configuration software is easy to use and allows flexible detection areas to be laid out including rectangular, circular, or irregular shaped. This flexibility allows the SX5-B to safely monitor only the area of concern, while excluding safe areas where an intrusion alert is not needed.

Connecting multiple safety laser scanners

For large detection areas IDEC has the SE2L-H05LPC safety laser scanner (Figure 3). It has much of the same features as the SX5-B with the added advantage of being able to connect four SE2L scanners acting together.

The SE2L-H05LPC connects to the local network using a waterproof 100Base-T Ethernet connector and is configured from a host PC using a USB 2.0 connection. Alternatively, configuration data can be transferred to the SE2L using a micro SD memory card. This makes transferring a new configuration to a different SE2L unit very fast and efficient by not having to connect it to a PC.

The SE2L is 95 mm high, making it easy to fit in small areas. The detection angle is 270 degrees with a maximum detection range of 5 m. It can filter out ambient light and is rated at IP65, preventing dust ingress and making it more resistant to false detection events.

For monitoring large floor areas, up to four SE2L scanners can be connected together. One host SE2L is connected to the main control board or programmable logic controller (PLC) responsible for the equipment and the scanners. Up to three more SE2L scanners are connected to the host scanner's RS-485 port. An alarm or event indication on any of these three SE2L scanners is communicated

Figure 3: The IDEC SE2L-H05LPC safety laser scanner supports a 270-degree protection field for up to 5 m. Four SE2L scanners can be easily connected together using RS-485 for simultaneous operation. (Image source: IDEC)

to the host scanner over the RS-485 connection. The host then communicates the appropriate action to the PLC or to any of the alarm indicators. This allows all four scanners to share common alarm and alert indicators for their individual detection areas. This greatly simplifies configuration and reduces wiring.

Conclusion

Keeping human operators safe is a top priority in industrial automation facilities. Some areas are too hazardous for people to access while equipment is operating, but at the same time human operators need easy access to the equipment when it is not operational. Safety laser scanners provide an easy and effective means of monitoring the floor area around hazardous equipment. This improves productivity by keeping human operators safe while allowing the equipment to be easily accessible when required during normal operation.