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SAFETY,
TECHNOLOGY
& INNOVATION

SAFETY SOLUTION

BASIC GUIDE

Second Edition

realizing

Y107-E1-10

⚠ Warnings

Serious injury may possibly occur due to loss of required safety functions.
When building the system, observe the following warnings to ensure the integrity of the safety-related components.

●Setting Up a Risk Assessment System

The process of selecting these products should include the development and execution of a risk assessment system early in the design development stage to help identify potential dangers in your equipment and optimize safety component selection.

- Related International Standards:
  ISO 12100 General Principles for Design - Risk Assessment and Risk Reduction

●Protective Measure

When developing a safety system for the equipment and devices that use safety components, make every effort to understand and conform to the entire series of international and industry standards available, such as the examples given below.

- Related International Standards:
  ISO 12100 General Principles for Design - Risk Assessment and Risk Reduction
  IEC 60204-1 Electrical Equipment of Machines - Part 1: General Requirements
  ISO 13849-1, -2 Safety-related Parts of Control Systems
  ISO 14119 Interlocking Devices Associated with Guards - Principles for Design and Selection
  IEC/TS 62046 Application of Protective Equipment to Detect the Presence of Persons

●Role of Safety Components

Safety components incorporate standardized safety functions and mechanisms, but the benefits of these functions and mechanisms are designed to attain their full potential only within properly designed safety-related systems. Make sure you fully understand all functions and mechanisms, and use that understanding to develop systems that will ensure optimal usage.

- Related International Standards:
  ISO 14119 Interlocking Devices Associated with Guards - Principles for Design and Selection
  ISO 13857 Safety Distances to Prevent Hazard Zones being Reached by Upper and Lower Limbs

●Installing Safety Components

Qualified engineers must develop your safety-related system and install safety components in devices and equipment. Prior to machine commissioning verify through testing that the safety components work as expected.

- Related International Standards:
  ISO 12100 General Principles for Design - Risk Assessment and Risk Reduction
  IEC 60204-1 Electrical Equipment of Machines - Part 1: General Requirements
  ISO 13849-1, -2 Safety-related Parts of Control Systems
  ISO 14119 Interlocking Devices Associated with Guards - Principles for Design and Selection

●Observing Laws and Regulations

Safety components must conform to pertinent laws, regulations, and standards. Make sure that they are installed and used in accordance with the laws, regulations, and standards of the country where the devices and equipment incorporating these products are distributed.

●Observing Usage Precautions

Carefully read the specifications and precautions as well as all items in the Instruction Manual for your safety component to learn appropriate usage procedures. Any deviation from instructions will lead to unexpected device or equipment failure not anticipated by the safety-related system.

●Transferring Devices and Equipment

When transferring devices and equipment, be sure to retain one copy of the Instruction Manual and supply another copy with the device or equipment so the person receiving it will have no problems with operation and maintenance.

- Related International Standards:
  ISO 12100 General Principles for Design - Risk Assessment and Risk Reduction
  IEC 60204-1 Electrical Equipment of Machines - Part 1: General Requirements
  ISO 13849-1, -2 Safety-related Parts of Control Systems
  IEC 62061 Functional Safety of Safety-related Electrical, Electronic and Programmable Electronic Control Systems

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Chapter 1

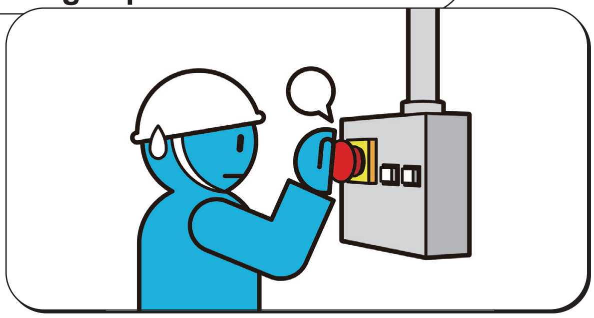
Introduction to Safety of Machinery

1. Safety of Machinery

Safety of machinery is the concept of ensuring safe use of machinery through machine design.
Machine malfunctions and human errors can occur. Therefore, in order to ensure safety, the machine must be safe to use even if it malfunctions or its operator makes a mistake.
Designing a machine based on the concept that “Humans make mistakes” and “Machines malfunction” is the basis of the safety of machinery.

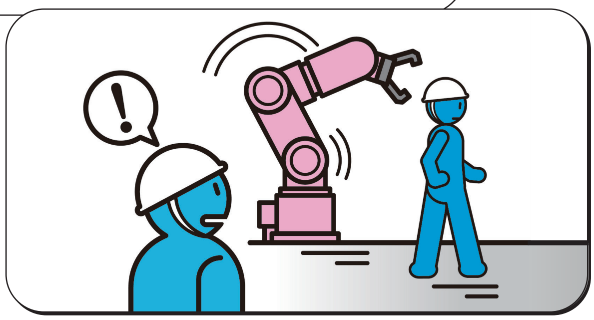
Humans make mistakes.

Ensure safety irrespective of operating experience



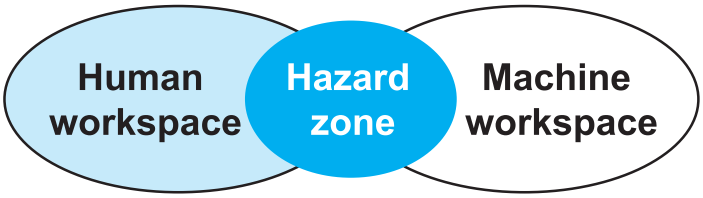
Machines malfunction.

Ensure safety during machine setup and maintenance

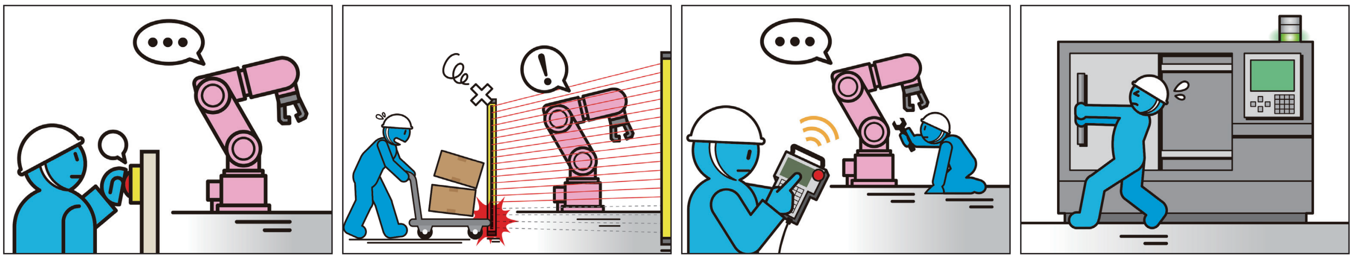


Machinery hazards occur in the areas, where the human workspace overlaps the machine workspace.
Preventing machinery hazards begins by eliminating mechanisms that facilitate hazardous conditions.
The following principles can be used to achieve this goal.

1. Spatial separation between human and machine workspaces (Isolation principle)
2. Temporal separation between human and machine (Stoppage principle)



By using the “Isolation principle” and “Stoppage principle”, machines can be designed to ensure human safety.



Emergency stop ensures termination of the power source.	The machine stops safely even if a failure occurs on light curtains.	Unauthorized personnel intrusion disables the restart.	A door will not open until a machine stops.

2. Background for the Need of Safety of Machinery

Changes in Social Consciousness

In recent years, there has been increasing interest in corporate social responsibility. For example, product safety to protect consumers is stipulated by law in each country, and companies are obliged to fulfill their responsibilities as a manufacturer. It is not necessary to provide examples of product accidents to realize the very strict monitoring of manufacturing liability for safety and ease of mind in societies that share a common ideal of respect for human beings. And the responsibility of companies for the safety of workers on production sites is also strictly monitored. Companies face not only criminal, civil, and damage liability for any accidents that might occur, but their corporate image may become greatly damaged as a result. The social responsibility of companies to promote safety has skyrocketed in recent years.

Changes in People

In some countries, changes in social structure have brought changes in the people that work at production sites. For example, trends such as a decline in the workforce due to the retirement of skilled workers and a declining birthrate, diversification of employment patterns, and an increase in foreign workers have become evident everywhere in all industries. As a result, diversification continues to increase in other ways, such as experience, language, and social habits.

Changes in Production Locations

Market globalization has taken production sites from fixed sites across national borders. Production is faced with the need for more competitive products and new markets combined with demand for production sites in newly industrialized countries. Offshore production means dealing with different laws, infrastructures, cultures, and values. Thus, it is necessary to design production facilities and machines that can be used in a different environment from conventional ones.

Changes in Machines and Production Facilities

Manufacturers are facing more diversification in consumer needs driving demand for more variation in products. Production sites are required to change between many different products at relatively short intervals, resulting in frequent changes in production facilities. Machines must support more functionality. As equipment and machinery are becoming more complex and multi-functional, the potential of dangerous events different from conventional ones is increasing.

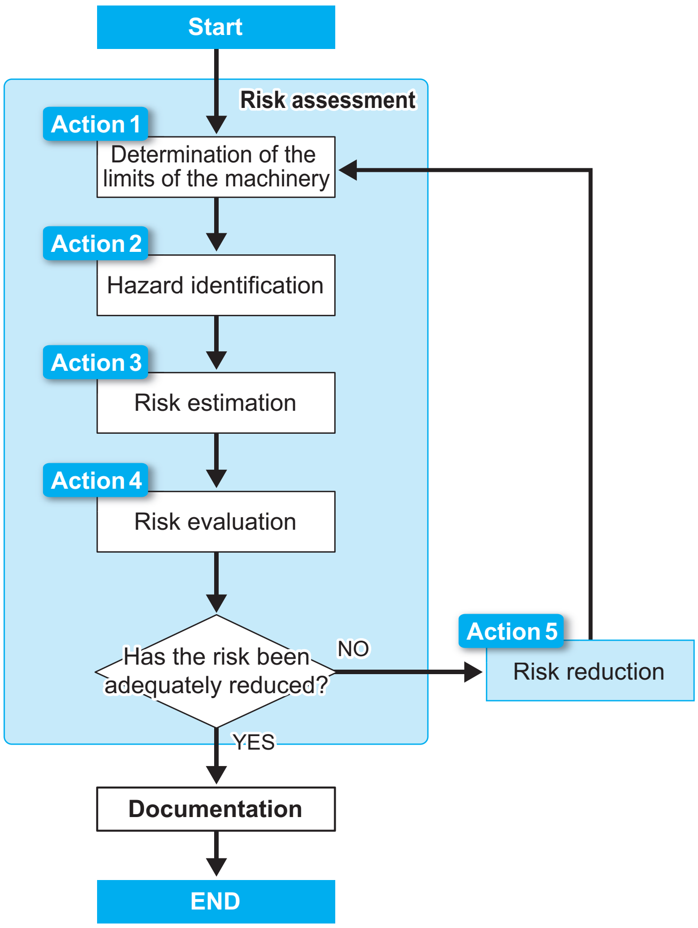
The relationship between workers and machines and the environment in which they operate has thus changed in various ways. And yet, manufacturing is not possible until a worker operates a machine. Across changes in the operating environment, society demands that machines and production facilities must be safe regardless of where they are used or who uses them. This is required not only in the workers, but also in the technologies. This is the concept of Safety of Machinery.

3. How to Ensure Safety of Machinery

The key to creating a safe manufacturing site based on the concept of machine safety is to analyze where and how hazardous events associated with the machine occur, and to implement measures that match the analysis results. These steps are called “risk assessment” and “risk reduction” respectively. The general procedures for these steps are standardized as an international standard called ISO 12100.

The ”Risk assessment” and “risk reduction” process according to ISO 12100 is as follows:
For more details, refer to *Chapter 2 Risk Assessment and Risk Reduction*.

