

Guidance Notes for
ELECTRICAL INTERLOCKING
FOR **SAFETY IN**
INDUSTRIAL PROCESSES

**Addendum: Health and Safety in
Employment Amendment Act 2002**

Since this document was published the Health and Safety in Employment Act 1992 has been amended by legislation which came into effect from 5 May 2003. While the technical and general information in this document remains current, there may be instances where it does not reflect the changes contained in the amended Act. Your local Occupational Safety and Health Service office can provide further information or you may call:

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STATUS AND OBLIGATIONS UNDER THE HEALTH AND SAFETY IN EMPLOYMENT ACT 1992

Electrical Interlocking for Safety in Industrial Processes provides guidance for equipment owners with responsibility for managing design and fitting electrical interlocking systems.

It is a presentation of the advantages and snags of various methods of switching electric current which may be used to control motion to achieve safety. An informed choice based on knowledge of switch operation should be possible when this booklet is used as a reference.

As part of their obligations under the Health and Safety in Employment Act 1992, employers using machinery in a place of work are required to perform a hazard identification and analysis. This hazard analysis will precede an informed decision about eliminating, or isolating, or minimising the hazards people at work are exposed to.

The process of interlocking described assumes the presence of a hazard, so the process is a method for isolating people at work from the hazard or is a method for minimising the likelihood of the hazard becoming a source of harm.

The Act requires that persons with control of places of work, including a person who is the owner, lessee, sublessee, or bailee of any plant in a place of work, shall take all practicable steps to ensure that people in the place of work, and people in the vicinity of the place of work, are not harmed by any hazard that is or arises in the place of work.

Electrical Interlocking for Safety in Industrial Processes will help persons with control of plant and machinery to fit appropriate interlocking systems. Use of the methods described is one way of fulfilling obligations under the Health and Safety in Employment Act 1992. It provides examples taken from good practice in electrical interlocking.

Use of the methods described provides ways of minimising danger. It is not a prescriptive text, and is not intended to inhibit development.

These guidance notes have only a few allusions to the effects of wear on interlocking systems, and of the necessity for minimising the effects of wear on reliability. The process of minimising hazards should include identification of causes of wear which will reduce system reliability, and the institution of a process of test, and repair or replacement, to keep interlocks working safely.

Standards of work shall comply with provisions of the Electricity Regulations 1993, and codes of practice approved pursuant to the Electricity Act 1992.

Users who develop equivalent or safer interlocking systems than those described in this guide, should continue their work.

INTRODUCTION

Electric power to drive and control machines is used in every factory. Electricity powers motors or prime movers. Electricity powers electric and electronic control systems. All electric circuits consist of a power source, a means of converting power to energy, and a switch to connect and disconnect power.

Human safety depends on reliable switching, so choosing the right switch for the job is an essential part of machine design. It is the purpose of this book to provide advice for owners and designers who make machines safe by reliably interlocking electric circuits.

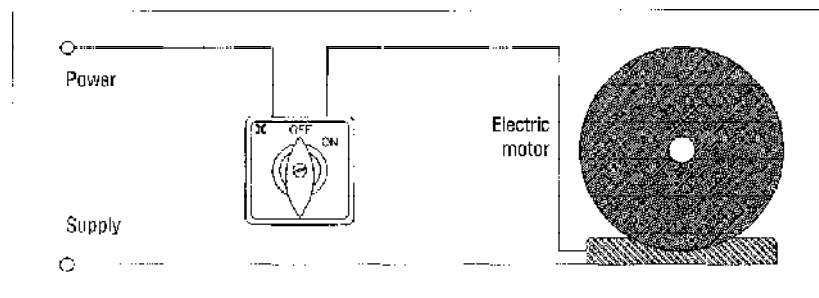


Fig. 1 An electric circuit

Scope of the book – electric switches affect safety

On many machines, the choice of switch is an important part of reducing hazards. The dangerous operations of a machine, which an operator has to reach into, must be automatically guarded. Usually, the position of a guard will result in a switch breaking or closing a circuit. As the switch detects the physical limit of guard movement, it is called a limit switch. Its electric circuit is interlocked with the mechanical function of guard position. Means of interlocking guard position with machine operation to achieve operator safety will be the main emphasis of this guide.

Most commonly, contacts are fastened to the plunger of the switch so that they move with it.

In Fig. 2 a rotary cam which moves with a hinged guard opens switch contacts when the guard is lifted open. Interlocking is traditionally about separating machine operators from forceful physical contact. When a potential hazard occurs, for example the movement of parts of a large rotating machine after power is turned off, the interlocked guards are locked closed. Guards may be opened after run down is timed out.

In general, switches are used for interlocking either sense position, or sense motion or time. In other specialised uses they sense temperature, or pressure, or vapours present in the atmosphere.

Interlocking also separates staff from the harmful effects of industrial processes, especially processes which require the staff member to be close to the operation. In spray painting booths, an air velocity sensor or Pitot head interlocked with spray gun operation ensures that spray coating occurs with adequate ventilation, thus refreshing the air which the painter breathes.

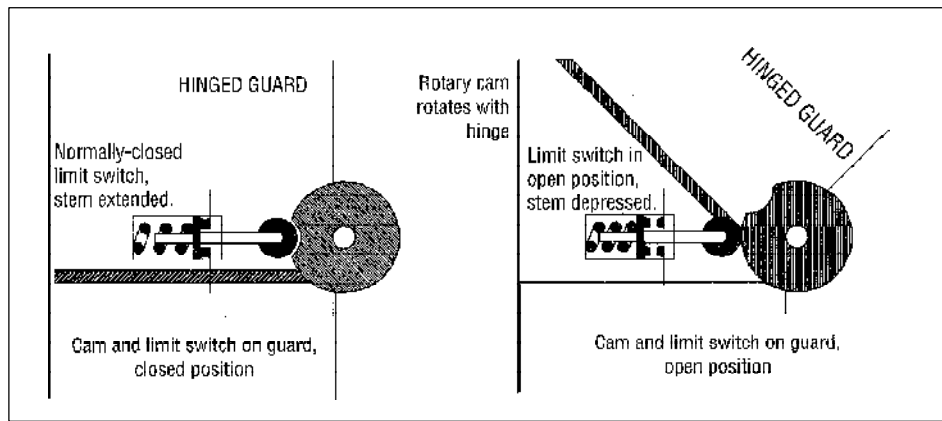


Fig. 2 Normally-closed switch operated by a rotary cam

In other safety-related functions, special detectors monitoring a rise in heat or pressure, or a fall in fluid level, can change the input signal of an electric circuit, initiating some event such as starting fire sprinkler pumps, lighting exit signs, or calling out service staff, but this book will be confined to safety interlocking in ordinary production. The choice of sensors for connection to alarms which indicate abnormal conditions is a specialised area outside the scope of this guide.

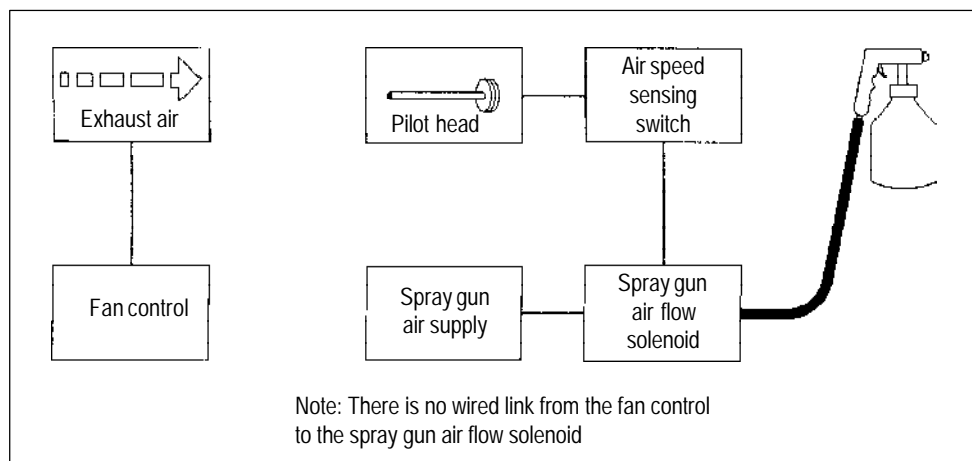


Fig. 3 Spray booth control circuit

1. USE OF SWITCHES

1.1 Switch choice – how specifications aid selection

Maximum current and maximum voltage to be switched are usually the first specifications to determine switch choice. Reliable manufacturers publish these figures in their catalogues, and frequently mould them or stencil them on the body of the switch. More difficult to find is the minimum voltage required for reliable operation. This is the “wetting” voltage, and may exclude the use of mains voltage switches from extra low voltage safety circuits. Where there is a combination of factors such as switch contacts prone to oxidation, operating voltages in the extra low range, that is, less than a few tens of volts, and currents measured in milliamperes, reliable circuit closure may be impossible to achieve. In this case, switches with enclosed contacts plated with gold or silver should be used. Switch vendors should be able to provide data for low voltage switching.