1. Determine the requirements for those who use the machine and the conditions for its operating environment [Action 1. Determination of limits of the machinery]
2. Find hazards that may occur throughout the machine lifecycle (from manufacturing, usage, maintenance, to disposal) [Action 2. Hazard identification]
3. Examine the probability of occurrence of the identified hazards and how much harm they may cause if they occur [Action 3. Risk estimation]
4. Determine whether or not “risk reduction” is necessary as a result of examination in Action 3. [Action 4. Risk evaluation]
5. Implement necessary risk reduction measures. [Action 5. Risk reduction]

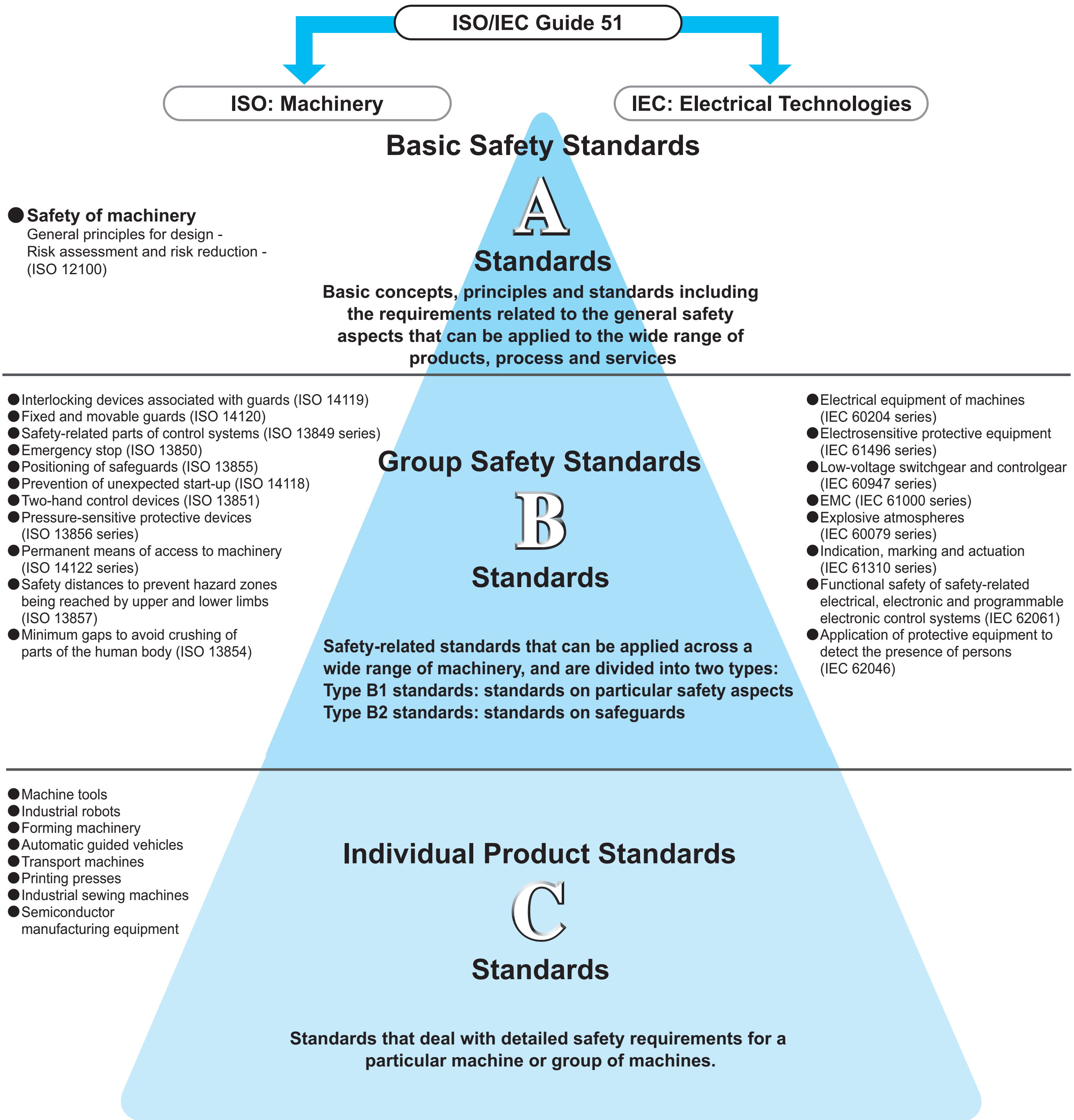


One of the “risk reduction” actions to prevent hazardous events relevant to machines is to use control devices called safety components. You also need to evaluate the safety of control circuits using such safety components according to international standards. For risk reduction using safety components, see *Chapter 2*. For more details about evaluation of control circuit using safety components, refer to *Chapter 1 Performance Level in the Safety Component Technical Advanced Guide* (Cat. No. Y221).

4. International Standards for Safety of Machinery

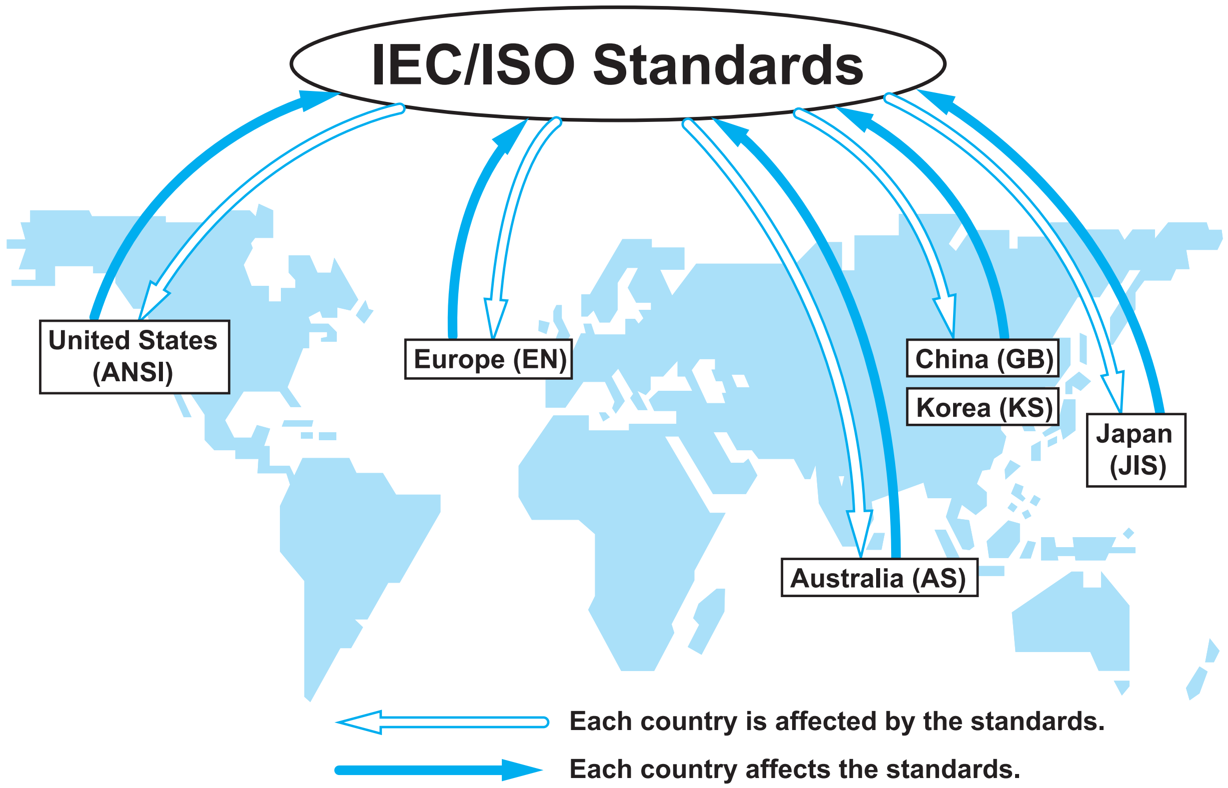
System of Standards for Safety of Machinery

The international standards for machine safety is created by the International Electrotechnical Commission (IEC) which prepares international standards for all electrical, electronic and related technologies, and the International Organization for Standardization (ISO) which prepares international standards for all technologies other than electrical and electronic technologies (machinery and management). European countries often take the initiative in proposing the standards and establishing them as ISO/IEC international standards. The standards related to the safety aspects are classified into three tiers of standards of A, B and C as shown below for coverage of a wide variety of machinery as well as for fulfilling the specific purposes.



Accelerated International Harmonization of Safety Standards

The safety standards which have been created by each country on its own are now geared to the harmonization with ISO/IEC standards by the WTO/TBT Agreement. It is mandatory for WTO members to adopt policies conforming to ISO/IEC standards into their safety regulations of each country. With technological advancement, the international standards are actively greeted with new proposals and amendments each year and the integrated standards are now simultaneously under way throughout the world.



International Standards and Design of Machines

It is effective to consider the following in today's machine designs.

- The newest information on international standards and industry standards must be collected, and the contents of new and revised standards must be understood.
- The relationships and differences between related standards such as ISO, IEC, EN, ANSI, and JIS must be understood.
- Global safe designs must be created by taking into account the differences.

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Chapter 2

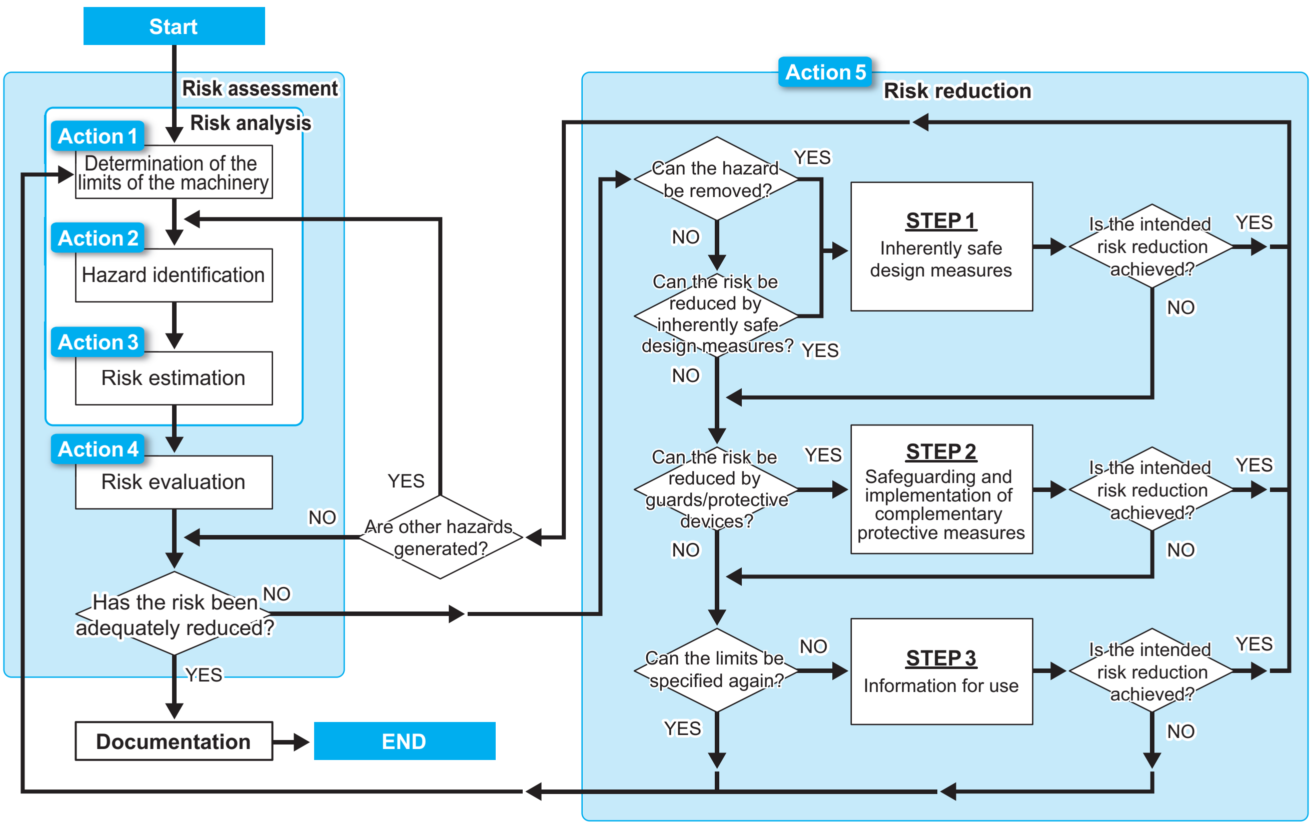
Risk Assessment and Risk Reduction

1. Risk Assessment According to ISO 12100

Risk Assessment and Risk Reduction Process

To operate machines safely, risk must be reduced by analyzing and assessing machine hazards. ISO standards define the procedure to achieve risk assessment and risk reduction.
The hazards and risk levels present at the machine are different for each phase of the machine lifecycle (construction, modification, transportation and disassembling, decommissioning, etc.). Machines must be designed and manufactured so that they operate safely in every phase of their lifecycle. ISO 12100 is a standard that stipulates principles to logically perform the risk assessment and to correctly select the subsequent risk reduction measures.

Implementation of the safety of machines can be determined in 5 actions. The details examined during the process must be documented and kept as the evidence for the safety design of the machine.



Action 1 Determination of the limits of the machinery

Defining the limits of machinery requires the premises to consider when performing risk assessment. Usage limits must take into account the following:

- Requirements for each phase of lifecycle
- The intended use and operation and the reasonably foreseeable misuse and malfunction
- Restriction by factors such as the operator's gender, age, dominant hand, and physical abilities (e.g., impaired eyesight or hearing, size, and strength)
- Expected user training, experience, and competence

  etc.

In addition to the above, the following limits must be taken into consideration: the "space limits" such as the range of movement of the machine and the space required for machine maintenance, "time limits" such as the machine life and inspection intervals, and "other limits" including the materials processed by the machine as well as the environmental requirements for operating the machine.

Action 2 Hazard Identification

Hazard identification means checking for all the hazards, hazardous conditions, and hazardous events associated with the machine. Typical examples of hazards include the following:

- Mechanical hazards
- Electrical hazards
- Thermal hazards
- Noise hazards
- Vibration hazards
- Materials and substances hazards
- Ergonomic hazards
- Hazards associated with the environment in which the machine is used

For more information, refer to *Typical Hazards* on the next page.

Action 3 Risk Estimation

The following set of operations are called "Risk Estimation": after checking for hazardous conditions and hazardous events, the risk factors are determined and the risks are estimated from the severity of the possible harm and the probability of the hazard occurring. During the risk estimation, risks are estimated as quantitatively as possible against all hazards including sources appearing unexpectedly as well as lasting sources.

Action 4 Risk Evaluation

After estimating the risk, the risks are evaluated to determine whether the level of risk must be reduced.
If the level of risk must be reduced, safety measures as described in Action 5, such as changing the design or providing safeguards, are taken.

Action 5 Risk Reduction

Taking the following measures against each risk is called "Risk Reduction." Proper risk reduction must be accomplished through three steps: "Step 1. Inherently safe design measures", "Step 2. Safeguarding and complementary protective measures", and "Step 3. Information for use".

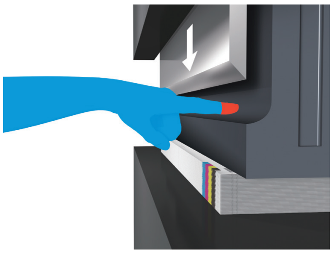
- Eliminate or reduce hazards as much as possible.
- Reduce the probability of exposure to hazards and severity of harm.
- Use safeguards and safety devices.
- Determine that the performance and functional characteristics of the safety measures are suitable for the machine and its use.

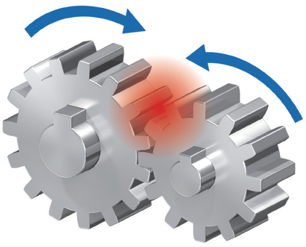
Typical Hazards

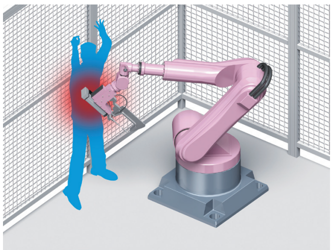
In risk assessment, the following hazards are identified. Typical hazards are also introduced in ISO 12100 Annex B.

Mechanical Hazards

Cutting or severing with sharp edges, shearing, drawing-in, or trapping by rotating elements, impacts and crushing by movable elements, etc.





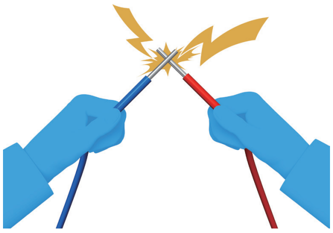


Electrical Hazards

Electric shock due to contact with live parts, fire due to arcing, etc.

Thermal Hazards

Burns from fire or explosion, frostbite due to extremely cold objects, etc.



Noise Hazards

Tinnitus, hearing loss, and other problems due to unbalanced rotating parts or moving parts

Vibration Hazards

Bone and joint disorders, neurological disorders, etc. caused by vibrating or mobile devices

Radiation Hazards

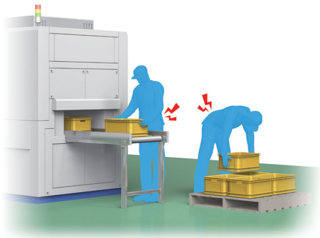
Damage or burns to eyes and skin, etc. from laser and infrared radiation

Materials and Substances Hazards

Respiratory distress, suffocation, and poisoning due to gas, hypersensitivity to dust, etc.

Ergonomic Hazards

Muscle and bone disorders due to physical exertion and posture, stress due to mental overload/underload, etc.

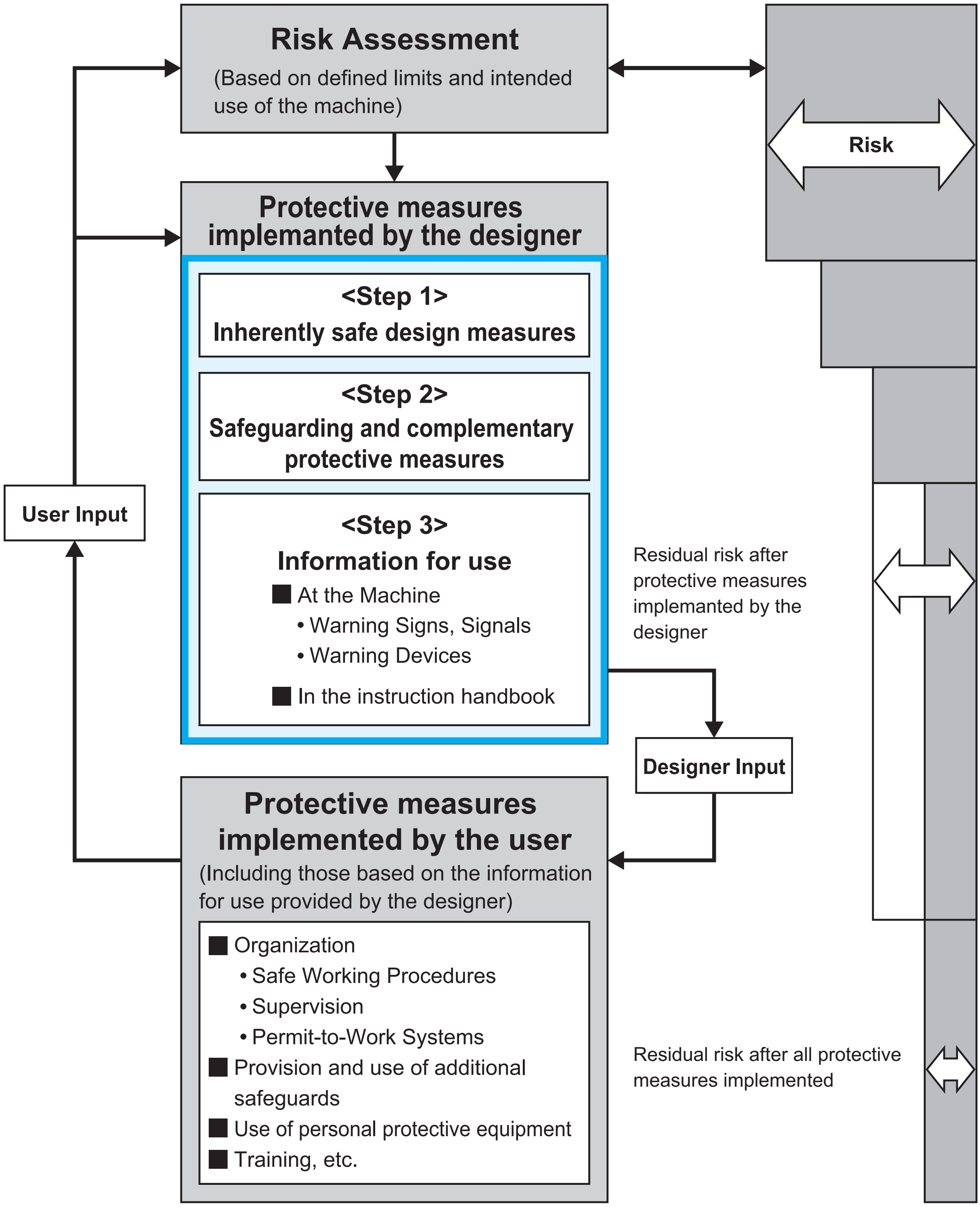


Hazards associated with the environment in which the machine is used

Combination of Hazards

2. Risk Reduction Process

Risk reduction is considered in three stages: “Step 1: Inherently safe design measures”, “Step 2: Safeguarding and complementary protective measures”, and “Step 3: Information for use”. This methodology for implementing risk reduction measures are called “3-step method”.

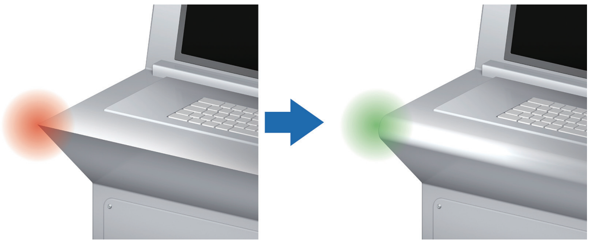


Risk Reduction Example

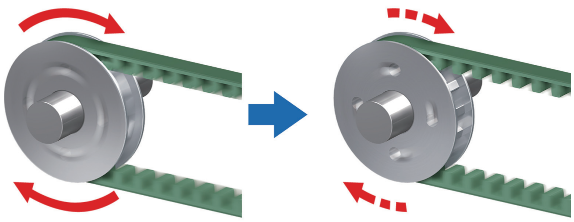
• Step 1: Inherently safe design measures

The first thing to consider among the 3-step method is the “Inherently Safe Design Measures”. The following examples are provided in ISO 12100.

- Remove hazards and reduce exposure frequency
- Maintain visibility, and avoid sharp edges and projections
- Use alternative materials with few dangers that reduce noise and radiation levels, and reduce actuation force
- Select appropriate materials (Material quality, stresses, corrosiveness etc.)
- Use inherently safe design measures in the below control system
  - Perform automatic surveillance of safety functions implemented under safeguarding measures
  - Employ diagnostic system to support fault detection
- Use measures listed below that minimize the failure probability of safety functions
  - Use reliable components
  - Use "oriented failure mode" components
  - Employ redundant systems for components and sub systems
- Automatically limit exposure to hazards
- Limit exposure to hazards through location of setting and maintenance points outside hazard zones.



Example of avoiding sharp edges



Example of reducing operating force

As for the specific method to use as the inherently safe design measures, you must take into account not only the effect of risk reduction but also the possibility of creating a new hazard by using the method before making a decision. Some examples of effective viewpoints are listed below:

- Ability of movable elements such as robots, optimization of specifications (size, number of control axes, movable range)
- Hazards that may be exposed depending on the positional relationship between an operator and machine (mechanical hazards, thermal hazards)
- Workability (handling workpieces, repeated operations, manual operations, etc.)
- Teaching operability (operating procedure, operating position, etc.)
- Safety of maintenance (visibility, lockout and tagout of main breaker, residual pressure release mechanism of pneumatic circuit, etc.)

• Step 2: Safeguarding and complementary protective measures

The second thing to consider is “safeguarding” and “complementary protective measures”.
The following measures can be considered for safeguarding:

- Employ fixed guards
- Employ sensitive protective equipment (safety light curtain, safety laser scanner, safety mat, etc.)
- Employ interlocking movable guards

For details of risk reduction using safety components such as sensitive protective equipment and interlocking devices, see the next section *Risk Reduction with Safety Components*.
In addition, typical examples of complementary protective measures include the followings:

- Provide an emergency stop function that can be applied quickly
- Employ an isolation device that can be locked

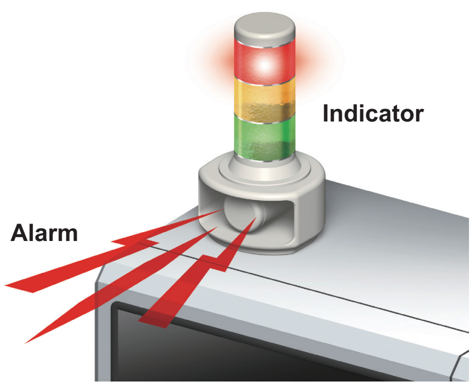
Example of emergency stop equipment

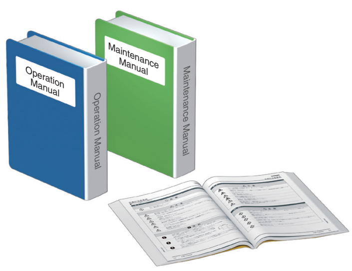
Example of isolation device that can be locked

• Step 3: Information for use

”Information for use” to alert machine operators or notify them of safe work procedures is the last step in the 3-step method. The following examples are provided in ISO 12100.