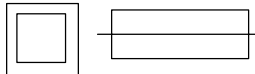
| | |
|--|---|
| IP67 U _i 500V ~ 600V — | IP rating: insulation rating |
| AC11 U _e 220V~I _e 2A | AC voltage and current rating |
| DC11 U _e 220V — L _e 0,5A | DC voltage and current rating |
|  T10A F16A | Double insulation; fuse rating 10A slow fuse rating 16A fast |

Fig. 4 Detail of an informative switch label

Switches are chosen for the working environment and should operate predictably in real life conditions of dirt and wet. International Protection (IP) ratings are provided by switch manufacturers and consist of two figures following the letters “IP”. The first numeral indicates protection of persons against access to dangerous parts and protection of internal equipment against the ingress of solid foreign objects. The second numeral indicates protection of internal equipment against harmful ingress of water. The range is from IP 00, indicating that no special protection is provided, to IP 68. The digit 6 indicates complete protection against entry of dust, 8 assures protection against submersion. Test procedures are described fully in AS 1939: 1986 *Classification of degrees of protection provided by enclosures for electrical equipment*, which includes a chart for the IP code. IP rating often indicates a degree of protection for electrical contacts. Around machine tools, where conductive dusts and moisture are likely to be an inevitable part of their use, switches should be rated at least IP 54 or they should be housed in such a way that equivalent protection is achieved.

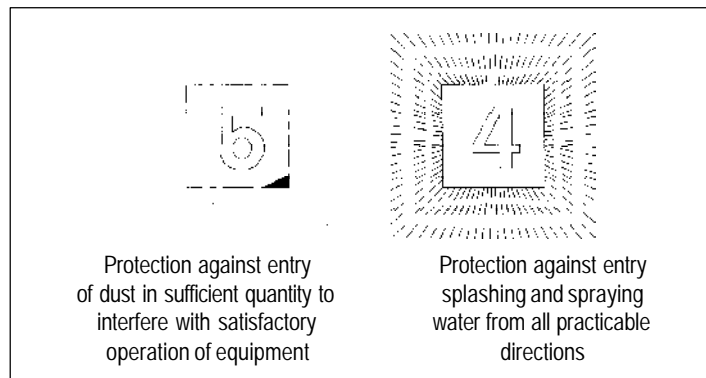


Fig. 5 IP 54 — Minimum rating for machine tools

Operating levers and cams are not usually rated this way, and must continue to function in dirty, wet conditions while electric contacts are enclosed. Switch choice therefore includes consideration of maintenance, to ensure that the means of operating switches will move freely as required.

When the atmosphere about a switch is explosive, or is not normally explosive but infrequently explosive, special precautions must be taken. Making or breaking electrical connections must avoid introducing a source of ignition. When an employer identifies a hazardous or potentially hazardous area, the employer must ensure that the switches fitted are safe for the zone.

Switches wired in areas which are explosive, wet or dusty, will only function at their ratings when the conduits and glands containing wire are fitted and sealed appropriately. Wiring specifications must therefore include ratings of switches and also ratings of protective conduits and glands.

Switches are specified for a finite number of operations, about 10,000,000 or so. Numbers of reliable switch operations will fall drastically as the electrical load is increased; some manufacturers' tables show that while an unloaded switch is good for over 10,000,000 operations, the expectation of the switch manufacturer is that when the switch is electrically loaded to switch its full load, reliable operations will be less than 500,000. This could make replacement essential in less than one year on a busy, cycling machine, to avoid electrical failure. There are places where mechanical failure will occur before electrical failure because of debris spoiling cam operation.

As switch failure is a fact of life, planning an installation to avoid failure to danger is essential.

Direct current circuits open with more arcing and heat than alternating current circuits of the same average value. Therefore, de-rating of any a.c. rated switch in a d.c. circuit is essential to achieve the same reliability. The manufacturer, whose label illustrates Fig. 4, specifies that d.c. operations be de-rated to 25% of a.c. It must be emphasised that each switch type will have a distinct specification and that manufacturers' tables must be consulted at the design stage. It may be dangerous to assume that the specification of Fig. 4 applies to all switches. Another manufacturer supplies tables showing that switch contacts should be aerated to less than 10%.

For direct current, the characteristics of electrical forces in the circuit are distinct from alternating current. Electrical switchgear rated and tested to comply to the specific parameters of each individual application must be installed.

One square inside another shows that there are two separate insulators between the switch contacts and the operating shaft. This is double insulation of current carrying parts from the outside.

As peak current through a slow blow fuse may exceed nominal current levels for some time without blowing the fuse, the options for current limit are to use a fast-blow fuse to protect the switch contacts, or to de-rate the slow blow fuse as recommended by the switch manufacturer. Contacts for signal currents of milliamps will operate safely without fused circuits.

Some manufacturers offer a model with an external shaft for connection to a hinged guard. The shaft passes inside the body of the switch through a sealed bearing. The switch end of the shaft is fastened to a rotary cam which operates a limit switch. The cam housing is therefore rated similarly to the contact housing.

1.2 Switch type – normally open and normally closed

“Normally closed limit switches” are the type most frequently specified for safety applications, especially where frequent access is needed to some part of a machine which could cause serious injury. When only one interlocking switch is fitted to a guard, it should be a normally closed positive break limit switch, unless there are other compelling reasons.

The “normally closed” contact configuration is used because it is the simplest and most effective means of incorporating a switch into an electrical circuit which will allow failure to a safe condition. This “failure to safety” or “fail safe” or “no failure to danger” concept is the basis for interlocking in circuit design.

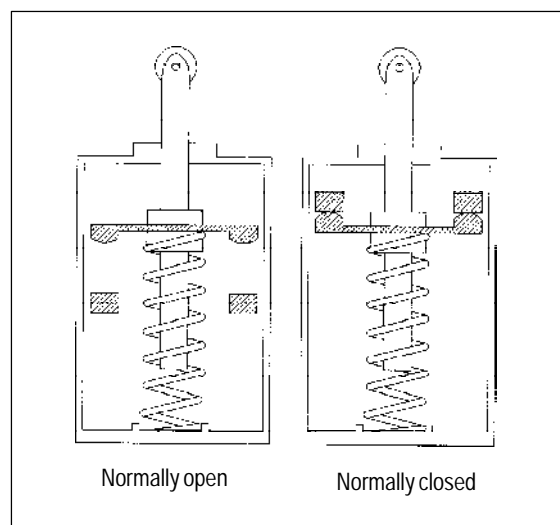


Fig. 6 Normally open (n.o.) and normally closed (n.c.)

“Normally closed” describes the condition of the closed contact set when the switch is in the unoperated position. In this condition, there is no depression of the plunger which operates the contacts. The switch will conduct in the unoperated position and break the circuit when operated.

Similarly, “normally open” contacts are open in the unoperated position and closed in the operated position. This is the convention which will be used in this guide.

While there are common applications which utilise “normally open” switches in process control, “normally closed” is the usual choice in all stop, emergency stop, and protection circuits.

Manufacturers who use a different convention will provide catalogues which contain a full description of the operating conditions for “normally open” and “normally closed”. “Normally open” and “normally closed”. may describe contact position when an actuator is engaged (see Fig. 26.)

To provide adequate safety from mechanical hazards, the switch used must provide a physical gap across the terminals when the switch is in the open position. Under no circumstances can a solid state switch be used to provide such protection.

1.3 Switch description – the preference for safety

Most interlocked guards will be fitted with only one switch. When a guard has only one switch, normally closed positive break is the type of switch which should be fitted to machinery where frequent access, say once per machine cycle, is required. When such a switch is opened by the opening of a guard, a cam is arranged to depress its plunger before the guard is opened far enough to allow access to potentially injurious movement.

Independent of switch orientation, and without relying on the tension of a spring, even contacts which have become welded or closed by stiction are forced open. The most serious electrical problem is that the break can be slow enough to put spurious signals into electronic logic, allowing unwanted operations to occur.

Caution must be exercised, however, when only one limit switch is used. In most arrangements, removal of the cam, or of the cam and guard, will allow a normally-closed switch to move to the closed circuit position, allowing machinery to operate unguarded.

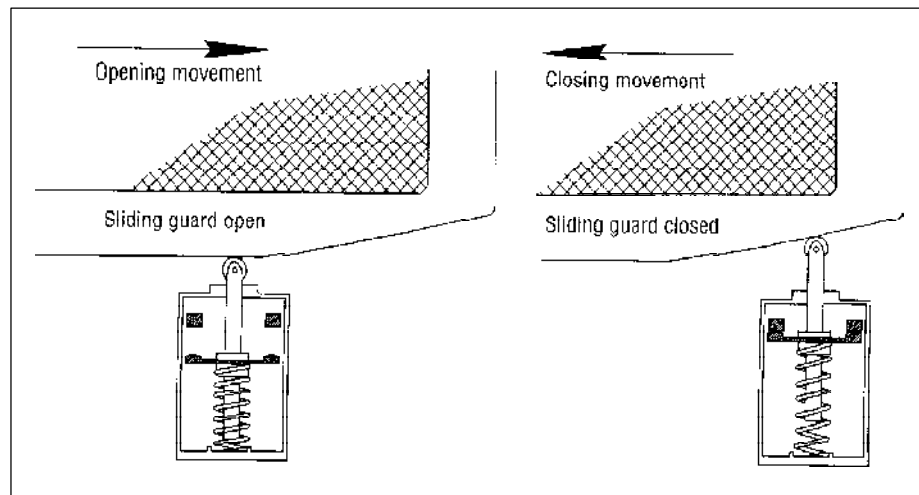


Fig. 7 Normally closed switch operated by a linear cam

2. TYPES OF SWITCHES AND APPLICATIONS

2.1 Limit switch with cam

Normally-closed positive break is probably the most common type in safety applications and is illustrated in Figs. 2 and 7 in use with both rotary and linear cams.