- Supplementary documentation or labels should notify of residual risks, and necessary training, personal protective equipment, and additional protective devices
- Emit an audiovisual warning
- Display manufacturer, model, and specifications on the machine
- Supplementary documentation to include storage conditions, weight, dimensions, and installation and disposal methods

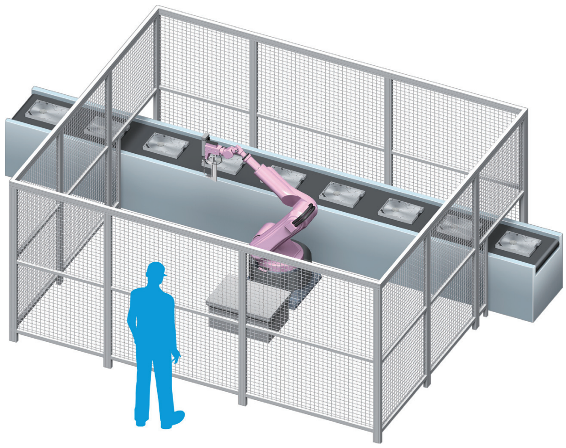




Risk Reduction with Safety Components

For risk reduction, devices called safety components are used in “Step 2. Safeguarding and complementary protective measures”.

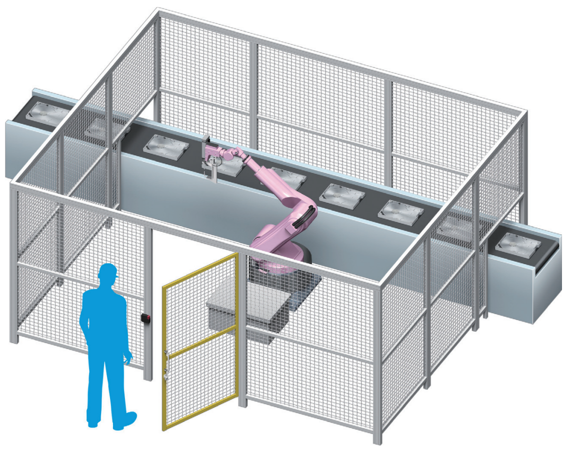
As shown in the figure below, for example, safeguarding with only a fixed guard seemingly ensures safety because the operator and the machine can be spatially separated.



However, if the whole workspace is enclosed by a fixed guard, and if the machine breaks down and parts need to be replaced, the operator cannot approach the machine unless the fixed guard is removed with a tool. Removing and restoring the fixed guard will require a lot of effort. Moreover, once the fixed guard is removed, it may not be installed as it was before, which may result in a hazardous situation. By utilizing safety components to implement a measure to allow operators to safely approach the machine, it is possible to ensure both safety and work efficiency.

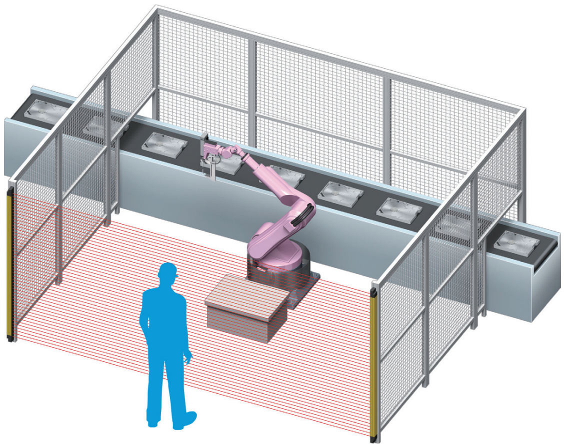
• Example 1: Using a movable guard and an interlocking device

First, a movable guard (door) is installed for a worker to enter the area around the machine. Next, an interlocking device is installed to detect the opening and closing of the movable guard. Then it is possible to construct a circuit that stops the system when a worker opens the movable guard to approach the machine.
In general, a guard interlock switch is used as an interlocking device to detect the opening and closing of movable guards. Some guard interlock switches have a lock mechanism to prevent frequent opening and closing while the machine is in operation, and some have a lock mechanism with a portable key to prevent a worker outside the guard from accidentally closing the movable guards when another worker is inside the guard.



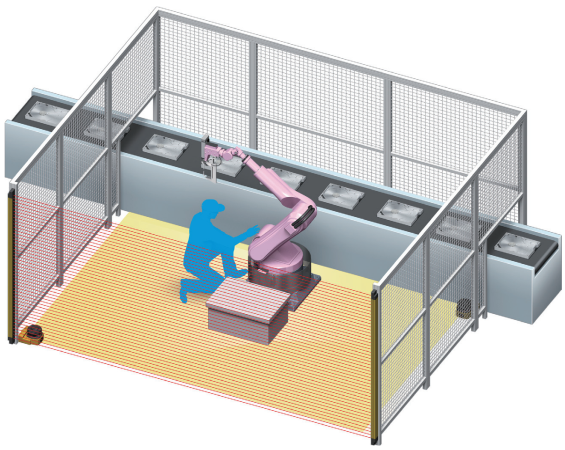
• Example 2. Using a safety light curtain

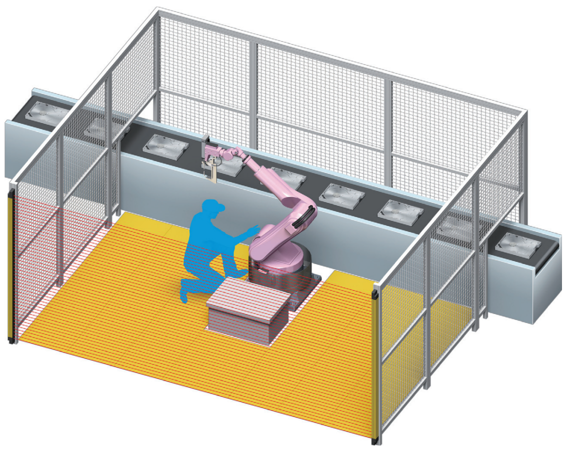
Safety light curtains can be used in places where workers are expected to enter frequently. The safety light curtain can be used in a circuit that stops the system when the safety light curtain detects the presence of a worker approaching the hazard of the machine from the sensor beams blocked by the worker.
There are various types of safety light curtains, depending on the size of the detectable object that blocks the beams, and a muting function that allows workpieces to pass through while preventing workers to do so. Also, the installation position of a safety light curtain needs to be examined based on the distance from the hazard and the time it takes for the hazard of the machine to stop.



• Example 3. Using a safety light curtain and a presence sensing device

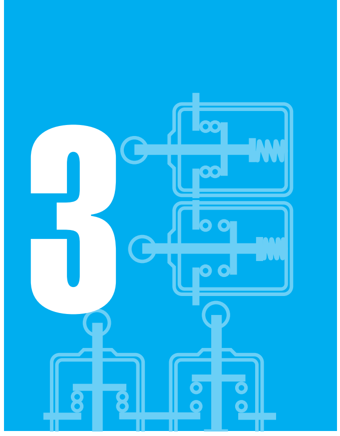
To ensure a wider opening for workers to approach the machine, a combination of a safety light curtain and a safety laser scanner and/or a safety mat is also effective. The combination allows construction of a circuit that keeps the moving parts of the machine stopped while a worker stays within the perimeter of the machine after blocking the safety light curtain to enter the area.
The selection of presence sensing devices such as safety laser scanners and safety mats to detect the presence of workers around the machine is determined by the size, shape, and environment of the workspace where the workers can stay.





To select and install safety components, you need to consider specifications of the machine for risk reduction.
In addition to the above-mentioned input devices that detect the worker approaching the machine, safety components include safety logic devices that control the machine to stop and safety output devices. For more details about safety components, see *Chapter 3 Safety Component Characteristics*.

MEMO



Chapter 3

Safety Component Characteristics

1. Definition of Safety Components

Safety components are control equipment to construct safety-related control systems to attain safety in machines.

Definition of Safety Components

Safety components are defined in general as shown below according to the EU Machinery Directive (2006/42/EC).

- A component serves to fulfil a safety function
- A component is independently placed on the market
- The failure and/or malfunction of a component endangers the safety of persons
- A component is not necessary in order for the machinery to function, or for which normal components may be substituted in order for the machinery to function

Omron refers to those that mainly fall under these definitions as safety components.

Examples of Safety Components

The following components are mentioned as safety components in the Machinery Directive. Refer to the Machinery Directive for details.

- Protective devices designed to detect the presence of persons
- Power-driven interlocking guards used in presses and molding machines
- Guards and protective devices used for protection from moving parts
- Logic units to ensure safety functions
- Emergency stop devices
- Two-hand control devices

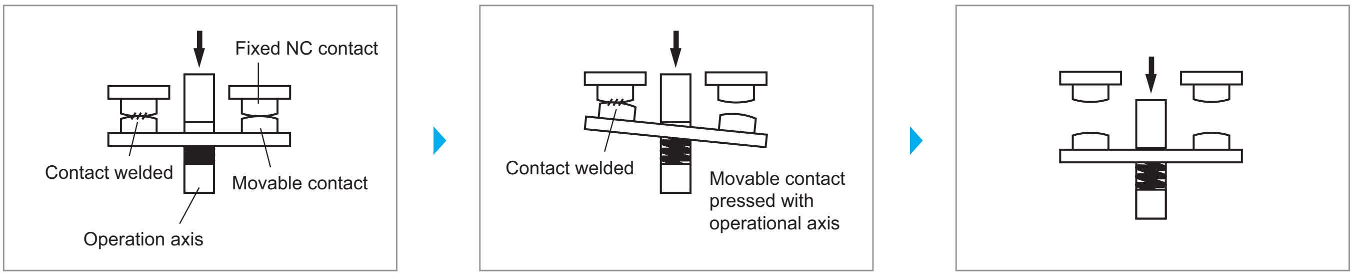
2. Safety Input Device - Safety Switch

Safety switches are used for various purposes such as interlocking, emergency stop, and mode switching.
With a mechanism called direct opening action and a structure that cannot be easily defeated, safety switches are designed to ensure safe operation.

Feature of Safety Switches

• Direct Opening Action

A mechanism used for safety switches that transmits a safety signal through opening and closing of contacts. With this mechanism, contacts can be opened by moving the actuator even if a contact is welded. IEC 60947-5-1 describes it as direct opening action.



(1) Contact welded

(2) Opening welded contact

(3) Completed Opening

Contacts with direct opening action can be opened by applying the specified direct operating force (DOF) to the actuator to move it to the end of the direct operating travel (DOT) even when the force equivalent to the contact welding force (10 N) is applied in the direction of closing the contacts. The gap between open contacts must withstand the specified impulse voltage.

Guard Interlock Switch

The guard interlock switch is a component of a safety circuit that detects that a movable guard provided for preventing operators from entering the hazardous zone of the machine is opened, and safely stops the machine. Switches such as safety door switches and safety limit switches are classified as the guard interlock switch.

Guard interlock switch is a protective device to prevent dangerous situations by stopping the machine when the guard is opened. When it is decided to protect humans by using guards, entry into the dangerous area must only be through the guard opening. To ensure the safety of personnel, interlocking switches are commonly used for guards to detect that the door at the opening is opened. If such an interlocking movable guard is opened, it is necessary to stop the machine before anyone can reach the hazardous moving parts of the machine.
The important points for selecting a guard interlock switch are:

- the conditions of use and intended use
- the type of the hazard present at the machine
- the severity of the possible harm
- the probability of failure of the interlocking device
- stopping time and access time considerations
- the frequency of access
- the duration of person’s exposure to the hazard
- performance considerations

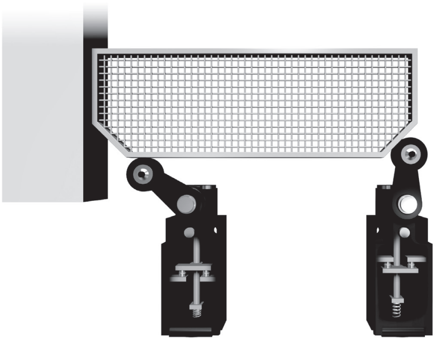
• Characteristics of Switch Actuation Mode

Switches used as guard interlock switches have the following features for the respective actuation mechanisms.

Cam operated actuation

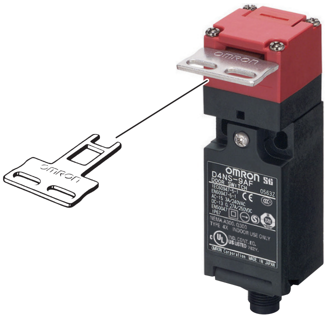
When a single safety switch with an actuator operated by the cam is used, it should be installed to actuate by direct mechanical action or a combination of direct and non-direct mechanical actions to prevent the safety switch from being defeated in a simple manner. A higher level safety protection against defeat can be achieved, e.g., by enclosing the cam and safety switch in the same housing.

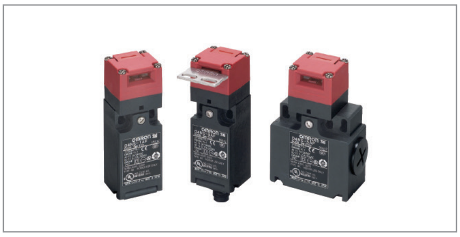
D4N Safety Limit Switch



Tongue-operated actuation

The tongue-actuated switch requires a dedicated tongue and can prevent easy cheating of the switch. However care should be taken because it can be defeated by using a spare tongue.

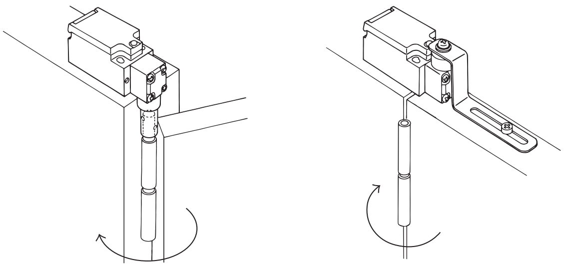


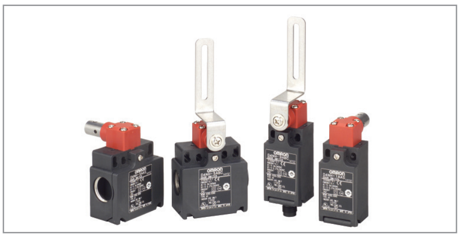


D4NS Safety-door Switch

Hinge operated actuation

Hinged door switches have two features. One is that it is difficult to defeat the switch. The other is that it can be used for small size guards thanks to no limitation to tongue radius as opposed to tongue-actuated switches. Prior confirmation is required for a possibility of a gap large enough to approach hazards to be generated, depending on a door size, at the same time when the opening of the door is detected.

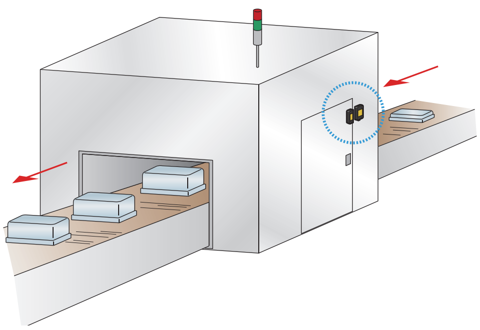


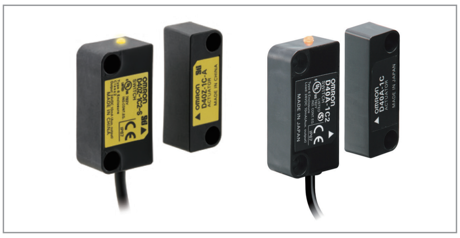


D4NH Safety-door Hinge Switch

Actuation by non-contact method

Non-contact door switches require a dedicated actuator for sensor parts and can prevent the switches from being easily defeated.
These switches do not have a direct opening action because they do not use the mechanical actuation method as opposed to the cam operated and tongue-actuated switches. Appropriate safety is ensured by providing a diagnostic function for switch failures. In addition, they are unlikely to suffer from the mounting limitation compared to the other switches because of the easy positioning during installation.

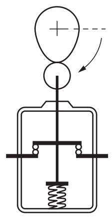
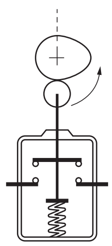
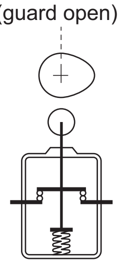
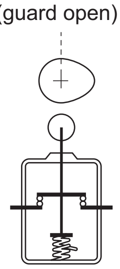
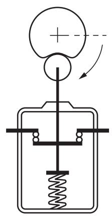
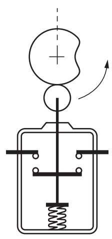
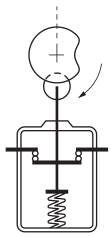
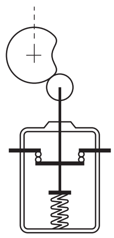
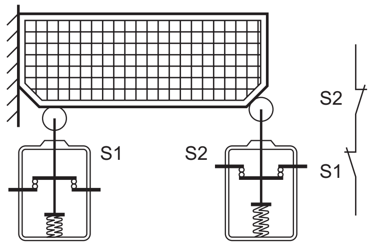
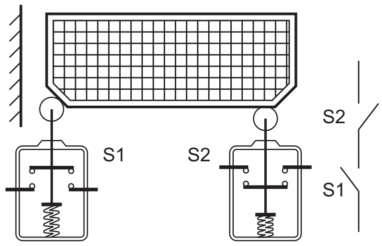




D40Z, D40A
Compact non-contact Door Switch

• Direct and Non-direct Mechanical Action

When using a safety limit switch as a guard interlock switch, it is necessary to install it considering the following characteristics of the operating methods.

		(A) Non-direct mechanical action		(B) Direct mechanical action		(C) Combined action
Operating status		Normal operation	Abnormal operation	Normal operation	Abnormal operation	Normal operation
		Contacts closed (guard closed)  Contacts open (guard open) 	a) No return due to contact welding (guard open)  b) No return due to spring damage (guard open) 	Contacts closed (guard closed)  Contacts open (guard open) 	a) Contact not open due to cam abrasion (guard open)  b) Contact not open due to improper cam position (guard door open) 	Contacts closed (guard closed)  Non-direct mechanical action Direct mechanical action Contacts open (guard open)  Non-direct mechanical action Direct mechanical action
Contact opening method		Opened by built-in spring.		Opened directly by externally operating unit like cam or dog.		Opened by built-in spring or externally operating unit.
Applicable contact		NO contact		NC contact with direct opening action (⊖)		NO contact and NC contact with direct opening action (⊖)
Characteristics	Pros	Contacts open in case of cam abrasion, improper cam positioning, or unexpected cam removal.		The actuator directly opens contacts if a contact welds or a spring is broken.		A combined action eliminates the disadvantages of both modes.
	Cons	Contacts cannot open in case of welding. The actuator may move accidentally with unexpected force and close the contacts.		Contacts may not open in case of cam abrasion, improper cam positioning or unexpected cam removal.		To synchronize the opening or closing of contacts in two switches, shapes of cams to operate the switches and installation positions of the switches must be carefully considered.

• Standards for Interlocking Devices Associated with Guards (ISO 14119)

ISO 14119 is the standard that covers the design and selection of guard interlock switches. This standard classifies guard interlock switches. Cam or hinge operated interlock switches are classified as Type 1, tongue-actuated interlock switches as Type 2, and non-contact interlock switches requiring a dedicated actuator as Type 4.
This standard requires consideration of defeating of interlock switches; you must design, select, and install them so as to minimize the motivation for defeating them with screws, wires, keys, and/or tools. The design of interlocking switches and interlocking circuits must conform to ISO 13849-1.

• Requirements for Guard Locking

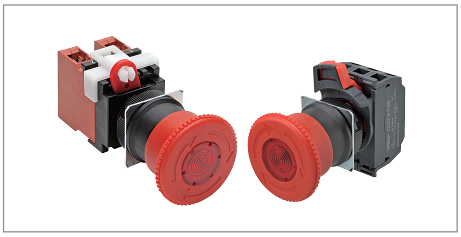
An interlocking device with a guard locking function should be used when the time required to stop the hazard is greater than the access time for a person to reach the danger zone.

The interlocking device with a guard locking is intended to lock a guard in the closed position so that:

- the machine cannot operate until the guard is closed and locked;
- the guard remains locked until the risk has passed.

Emergency Stop Switch

An emergency stop switch is a switch which is operated to stop the machinery in the event of an emergency.



A22NE-PD/A22NE-P/A22E
Emergency Stop Pushbutton Switch

• Types of Emergency Stop Switches

The following are typical types of emergency stop switches:

- A pushbutton switch
- A pull-cord switch

• Requirements for Emergency Stop Switches

ISO 13850 stipulates the design requirements for emergency stop devices (e.g., emergency stop switches) and emergency stop functions. Typical requirements include:

- Electrical contacts must have a direct opening action.
- Emergency stop devices must have a latching function that will mechanically hold in the stop position until the device is manually reset.
- Actuators of an emergency stop device must be colored red. The background immediately behind the actuator must be colored yellow.
- Consideration must be given to the following items when a rope or a wire is used as an actuator.
  - The amount of deflection of the rope/wire needed to generate the emergency stop command
  - The maximum deflection possible
  - The minimum clearance between the rope/wire and the nearest machine in the vicinity
  - The amount of force required for operation
  - The ease with which an operator can locate the device, by use of a marker flag or other method
  - The automatic generation of an emergency stop command in the event that the rope/wire breaks or becomes detached
- The circuit of the emergency stop function must be configured with Stop Category 0, which immediately shuts off the power supply to the moving parts of the machine, or Stop Category 1, which shuts off the power supply after the moving parts of the machine stop.

Other Safety Switches

Other safety switches include enabling switches used for maintenance, and switches for a mode change.

• Enabling Switch

A4EG Enabling Grip Switch

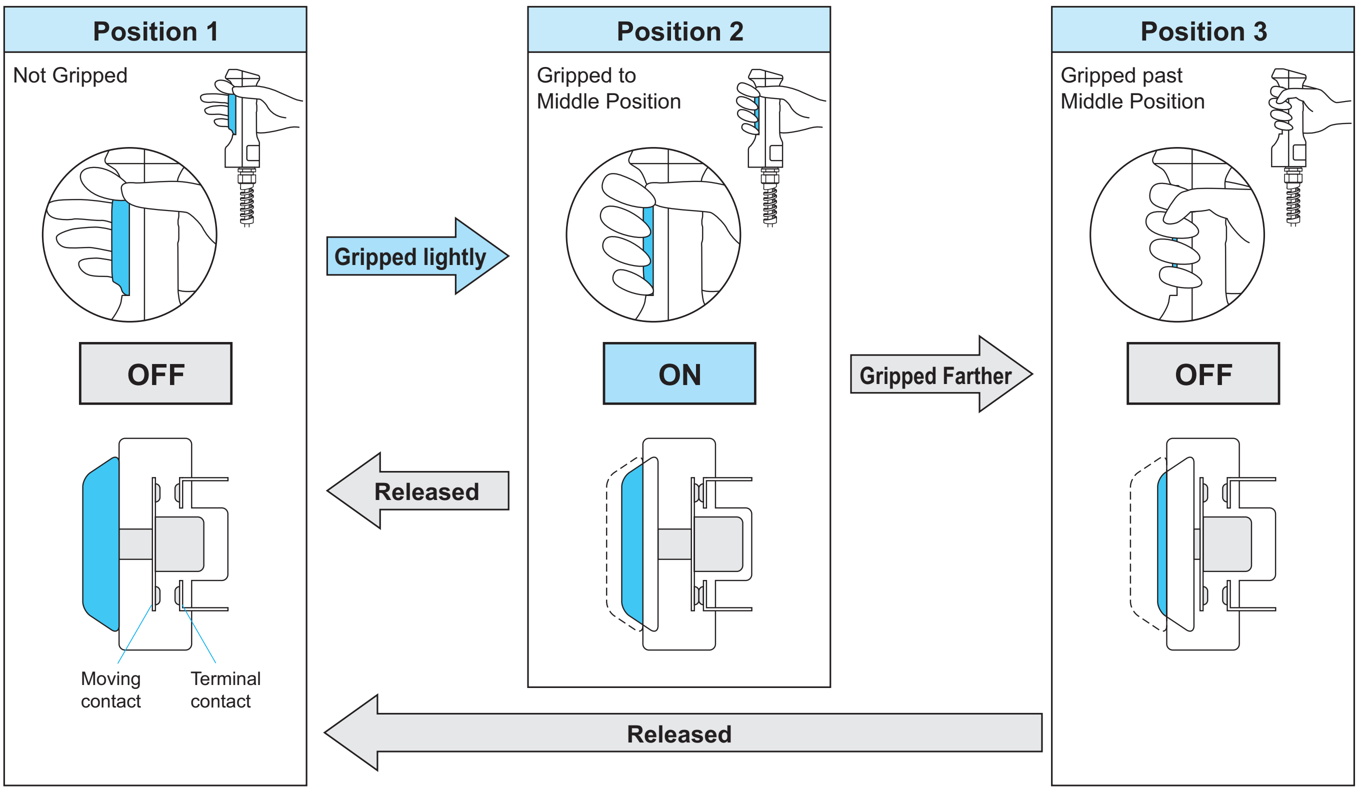
An enabling switch is a safety component used so that various hazards such as inadvertent entanglement can be avoided or reduced when performing non-scheduled maintenance work or other non-scheduled operations in hazardous areas, such as those inside safety fences. It can be used by incorporating into a teaching pendant or used as an independent operating device such as a grip switch.