Correctly positioned with a positive cam, and wired in the normally closed mode, a normally closed positive break limit switch is the type which will avoid failure to danger, or be fail safe.

Limit switches can operate in two modes, “normally closed” and “normally open”. In cam-operated interlocking systems, the limit switch must always be installed in the normally-closed mode, to ensure against both interference with the switch and failure to danger due to contact fusing or welding, spring failure, mechanical stiction or seizure.

2.2 Snap action with over-travel

To avoid spurious signals which result from contacts breaking slowly, snap-action switches are used. These switches have the fast “snap” action of microswitches, with mechanical over-travel to force apart contacts which might remain closed in fault conditions.

Snap action switches are similar in appearance to the normally closed positive break limit switch used with a cam, but fast opening or closing.

Contacts are held by a sprung contact support (see Fig. 8) and change position rapidly.

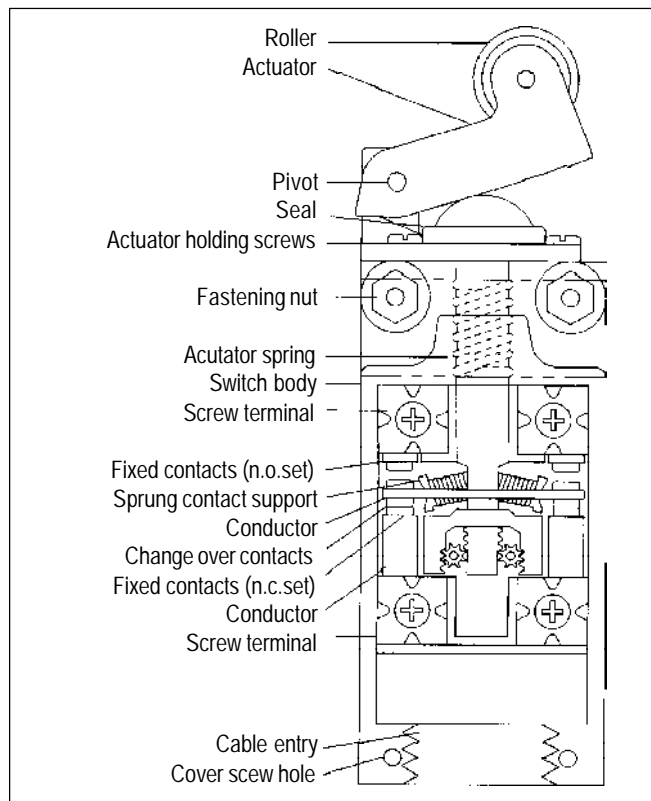


Fig. 8 Snap action switch with over-travel

Fig. 9 gives an idea of the amount of actuator movement for contact change over. The essential precaution in safety applications is ensuring that camforced movement is sufficient to open contacts should the spring fail.

Snap action with over-travel is illustrated by showing the rack and pinion pusher system in Omron D4D limit switches. Other manufacturers achieve equivalent performance and safety. The rack and pinion pusher system forces the contact support to the open contacts position should the spring fail.

Shading shows the current paths in Figs. 9 and 10.

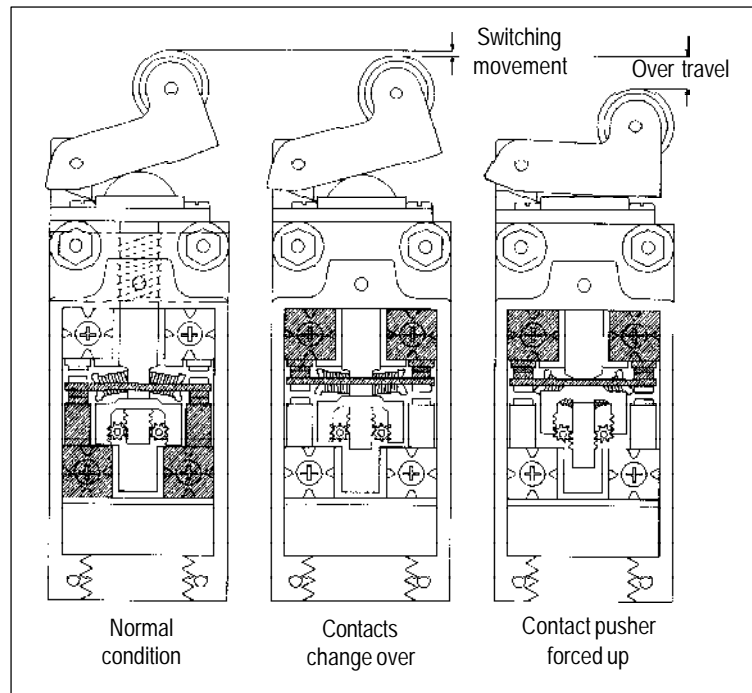


Fig. 9 Actuator movement

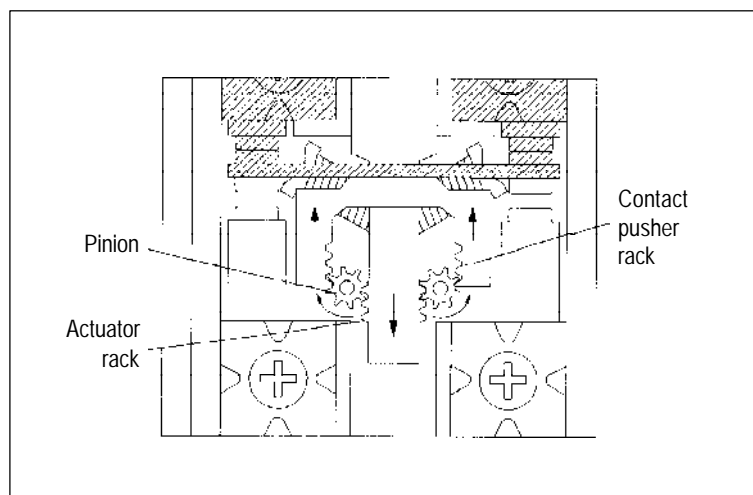


Fig. 10 Contact pusher movement

2.3 Monitoring normally open and normally closed switches together

Normally-closed limit switches should be the first choice for safe interlocking. They should be wired and positioned so that their contacts can close only when the guard is closed. When the guard opens, by a mechanical link to the contacts, the switch contacts open also. Most manufacturers offer normally closed switches with contacts which close under spring pressure, while a mechanical operation ensures that contacts part. Wired and positioned to work as intended, the mechanical link from guard to contacts will ensure that normally closed switches cannot fail to danger. A dangerous occurrence is when switches close by accident or interference in such a way that potentially harmful motion occurs without isolation from people near the machine.

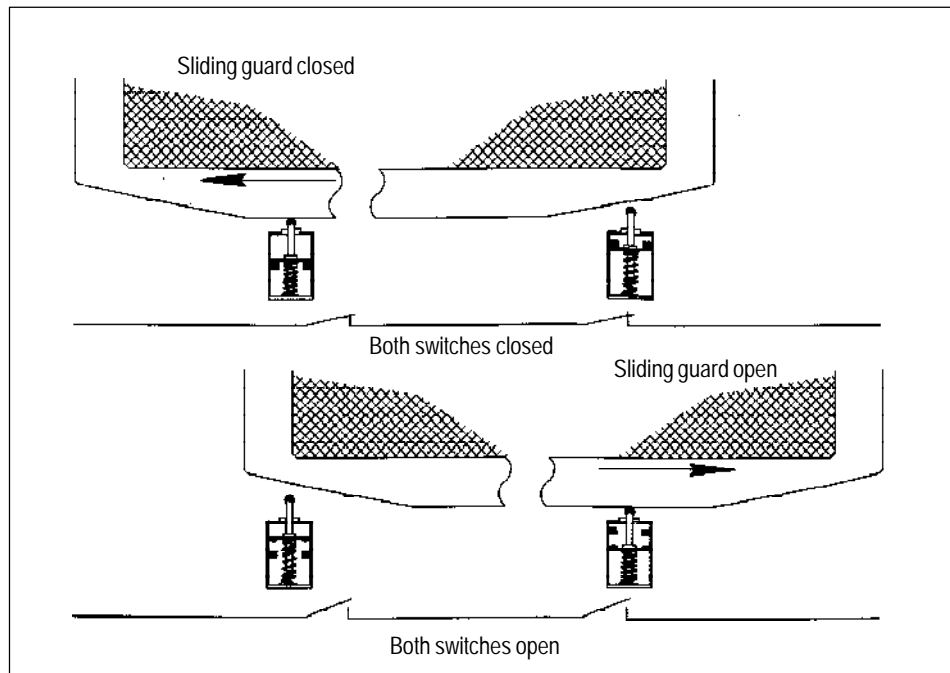


Fig. 11 Normally open and normally closed switches on one guard (For details of switch structure, refer to Fig. 6)

Because it may be easily held closed, or because it may fail to danger, a normally open switch should not be used alone for safety interlocking with a guard.