When an operator teaches a robot or perform equipment changeovers and maintenance in a dangerous area, unexpected movement of a hazard and/or operator's inadvertent behavior can result in a hazardous state. An enabling switch is used to prevent operator accidents in such situations. With an enabling switch, machines or robots can be controlled only when the switch is gripped lightly to the middle position. If the switch is gripped with force past the middle position or if the switch is released, the signal will be turned OFF, disabling the machine operation. The mechanism, which turns OFF the signal when the switch is gripped with force or released, is designed according to ergonomic principles.

• Structure of Enabling Switches

Enabling switches transmit signals through three positions depending on how much the switch is gripped.
The signal is OFF when not pressed, ON when pressed to the middle position, and then OFF again when pressed past the middle position.

Three Positions: OFF - ON - OFF



• Mode Selector

These switches are used to change the machines from operation mode to maintenance mode during machine maintenance, setup, cleaning and others. Incorporating the direct opening action ensures mode switching.

A22TK Safety Key Selector Switch

3. Safety Input Device - Safety Sensor

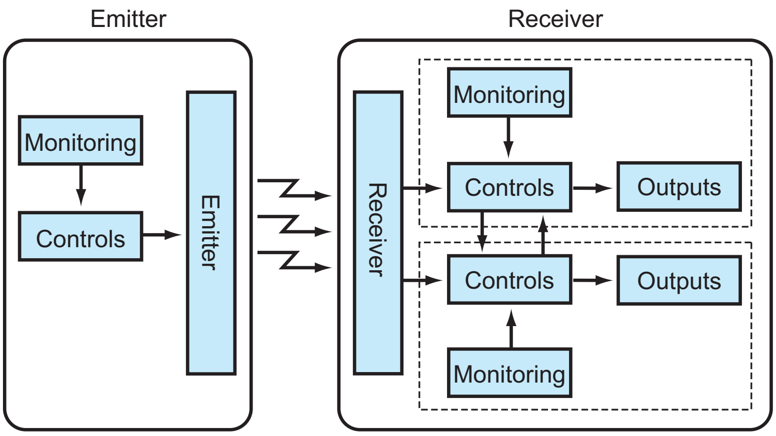
Safety sensors are used to stop the machinery when detecting that a person is approaching or present in the hazardous area surrounding the machine.

Features of Safety Sensors

• Diagnostic system

IEC 61496-1 that defines requirements for all the different types of safety sensors stipulates types based on the capability to detect a safety sensor failure and sensor behavior when failure is detected. Type 4, many safety light curtains meeting its requirements, is stipulated to have performance equivalent to PLe according to ISO 13849-1, with mutual check by dual CPUs and redundant signal processing and output circuits as shown in the figure below. Type 3, many safety laser scanners meeting its requirements is stipulated to have performance equivalent to PLd according to ISO 13849-1. Both of these have a diagnostic system inside the sensor to ensure performance.

Circuit block diagram of Type 4 safety light curtain



• Safety Distances

When a safeguard, such as a safety sensor, is installed, the machine must be stopped before a person who enters the hazardous zone will reach the hazard such as a moving part. The distance required for the above purpose is stipulated by ISO 13855. The concept of the safety distance in ISO 13855 is particularly important for determining the minimum size of the object to detect, which indicates the detection capability of the safety sensor, and the installation position of the safety sensor.

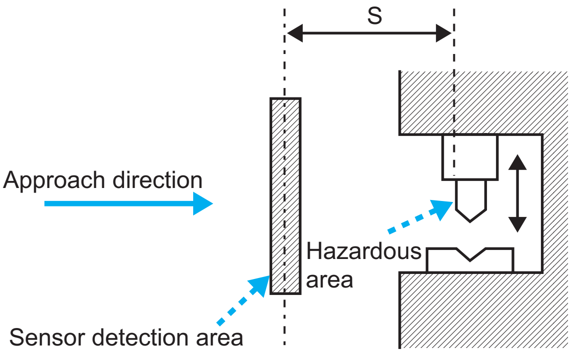
Calculating the minimum distance based on ISO 13855

ISO 13855 defines the safe distance that should be kept between a safeguard and a hazard as “minimum distance (S)”. The minimum distance can be calculated as shown below:

Minimum distance (S) = Approach speed of human body (K) x Response time from when the safeguard starts operation to when the entire system stops (T) x Additional distance based on the characteristics of the safeguard (C)

The minimum distance (S) when using a safety sensor must be considered taking into account the relationship between the approach direction to the hazard and the detection area of the safety sensor.

A. Detection area vertical to the approach direction



Finger or hand detection (detection capability "d" of the safety sensor is 40 mm or less)

• S = (K × T) + 8 (d - 14)

S is calculated using this formula with the following conditions.

K = 2,000 mm/s (assuming entry speed of finger)
T = Maximum stopping time of machine + response time of safety sensor (s)
d = Detection capability of safety sensor (mm) (detection capability ≤ 40 mm)

Note: If d < 14 mm, the additional distance C = 8 (d - 14) = 0 mm.

If the calculation result is S < 100 mm, use S = 100 mm. If S > 500 mm, use the value re-calculated with K = 1,600 mm/s. If S < 500 mm, after the re-calculation, use S = 500 mm.

Body detection (detection capability "d" of the safety sensor is between 40 mm and 70 mm)

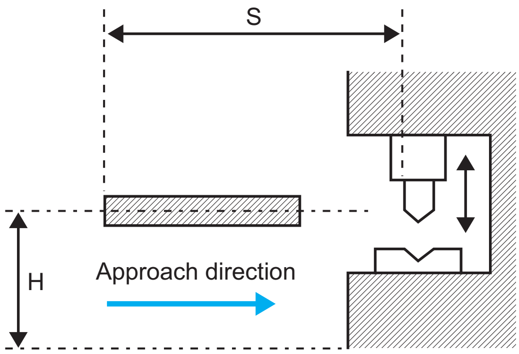
• S = (K × T) + 850

S is calculated using this formula with the following conditions.

K = 1,600 mm/s (assuming person’s walking speed)
T = Maximum stopping time of machine + response time of safety sensor (s)
C = 850 mm (Constant regardless of the safety sensor’s detection capability, assuming standard arm length)

This formula can also be used to calculate the minimum distance for safety sensors with wider beam gap used in applications that detect the entire human body, such as multi-beam safety sensors. However, in such cases, it is necessary to consider in the risk assessment the possibility that a person will passing through the beams or crawl on the floor to avoid the beams and approach the hazard.

B. Detection area parallel to the approach direction



• $S = (K \times T) + (1{,}200 - 0.4\ H)$

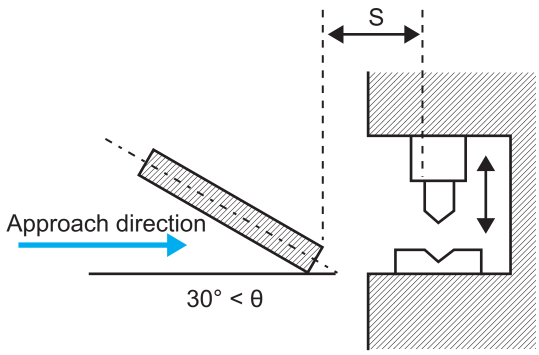
S is calculated using this formula with the following conditions.

K = 1,600 mm/s (assuming person's walking speed)
T = Maximum stopping time of machine + response time of safety sensor (s)
H = Installation height of safety sensor

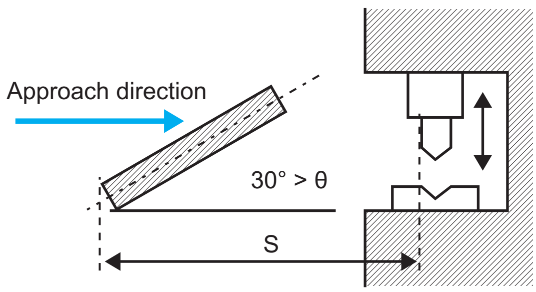
Note: If H ≥ 875 mm, the additional distance C = 1,200 - 0.4 H = 850 mm.

Installation height (detection area height) H of the safety sensor must be H ≥ 15 (d - 50) using the detection capability d of the safety sensor. H must not exceed 1,000 mm, and not drop below 0 mm even if d < 50 mm. When H > 300 mm, in the risk assessment it is necessary to consider the possibility of a person passing under the detection area and approaching the hazard, taking into account the additional protective measures.

C. Detection area angled to the approach direction



When the angle of the detection area exceeds ±30° with respect to the approach direction, the approach is considered as vertical approach and the calculation formula of A is applied.

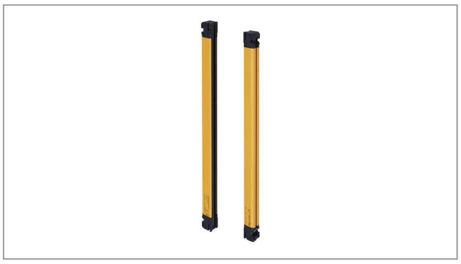


When the angle of the detection area is less than ±30° with respect to the approach direction, the approach is considered as parallel approach and the calculation formula of B is applied.

The safety distance (minimum distance) must be considered when determining the installation position of a guard interlock switch without locking function, a two-hand control device such as a two-hand control switch, and a safety mat, in addition to the safety sensor. For details, refer to ISO 13855.

Safety Light Curtain

The most typical safety sensor used as a safety input device is the safety light curtain.
The safety light curtain is used to stop the machine when detecting operators entering hazard zone by sensing that the beams between the emitter and receiver are blocked.
Various functions are provided to ensure detection of a human body.



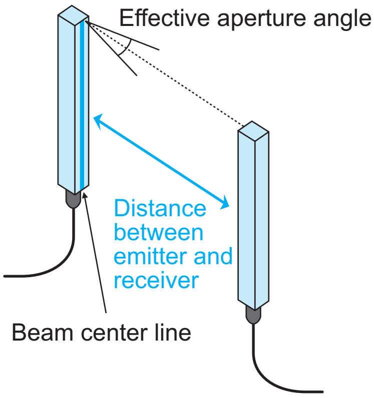
F3SG-SR-series Safety Light Curtain

F3SG-R-series Safety Light Curtain

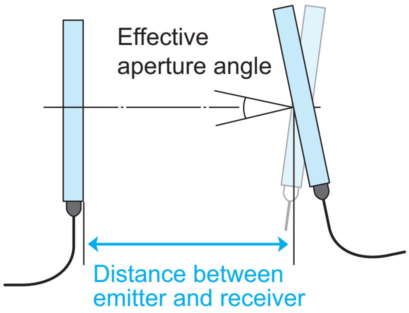
• Effective Aperture Angle

The effective aperture angle is the allowable angular deviation of the beams between the emitter and receiver of the safety light curtain, and is specified in IEC 61496-2. It is the angle where the output turns OFF when the light curtain is rotated. A narrower effective aperture angle is required to minimize the influence of optical reflections. A Type 4 safety light curtain must be designed to turn OFF output if the angular deviation exceeds 2.5° when the distance between the emitter and the receiver is 3 m.