There is an application for a normally open switch in Fig. 11, and the normally closed switch has a guard interlocking function.

The normally open switch has the function of verifying that the guard is correctly placed. It will only close when the guard closes its contacts.

The normally open switch can also verify that the guard is present. On most guards, removing completely the cam and guard which allows the normally closed switch to close, will close the circuit as if the cam was present and correctly positioned. When there is also a normally open switch wired in series with the normally closed switch, the absence of a cam or guard and cam will allow the normally open switch to open. Thus, the normally open switch will detect the absence of a cam or guard and cam.

If the normally-open switch fails with contacts closed, that failure will only show with a check of the switch and not during normal operation. The monitor circuit of Fig. 12 indicates a possible closed switch by switching off all three lamps during a fault.

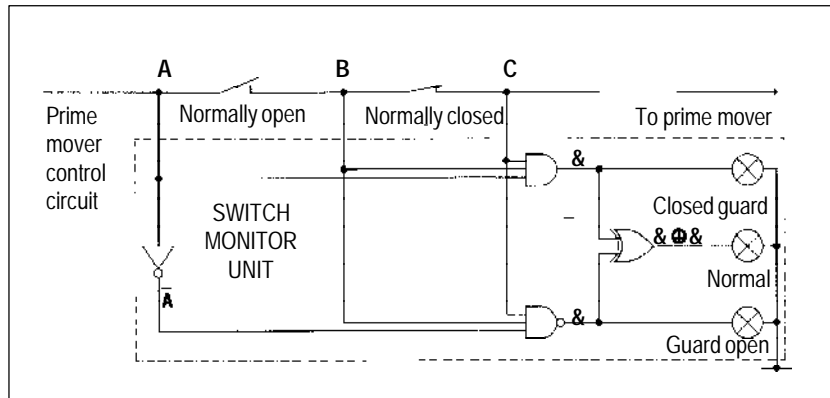


Fig. 12 Monitoring switches in two modes. Additional components may be needed for a working circuit.

This arrangement is useful to monitor two switches used in opposite modes. The purpose of the normally-open switch is to monitor correct guard position when machine design permits the guard to become misaligned, or the actuator roller to wear excessively. To perform its monitoring function, the normally open switch cam roller need make only limited contact with the cam. The normally closed switch cam roller is in contact most of the time. Without the cam closing the normally open switch, the circuit between prime mover power source and prime mover cannot be closed. Both switches should be monitored to ensure that the failure of either switch will be noticed to avoid failure to danger.

The switch monitor unit circuit diagram shows a system of monitoring which enables indicator lamps to be compared with guard position. A discrepancy indicates a fault requiring repair. To automatically monitor switch operation, the normal lamp supply could control the contactor supplying the prime mover power source.

| A | \bar{A} | B | C | & | \bar{C} | $\&\oplus\bar{C}$ | INDICATES |
|---|-----------|---|---|---|-----------|-------------------|------------------------|
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | GUARD OPEN NORMAL |
| 1 | 0 | 0 | 1 | 0 | 0 | 0 | FAULT |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | FAULT |
| 1 | 0 | 1 | 1 | 1 | 0 | 1 | GUARD CLOSED NORMAL |

Fig. 13 Logic table for the switch monitor unit

In the logic table of Fig. 13, “1” signifies that control voltage is present or that a lamp is on. “0” signifies low voltage or that a lamp is off. From the logic table conditions for “fault” indication can be read and, if required, a few components added to the circuit of Fig. 11 to include a “fault” lamp.

Note that “normally open” and “normally closed” describe the condition of the switch contacts only in their unoperated state. A normally open switch will be closed only when its actuator is under tension.

2.4 Emergency stop controls

Emergency stop controls should be designed considering the emergency and the intended action. An emergency stop on a circular saw, for example, is unlikely to

prevent kick back of wood from the saw, but it may stop the blade from turning if the operator sees that it is loose. Another consideration is that a person caught in a machine, who is in pain as a result, is unlikely to retain the presence of mind to find and operate an emergency stop. A designer who hopes that an injured person will voluntarily use an emergency stop will probably be disappointed. If an emergency stop is fitted, its operation should be involuntary, for example, a pressure bar in the way of an arm moving into a nip should immediately brake turning rollers.

It is better to design machinery to prevent access to moving parts than to try and stop machinery once people are caught in it.

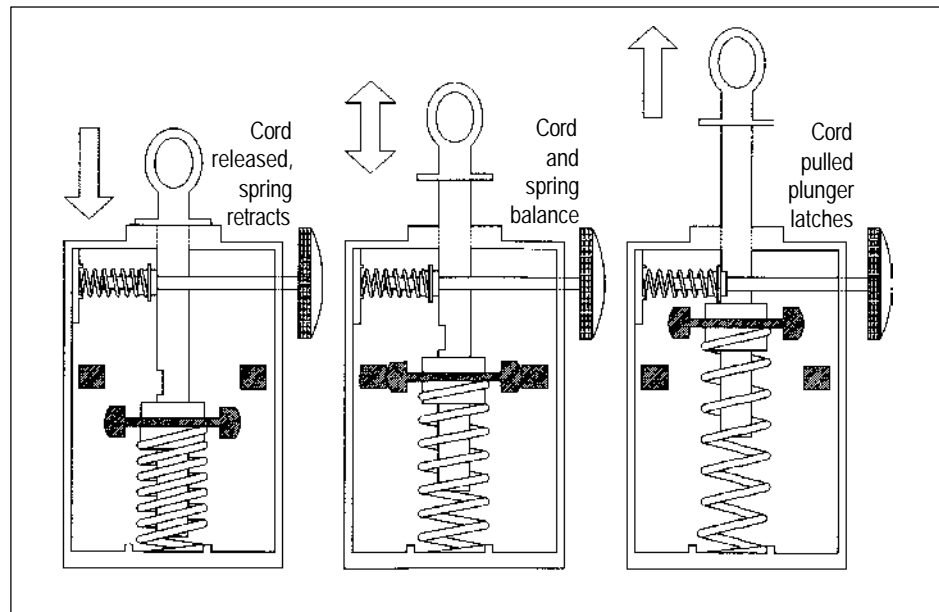


Fig. 14 Monitoring a line under tension

Emergency stop controls have a place at machinery whose operation is frequently monitored. At a long conveyor, an emergency stop cord may be fitted above the belt, to provide a means of stopping the belt quickly. An emergency stop circuit will be fast operating, avoid failure to danger, preferably through a self-monitoring system, and require a reset of machine control after every operation. The last condition avoids use of the emergency stop as a handy “on-off” switch with consequent increased wear.

The circuit could include normally open switches in a series circuit. A normally-tensioned pull cord will hold a switch closed, but a slack or broken cord should open the circuit. Thus, cord tension is monitored.

Emergency stop switches shall not be used for restarting machinery. Use of an emergency stop shall require a reset operation at the control panel.

Operating means, which may be a taut wire rope, or a bar, or a switch with a large mushroom-shaped head, shall be a conspicuous red.

2.5 Microswitches

Microswitches are named for the small amount of contact movement which occurs as they change from open to closed circuit, or as a closed switch opens. They therefore change from open or from closed very rapidly, free of contact bounce and consequent unwanted circuit operation. Fast contact movement occurs when

tension in a spring is released quickly, as the switch actuator moves. Integrity of the spring is therefore an essential requirement for predictable operation (see Fig. 8).

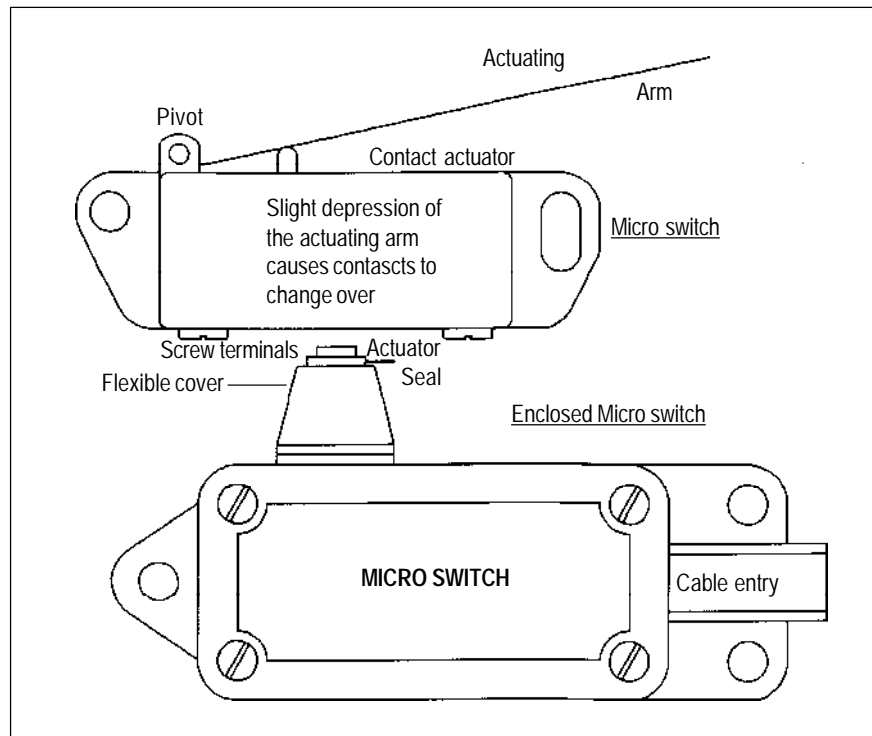


Fig. 15 Different types of microswitch

Should the spring fail or the contacts weld too completely for spring tension to separate them, contacts will remain closed without warning.

Thus, circuits which are supposed to open will continue to function in the closed circuit state. This is potentially unsafe in the guard-sensing circuit of a cycling machine, which relies on a switch opening at every cycle for safety. There is a place for microswitches on less frequently opened guards, for example, on the cover of a paper shredder emptied weekly. When microswitches are used with guards, they should be the kind of switch which has over-travel and linkages to open stuck contacts (see Fig. 8).

2.6 Magnetic switches

Magnetic switches rely on the change in magnetic field force to move switch contacts.

2.6.1 Electromagnet

The most common type is reed switches. These are operated by the magnetic field about a coil through which direct current passes. They are also operable by any permanent magnet. The most common reed switches only switch milliamperes. Reed switches do not reliably fail to safety.

2.6.2 Permanent magnet

Magnetic switches used in safety applications most often rely on contacts moved by a coded permanent magnet. Rating allows switching, for example, 1.3 A at 24 V or 300 mA at 250 V, adequate for many control applications. Contacts close or

change over as the permanent magnet is brought closer. When the permanent magnet moves away, the contacts change over or open. With no moving parts exposed, and a degree of protection as high as IP 67, these switches may be cleaned with high-pressure water and are well suited to use where hygiene is essential. IP X7 indicates protection against immersion. They are particularly useful when covers must be removed completely, as the actuator can be fastened to the cover. They are coded to reduce the likelihood of alternative actuators being used to make machinery run with guards off. Contacts are de-rated to approximately 15% of their rated current, to avoid contacts welding closed. A fast fuse should be wired in series with a magnetic switch to avoid excess current.

For use in safety applications, magnetic switches require a coded magnet for actuation and should be monitored by a control module to check whether they are still operable at each switching cycle. If the switch or switches no longer operate, the module should shut down the machine until repairs are done.

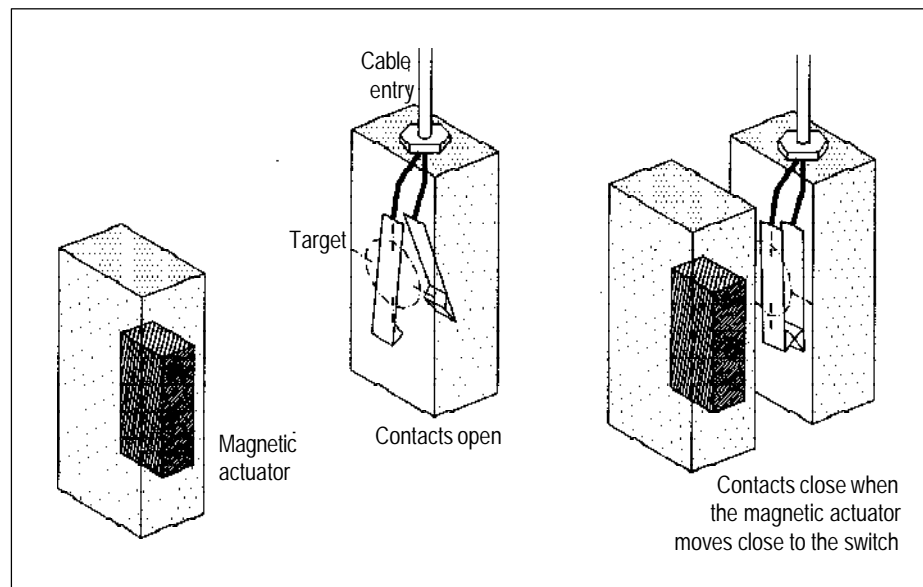


Fig. 16 Magnetic switch operation

2.6.3 Solenoid bolt

A solenoid bolt has a shaft or tongue which extends to secure a guard or cover. To withdraw the bolt, power is switched into a coil and the resulting magnetic force withdraws the bolt.

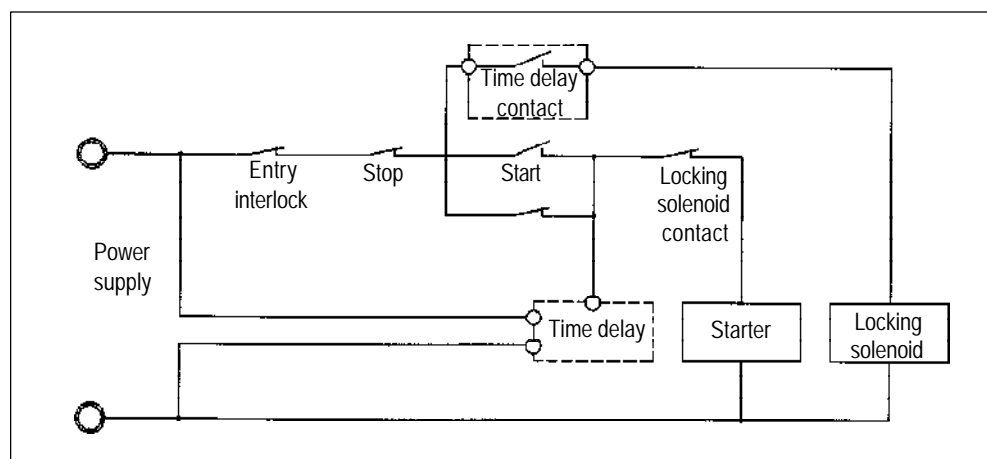


Fig. 17 Time delay circuit using solenoid bolt

In a typical safety application, a solenoid bolt will be extended by a strong coil spring while there is no current in its solenoid, or its coil.

In a safety application, a solenoid bolt can be actuated from a timer, or movement sensor when a cover must remain closed for a specified time or until movement ceases. For example, an operator can switch off a centrifuge but the bowl continues to spin. The act of switching off a motor can enable a timer or sensor of movement. At the end of the run down period, or when the movement sensor detects that the bowl has stopped, current is switched to the solenoid bolt which withdraws and allows the lid to be opened.

With the bolt extended the switch can be used to secure a guard until current is applied to its coil. A timer ending its period closes the solenoid circuit. As the electric coil is livened, the bolt withdraws under magnetic force, and the guard may be opened.

In the circuit diagram of Fig. 17, the usual convention of drawing with no power in the circuit is exchanged for showing how the contacts are arranged with a live power supply during the timed interval before the time delay contact closes. A necessary feature is the entry interlock switch, which only allows a start when the guard is closed.

2.7 Proximity switches

Proximity switches rely on detection of a suitable target, brought close to the switch. They are fast in action and sometimes well sealed, but security may be poor, as they respond to a variety of targets which may be different from the intended one. They operate without the application of any physical force, which has advantages in production applications, where a controller senses objects passing a point. High-frequency switching is possible with no effect on the life of the sensor. Switches are waterproof, and unaffected by vibration or dirt. There are switches suitable for use in hazardous areas. In safety interlocking applications, they require some care to avoid failure to danger.

Problems can be experienced with radio interference affecting the operation of these switches. Switches should be immune from radio interference, or the use of transmitters, such as cell phones, should be forbidden in the same area.

There are European standards available or becoming available for immunity from radio frequency interference, and for the use of non-contact safety switches.

For use in safety applications, proximity switches require a coded target for actuation and should be monitored by a control module to check whether they are still operable at each switching cycle and responding only to wanted signals. If the switch or switches no longer operate, or respond to interference, the module should shut down the machine until repairs are done.

A proximity switch used without monitoring its operation would not be adequately safe for interlocking a guard enclosing a hazard. Failure can be either open or closed.

2.7.1 Inductive proximity switches

Inductive proximity switches contain an internal oscillator with an amplitude which reduces in the presence of metal.

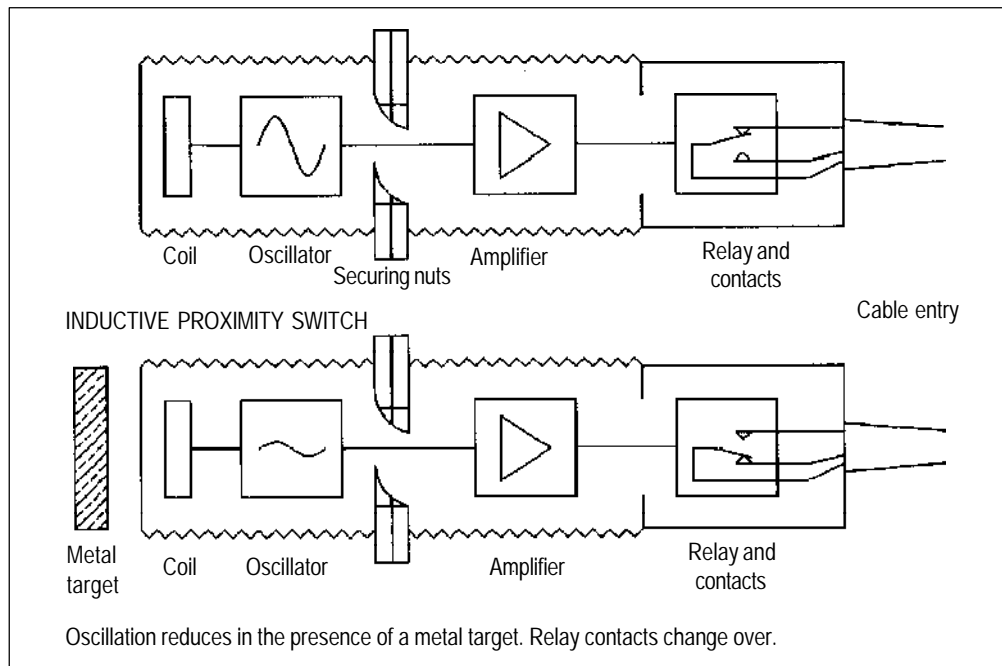


Fig. 18 Operation of an inductive proximity switch

When the change in amplitude is big enough, the switch contacts change over. There is not usually a restriction on the metal of the target, however, so any piece of metal which is large enough and close enough will change over the switch contacts.