Rotation along beam center line



Lateral rotation



Relation between distance between emitter and receiver and effective aperture angle of Type 4 sensor

Distance between emitter and receiver	3.0 m	1.5 m	0.75 m	0.5 m
Effective aperture angle	2.5°	5°	10°	14.7°

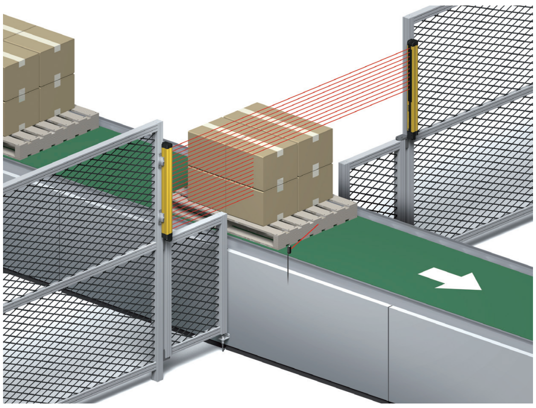
• Muting Function

The muting function temporarily stops the detection function of the safety light curtain and automatically keeps safety outputs ON regardless of whether the light is unblocked or blocked.

Typically when a workpiece passes through the detection zone, the work process is always stopped by blocking the beams of the safety light curtain. With the addition of the muting function, the safety output can be automatically maintained when a workpiece passes through, and the safety output can be turned OFF only when a person enters the area. This makes it possible for work to continue without stopping the production line even if a workpiece blocks the beam of the safety light curtain.

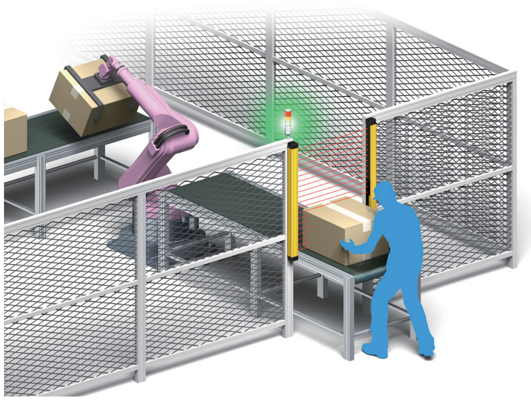
Partial Muting

Muting that disables only the beams blocked by workpieces that pass through the detection zone. Since other beams are enabled, an entry of a human body through the area where workpieces pass can be detected anytime. Also, by adding a sensor that is activated only when a workpiece passes, it is possible to turn OFF the safety output when a human body enters at other times than when workpieces pass.



Position Detection Muting

Muting that disables beams only when movable parts of the machine such as a robot are in the safe position for the operator. Muting ends when the movable parts are outside the specified area.

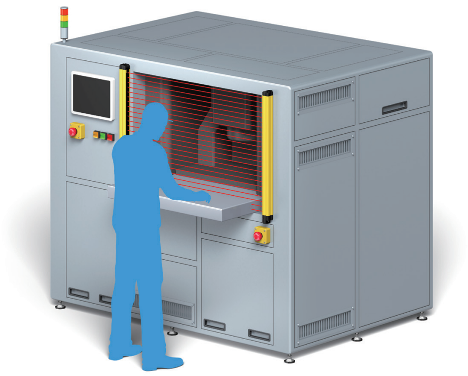


• Blanking Function

Blanking is a function to always disable a specified area of the detection zone of the safety light curtain.
It can be used when mechanical parts or accessories interfere with the detection area of the safety light curtain.

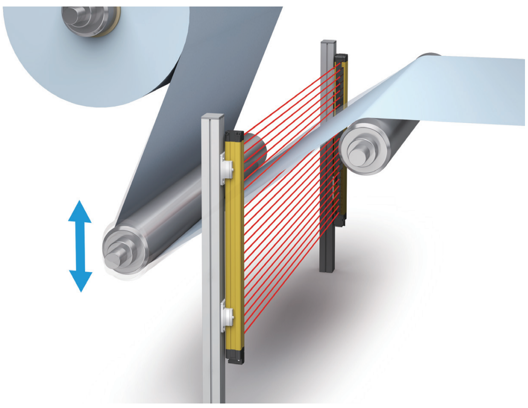
Fixed Blanking

Blanking used if an object that constantly blocks the beams is fixed, like a working table. This is effective when installing safety light curtains where beam interruption by a fixed object is unavoidable due to machine design.



Floating Blanking

Blanking used if an object that constantly blocks the beams is not fixed, such as a workpiece. This is effective when installing safety light curtains where the beams interrupted by an object change.



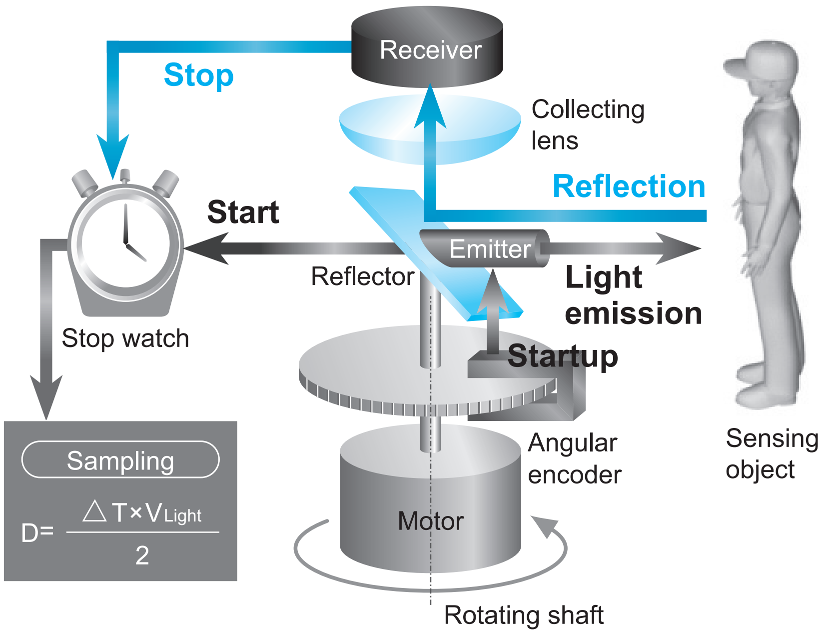
Safety Laser Scanner

A safety laser scanner is a safety sensor that can freely change the shape and size of the detection zone.
It is used to stop the machine by detecting the presence of workers in a preset detection zone.

OS32C Safety Laser Scanner

• Structure of Safety Laser Scanners

As shown in the figure below, the safety laser scanner emits a beam that is reflected by surrounding objects. It calculates the distance to the object from the time that it takes to receive the reflected light. This function prevents workers approaching the detection zone from coming into contact with the machine under operation.

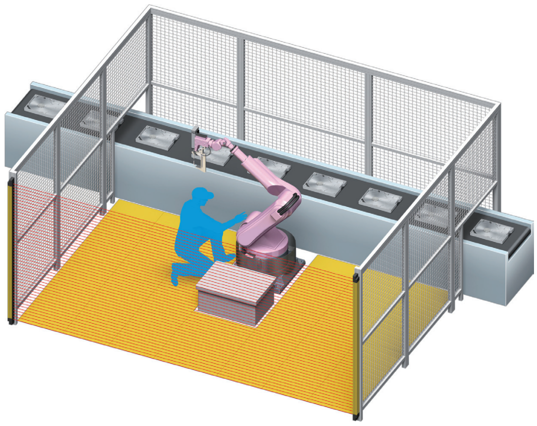


4. Other Safety Input Devices

A pressure-sensitive protective device that detects the presence of a worker around the hazard can be used as a safety input device.

Safety Mat

The sensor detects the presence of an operator in a dangerous area based on pressure detection. It has excellent environmental resistance.

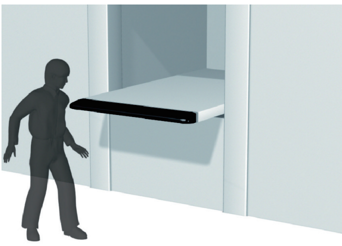


UMA-series Safety Mat

Safety Edge

A pressure-sensitive protective device that detects contact with the human body, mainly used by attaching to the moving parts of the machine.

Example: Shutter



Example: Shuttle table

SGE/SCC Safety Edge/Edge Controller

5. Safety Logic Device

A safety logic device receives signals from a safety component and controls the startup and operation of the machine. It outputs control signals to a safety output device based on the status of the signals received from a safety input device while the machine is operating. In addition, it can be used to monitor the status of safety input and output devices, and to shut off power to the machine when detecting a failure.

Safety Relay Unit

A safety relay unit consists of circuits combining multiple relays to perform processing required for safety logic devices. It is suitable for constructing safety control circuits on small machines with simple configurations of safety input devices and safety output devices.

G9SA, G9SE Safety Relay Unit

Flexible Safety Unit

A flexible safety unit is a safety logic device that features solid-state outputs for long life and multi-channel inputs, allowing flexible system configurations. You can connect multiple units to construct a larger safety control circuit than that using a safety relay unit.

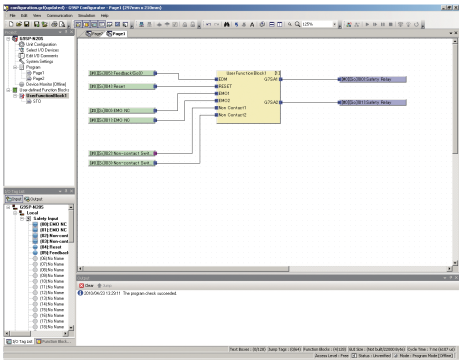
G9SX Flexible Safety Unit

Programmable Safety Controller

A programmable safety controller is a device that allows you to create a safety control program for a machine. It can more flexibly handle complex applications. The following features are provided for connecting various devices to create complex safety functions.

G9SP Safety Controller

• Features of Programmable Safety Controllers



Programming with Certified Function Blocks

Safety functions such as emergency stop and guard interlocking are provided with certified function blocks that have been proven safe. As the validity has been confirmed by a third party, it is possible to ensure safety as individual safety functions by using them.

Comparison of Programs between Controller and Software

Before starting the controller, it must be confirmed that the settings in the programming software match those transferred to the controller. This function prevents the machine from starting with unintended programs and settings.

Preventing System Access Except by Administrators

You can set passwords to limit access to the controller programs. Only authorized people can change programs and settings, preventing a dangerous state due to unexpected changes.

Prevention of Malfunction due to External Wiring Failure

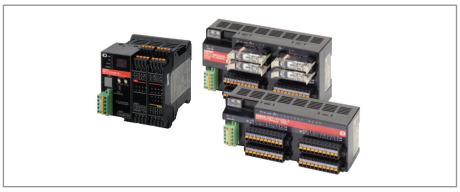
The programmable safety controller and function blocks have functions to detect external wiring failures such as incorrect wiring, ground fault, and short circuit. It is possible to configure the system so that unintended machine operation can be prevented in case of a failure.

When designing the safety-related parts such as equipment and machines using a programmable safety controller, safety of the entire program must also be validated. For more details, refer to *9. Validation for Programmable devices under Chapter 1 Performance Level in the Safety Component Technical Advanced Guide* (Cat. No. Y221).

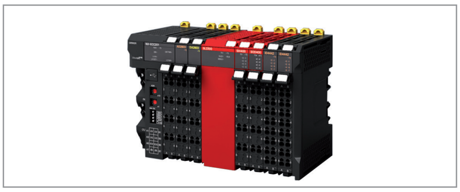
Safety Network Controller

Among programmable safety controllers, this device is capable of safety control via a network. A networked safety control system enables distributed allocation of safety components and expansion of I/O. The following measures are taken for networking.

NX-CSG/SL5/SI/SO
NX-series Communications Control Unit/ Safety Control Unit



NE1A/DST1
Safety Network Controller



NX-SL/SI/SO
NX-series Safety CPU Unit/ Safety I/O Unit

• Features of Safety Network Controllers

Communications Data Redundancy

Data is made redundant through simultaneous transmission and reception of safety data and inverted data and checking of response messages from transmission destinations, to ensure the transmission and reception of safety data.

Generation of Special Check Code for Safety Data

Check codes called Safety-CRC are attached to the safety data to ensure that any message corruption and/or impersonation are detected.