Although the diagram shows contacts at the output of the device, the output device will most likely be a semiconductor or solid state switch without moving parts.

2.7.2 Capacitive proximity switches

A resistor and a capacitor form a resonant circuit where oscillation occurs. When the value of the capacitor is reduced, by removal of the actuating target, oscillation ceases. Oscillation, or lack of it, is detected by a circuit within the switch which will change over the switch contacts. Actuation distance may be changed by adjustment of a sensitivity control.

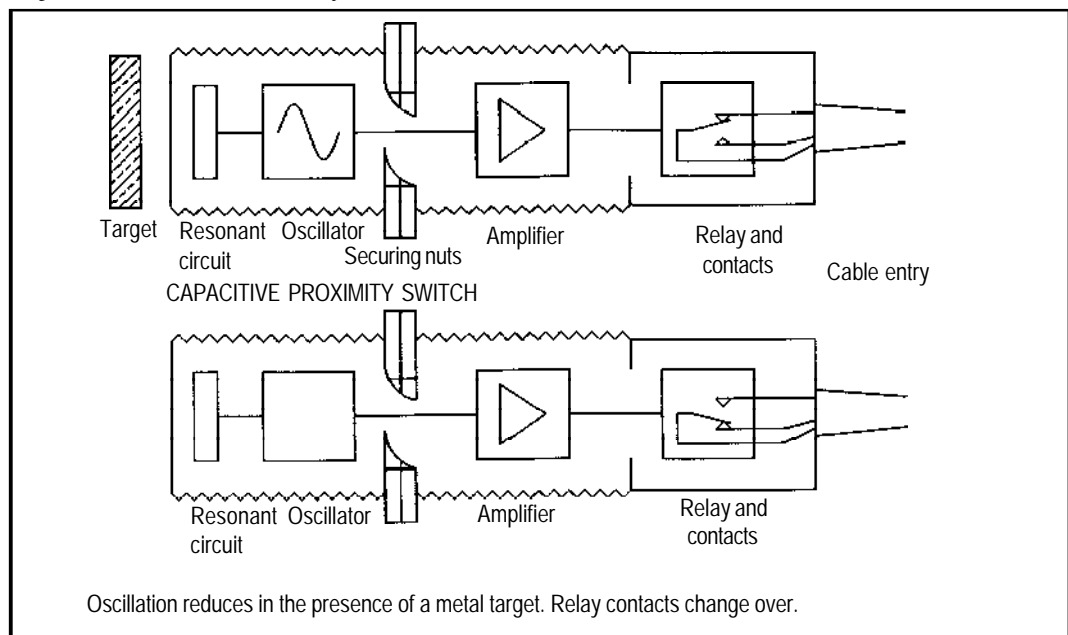


Fig. 19 Operation of a capacitive proximity switch

The sensor responds to a variety of solids and liquids such as water, foodstuffs, glass, wood, metal, paper, and plastic. In a humid atmosphere, a film of water remaining on the active surface may cause the switch to remain actuated. A change in humidity may cause unwanted operation of the switch.

Although the diagram shows contacts at the output of the device, the output device will most likely be a semiconductor or solid state switch without moving parts.

2.7.3 Restricting access of the target

In Fig. 20, the target is embedded in a material of different magnetic permeability or of different capacitive permittivity. Combinations of material can be obtained from switch vendors but nylon or other machineable polymer is probably suitable for a cam, with metal or ferrite for the target. Some caution will be necessary to ensure that consistent results are obtained if the humidity of the area around the installation is likely to change.

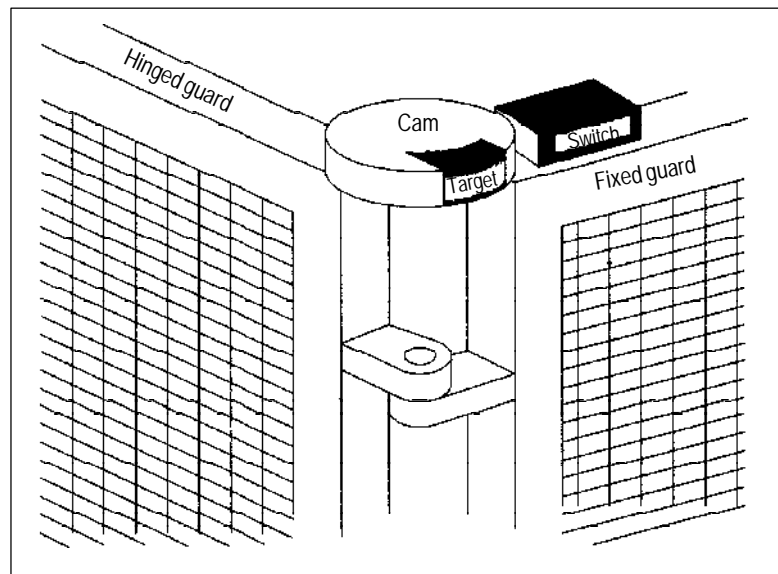


Fig. 20 Securing proximity switch with cam

With any proximity device it is essential to test the actual switch in the design location, because sensitivity, freedom from false triggering and other aspects of performance vary widely between manufacturers and models of switch.

2.8 Optical detection systems

Optical systems require a transmitter and a receiver. Photoelectric sensors interlocked with machine control systems have particular application for the protection of personnel where mechanical guards are impractical or severely impede access to the machine.

A light source transmits light. The receiver detects light from the source, and controls relay contacts. Light from the source is reflected back into the receiver, or shines directly to through beam sensors, with a change in the strength of received light changing position of relay contacts controlled by the sensor. Infra-red detectors are receivers only of light.

2.8.1 Infra-red light detection

A change in infra-red light, or radiant heat, should be detected as a person moves in front of an infrared light sensor.

They also detect other sources of heat, such as central heating, and the area under surveillance is not easily defined. Operation is too unpredictable for safety applications.

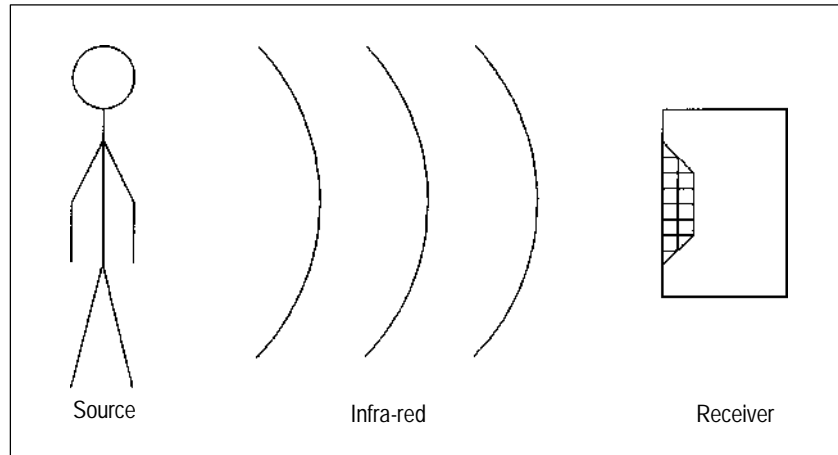


Fig. 21 Infra-red detection

2.8.2 Retroreflective sensor

Light is reflected from a retroreflector into the light receiver. Interruption of the light beam results in a change of position of relay contacts controlled by the receiver. In a safety system configuration, transmitter and receiver are housed together, with the receiver monitoring light reflected from a mirror. A retroreflective sensor will detect objects which are not themselves reflectors, by detecting an absence of reflected light.