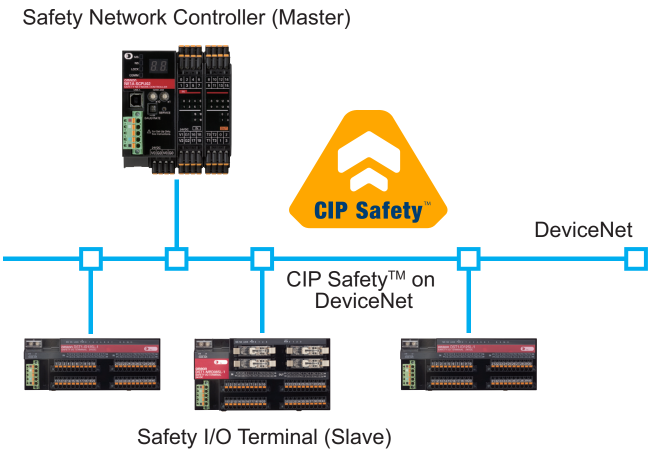
IDs for Transmitters

Mutually monitoring safety network controllers' unique ID code and/or implementing an unique ID code into the transferred data prevent data communications between incorrect devices.

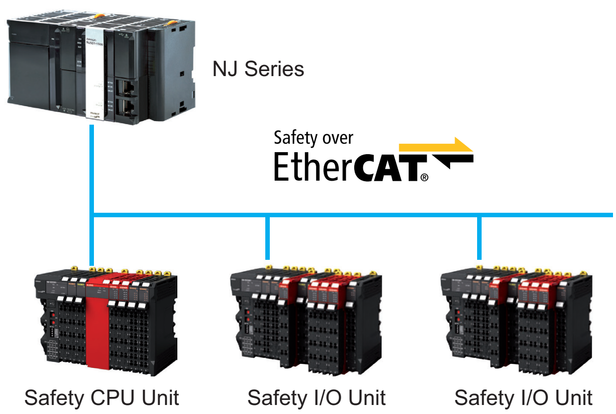
Data Time Management

Attaching time stamps to transmission data and detecting the time when destination nodes receive transmission data, the safety network controllers monitor reversed or late communications data.

CIP Safety™ on DeviceNet



Safety over EtherCAT (FSoE)

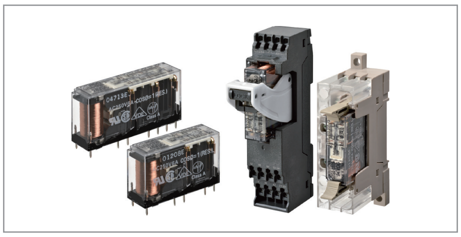


6. Safety Output Device

A safety output device operates by receiving signals processed and output by a safety logic device.
Typical examples include relays used to control or cut off power supply to hazards and motor drives used to safely control motors that are regarded as a hazard.

Safety Relay

A safety relay has forcibly guided contacts defined in IEC 61810-3. Even if one contact is welded, the forced guide keeps the other contact open. This means that the control circuit can detect the welded contacts by monitoring these contacts.

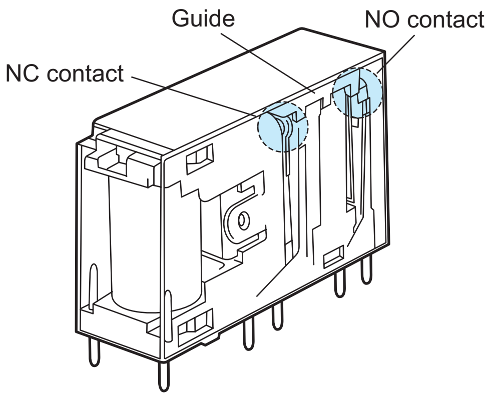


G7SA Relay with Forcibly Guided Contacts

• Main Requirements for Safety Relays with Forcibly Guided Contacts

- If at least one normally open (NO) contact is welded, when the coil is deenergized, all normally closed (NC) contacts maintain a gap of at least 0.5 mm.
- Even if a NC contact is welded, all NO contacts maintain a gap of at least 0.5 mm when the coil is energized.
- Contact load switching must conform to AC-15 and DC-13 (IEC 60947-5-1).
- The mechanical durability must be at least 10 million operations.

Relays in which all the contacts are forcibly guided are called Type A and indicated by the mark.



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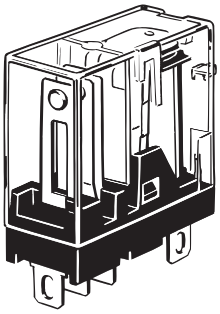
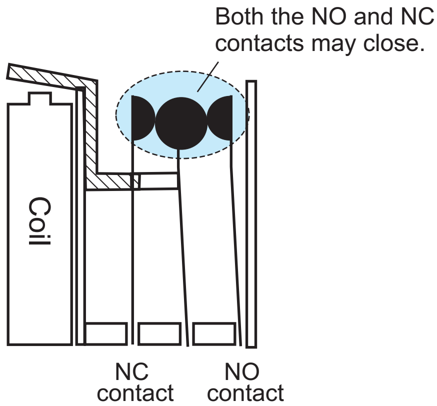
• Structural Comparison of General Relays and Relays with Forcibly Guided Contacts

General Relay



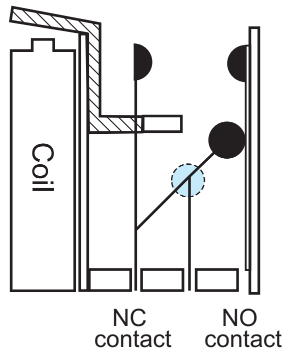
Structures of General Relays

(Coil: Not energized)



(a) When contact welding occurs

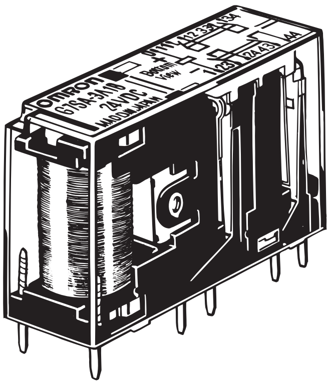
(Coil: Not energized)



• A broken movable spring may cause a short-circuit between electrodes

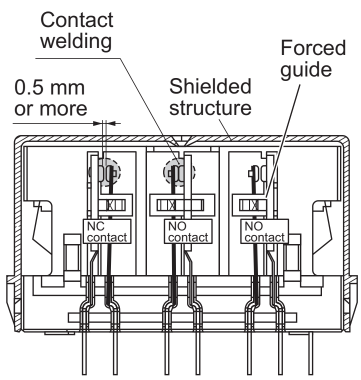
(b) When a movable spring is broken

Relay with Forcibly Guided Contacts



Structures of Relays with Forcibly Guided Contacts

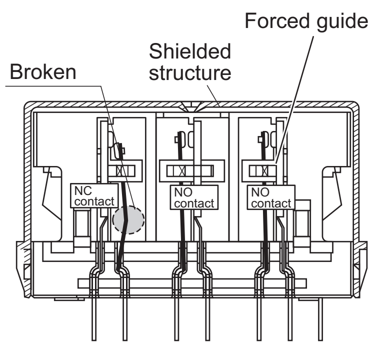
(Coil: Not energized)



(a) When contact welding occurs in the NO contact

The NO contacts will not close if the NC contact is welded.

(Coil: Not energized)



• The above shielded structure protects other contacts from being affected by the failure.

(b) When a contact spring is broken (broken NC contact)

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Drive Device with Safety Functionality

The safety functions for drive devices such as motor drives are defined in IEC 61800-5-2, which specifies the safety requirements for a power drive system (PDS). In addition to the function to cut off the power supply to the motor, the function to safely control the speed and rotation direction of the motor is also specified. These functions are increasingly used in machine design to ensure safety while improving productivity.

AC Servo System
1S-series with Safety Functionality

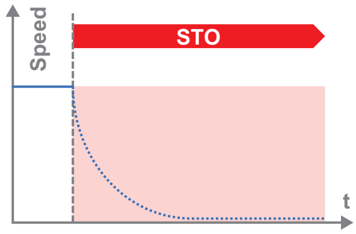
• Typical Safety Functions

The typical safety functions for drive devices are as follows. Designers need to understand the characteristics of each function and use the most appropriate function based on the results of the risk assessment of the machine.

Stop Functions

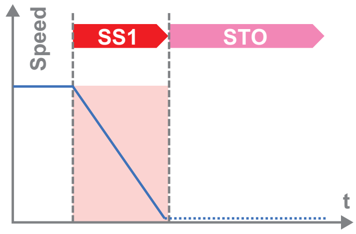
• Safe Torque Off (STO)

This function cuts off power supply to the motor. Since the standstill is not controlled, additional measures (e.g., mechanical brakes) must be provided as needed. You can use this function as a Category 0 stop.



• Safe Stop 1 (SS1)

The motor decelerates to a stop, and then STO is automatically applied to shut off the power supply to the motor. You can use this function as a Category 1 stop.



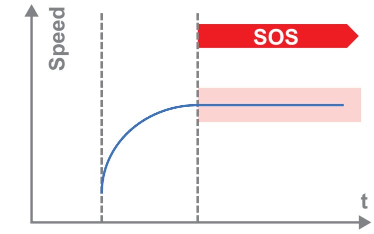
• Safe Stop 2 (SS2)

The motor decelerates to a stop, and then SOS is automatically applied to maintain the standstill while keeping power supply to the motor. You can use this function as a Category 2 stop.

Monitoring Functions

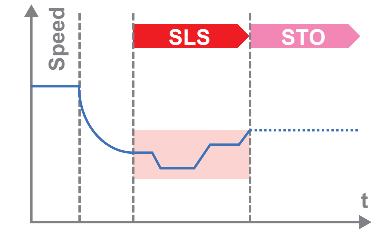
• Safe Operating Stop (SOS)

This function monitors standstill of the motor. By keeping the power supply to the motor after it stops, the function ensures that the motor is at the stop position.



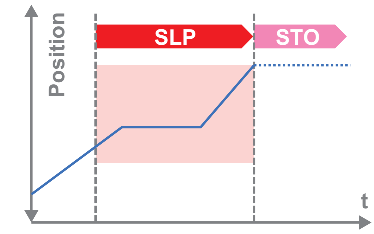
• Safely-Limited Stop (SLS)

This function monitors that the motor speed is within the specified range. If it detects that the speed exceeds the specified value, STO is applied to cut off the power supply to the motor.



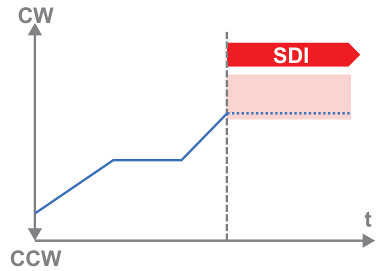
• Safely-Limited Position (SLP)

This function monitors that the motor shaft is at the specified position. If it detects that the motor is not at the specified position, STO is applied to cut off the power supply to the motor.



• Safe Direction (SDI)

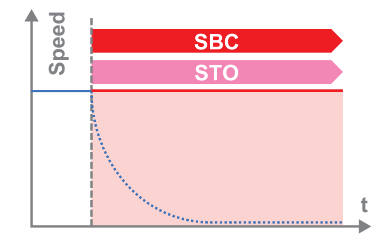
This function monitors that the motor shaft rotates in the correct direction. It prevents the motor from moving in an unintended direction beyond the limit.



Output Function

• Safe Brake Control (SBC)

This function outputs the safety signal to control the external brake of the motor. It can be used with activated STO for stop control after power shutoff by STO.



MEMO

Note: Do not use this document to operate the Unit.

OMRON Corporation **Industrial Automation Company**

Kyoto, JAPAN

Contact: www.ia.omron.com

Regional Headquarters

OMRON EUROPE B.V.
Wegalaan 67-69, 2132 JD Hoofddorp
The Netherlands
Tel: (31)2356-81-300/Fax: (31)2356-81-388

OMRON ASIA PACIFIC PTE. LTD.
No. 438A Alexandra Road # 05-05/08 (Lobby 2),
Alexandra Technopark,
Singapore 119967
Tel: (65) 6835-3011/Fax: (65) 6835-2711

OMRON ELECTRONICS LLC
2895 Greenspoint Parkway, Suite 200
Hoffman Estates, IL 60169 U.S.A.
Tel: (1) 847-843-7900/Fax: (1) 847-843-7787

OMRON (CHINA) CO., LTD.
Room 2211, Bank of China Tower,
200 Yin Cheng Zhong Road,
PuDong New Area, Shanghai, 200120, China
Tel: (86) 21-5037-2222/Fax: (86) 21-5037-2200

Authorized Distributor:

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