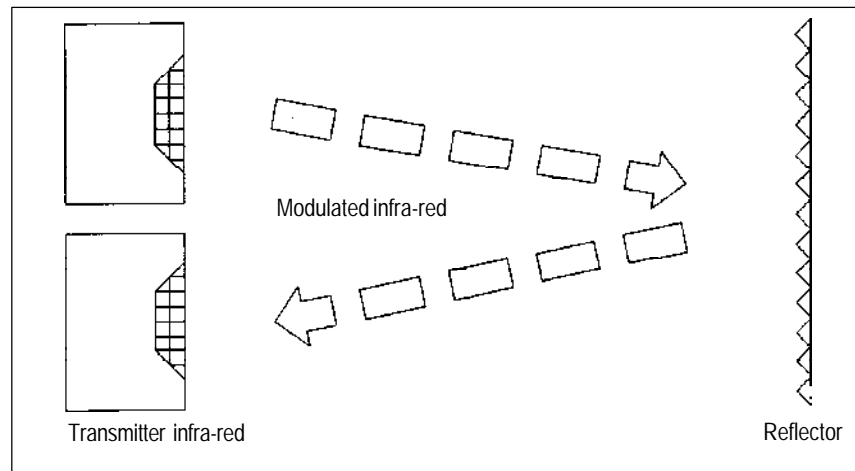


Fig. 22 Retroreflective sensor

2.8.3 Specular sensor

Usually for a shorter range than the retroreflective type sensor, specular-type sensors require a sufficiently reflective target, preferably bright or shiny, to reflect light back into the receiver. Operation is too unpredictable for safety applications.

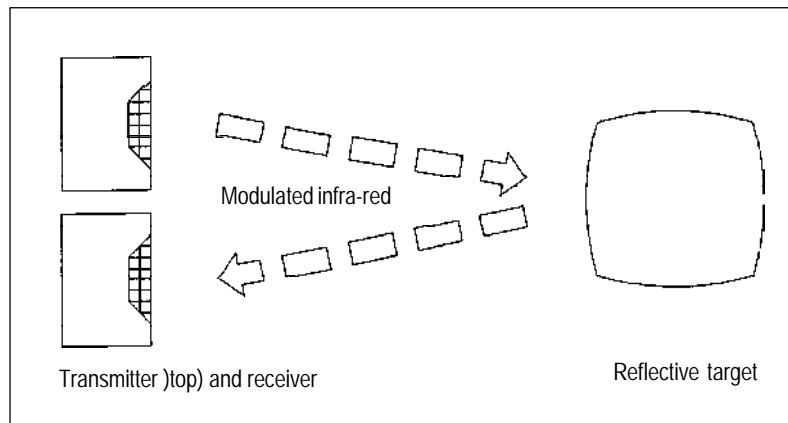


Fig. 23 Specular light sensor

2.8.4 Through beam sensor

Generally of longer range than retroreflective or specular sensors, through-beam sensors are found in production and in safety applications. Objects must be large enough to adequately block light from reaching the receiver. Information concerning the range and detection capabilities of optical systems will be available from vendors.

Light source and light receiver are usually housed separately. Throughbeam sensors for safety systems should meet a test of high performance, such as BS 6491: *Electro-sensitive safety systems for industrial machines*.

Only through-beam sensors or certified retroreflective sensors are recommended for protecting personnel near industrial machines.

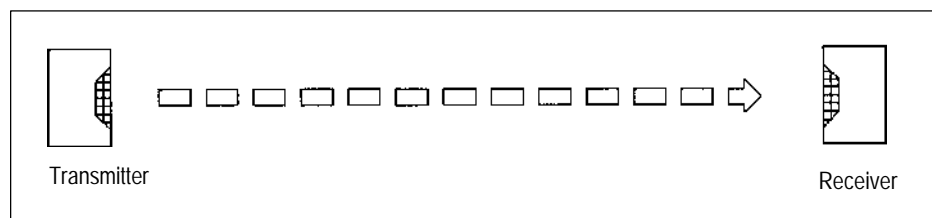


Fig. 24 Through-beam sensor

2.9 Actuator-operated switches

When switches are used to detect the presence of a cover, the cover may include a key to close a switch, only when the cover is on. The key is an actuator with an unusual shape which will open the switch as it is withdrawn. An unusual shape for the key is essential for the security of this system. The key actuator may work by turning a cam as it is withdrawn, or it may be a magnet of unusual shape.

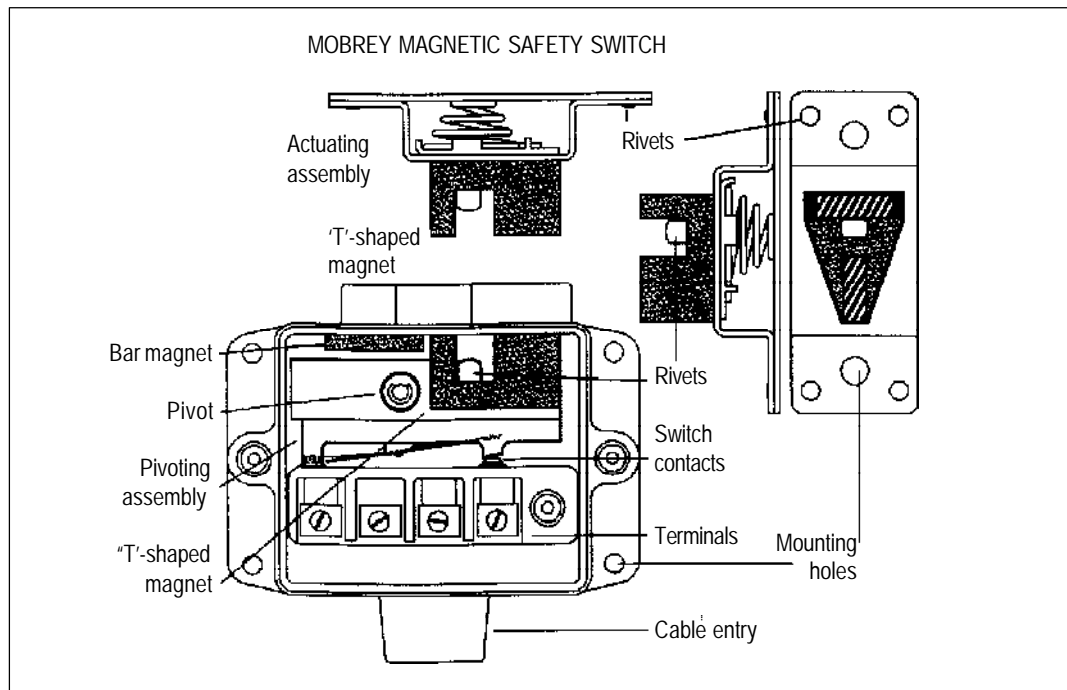


Fig. 25 Mobrey safety interlock switch with magnetic actuator

Actuator-operated switches are useful where a guard or cover must be removed from a machine completely to allow cleaning or adjustment.

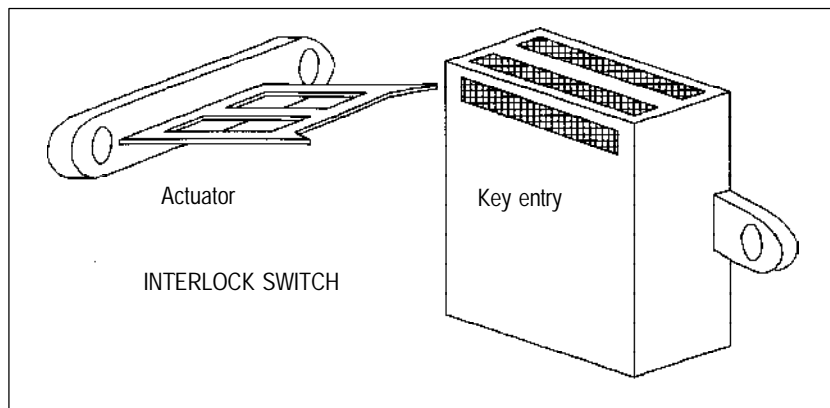


Fig. 26 The unusual key operates a rotary cam inside each of the openings. Each cam operates switch contacts.

3. TRAPPED KEY INTERLOCK

Access to hazardous areas requires the use of a key. The access key is only available from a retaining clamp when defined conditions have been met. Commonly, the access sequence is that the trapped key turns off an electrical supply to a hazard, the key is withdrawn, then the key is used to unlock a mechanical guard.

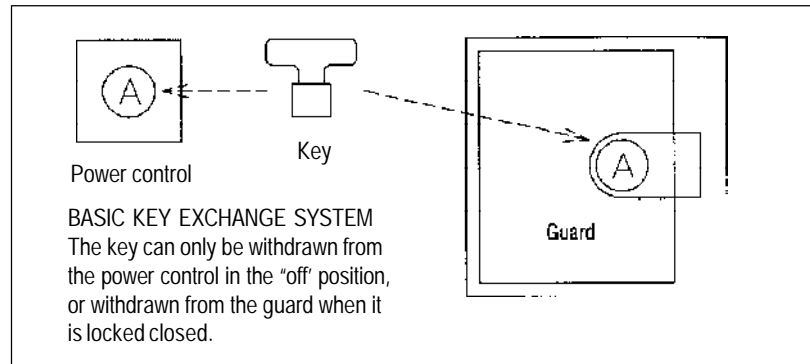


Fig. 27 Simple key exchange

Start up requires operations to be reversed. Until the guard is closed, and the bolt home, the key cannot be released to turn on power. When machines are big enough to have multiple opening guards, the key controlling electrical supply can be secured in a key exchange unit while the other keys are held in multiple guards.

When machine parts continue to move after power is turned off, motionsensing or time delay can be added to secure guards until machinery stops.

Trapped key systems are usually made for rugged environments where high security is needed, but where cam-operated limit switches would fail early — around wool processing machinery, for example.

Keys are usually too big to fit conveniently in a pocket, so are likely to stay with the machine.

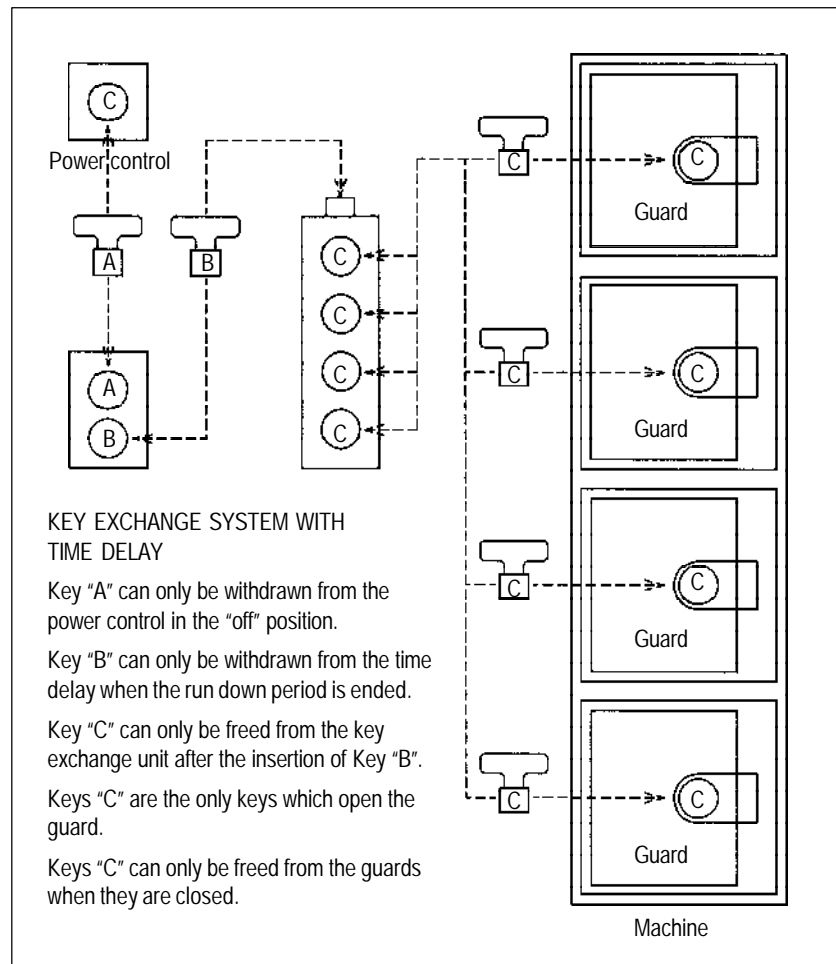


Fig. 28 Key exchange with time delay

4. LOCKOUT

4.1 Lockout procedures

When access to machinery requires shut down, that is opening of power sources for maintenance or tool changes, there may be periods while service personnel are out of sight of other people in the plant. Any of the others may have some reason for turning on the machine. The result may be mutilation or death for the person performing service.

Strict lockout procedures need to be formulated and enforced by owners of machinery. All staff need to be aware of lockout procedures. Wherever possible, power connections should be designed so that plugs can be disconnected or fuses removed.

Lockout or tagout places control in the hands of the person doing the service. No other person shall be able to restart machinery while the maintenance person is at work on it. Every person who performs maintenance should have a named lock and key. A locking tag and methods of fitting should be available for every machine.

Isolators appear to have opened circuits when the handle turns. An unpleasant, and maybe fatal, surprise awaits staff if the handle turns without opening contacts. Isolators shall have indicators to show the position of the moving contacts. If the handle is an indicator, it cannot indicate the open position unless the moving contacts are in the open position. The indicator shall not indicate OFF unless the contacts open. The fault is obvious and appropriate precautions must be taken.

A necessary addition to electrical lockout is reducing energy in the machine to zero from all sources. Thus, electrical lockout must include locking off power to prime movers, not only control circuits. This includes, for a.c. motors, locking off all three phases. Shut down shall include sensors and machine parts controlled by them, so all potentially moving parts in the section have zero energy and cannot move unexpectedly.

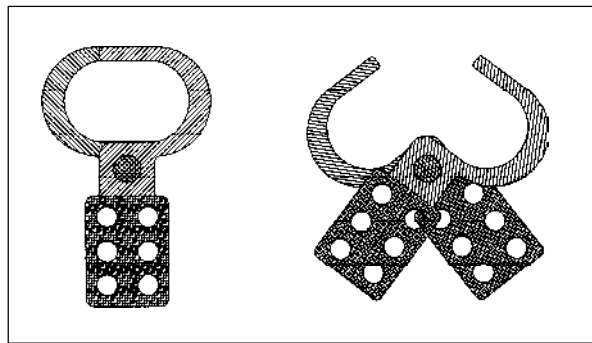


Fig. 29 Lock off safety clasp for six locks

Where the isolation point for machinery is distant in a large and complex operation, a written isolation procedure protocol is required. The isolation of fully-automated machinery can be very difficult, because often power must remain on the control system, which could prevent the main supply to a motor control centre from being disconnected. In this case, a written protocol for equipment isolation would be required. Writing and enforcing the protocol would be the responsibility of the company management. Appropriate wording would be:

*Senior management enforces strict and severe penalties for not following lockout procedures and applies the rules to everybody in the company.
Contractors on this site are bound by the same conditions.*

With zero energy where electromagnetic brakes are fitted, there shall be a procedure to prevent movement of any part of the machine where the brake force is removed.

Fuse removal to open circuits without locking off controllers has the disadvantage that fuses are easily replaced components with the ability to liven circuits. Fuse removal to open circuits without locking off controllers effectively removes control from the service personnel working on the machine.

Means shall be provided to remove hydraulic or pneumatic pressure which may cause an accident if it can cause movement. Hydraulic or pneumatic lockout includes relieving pressure to tank or to atmosphere.

Means shall be provided to secure machine parts of significant weight, and loads within the machine. Raised weights, such as platens, must be chocked if they cannot be lowered.

When the machine is in the “zero energy state” it can be worked on.

Every person who works on or in the machine adds a lock to the tagout, and pockets the key.

The advantage of named locks is that owners of securing locks are easily identified as maintenance is completed.

4.2 Power failure release

Should power failure to the machine occur, a potentially dangerous situation arises when power is restored if the machine automatically restarts. The potentially dangerous situation would be most obvious if a circular saw started unexpectedly. The Electricity Regulations 1993 require the fitting of switches which open when power supply ceases.

A power failure release device incorporated into the mains circuit shall be fitted to all machinery where unexpected starts would cause a hazard. The device will prohibit latching of the mains circuit if mains power is not present, and delatch the mains circuit if power fails during operation. The device will not indicate the “ON” position while power is not present.

5. BRAKING ELECTRIC MOTORS

5.1 Mechanical braking

Mechanical braking uses a friction device, such as pads, in contact with discs or brake shoes expanding against brake drums. The usual arrangement is that the brake is held off by the application of power from the motor circuit. When the motor power turns off, the brake is applied and the motor stops by the application of the brake. Brake force is usually applied by the retraction of springs.

5.2 Electrical braking

Electrical braking either changes the electric field of the motor to stop motion, or dissipates the rotational energy of the motor in a load which is specially connected for the purpose.

5.3 Electrical plugging

Electrical plugging for three-phase motors consists of swapping two leads. Plugging is reversing the supply connections to the motor while it is running in the first direction, in order to obtain its rotation in the other direction. This applies reverse torque to the motor which stops rotation with, however, a large temperature rise. The rotation of the motor shaft must be sensed to ensure that current is disconnected when rotation stops. If reverse power is applied continuously, the motor will start to turn in the opposite direction. Usually a direct-on-line reversing starter is used for this duty. Squirrel cage motors are used for plugging, and also starting and inching.

5.4 Direct current injection

Direct current injection consists of disconnecting power from the stator winding, and connecting d.c. to set up a stationary field. The braking effect is small at high motor speeds unless high currents are applied. Direct current is disconnected after a time delay, but reversal of the motor cannot take place.

Direct current shunt motors may be used for starting, plugging and inching, and for dynamic braking. Series motors may be used for the same purposes.

5.5 Capacitor braking

Capacitor braking connects capacitors across the motor terminals when the power supply to an induction motor is opened. The capacitors force the motor to run as an induction generator, with its power dissipating into the capacitors. The motor terminals are then short-circuited and magnetic braking occurs. Capacitor braking followed by simultaneous magnetic and direct current injection braking may be applied when load inertia is very high.

6. PROGRAMME ELECTRONIC SYSTEMS

Programmable electronic systems provide automation for industrial processes to enable machinery to perform repetitive tasks with more consistency and sometimes in more dangerous conditions than a human operator

A design document should be available for any programmable electronically controlled, automated industrial process or machine. It should clearly describe the operating environment, features designed and tested for the operating environment, circuit design features, and programme design.

The operating environment may include the presence of hazardous atmospheres, potential rises in signals earths, vibration where the controller or some of its modules are to be mounted, dust, corrosive atmospheres, extremes of temperature and extremes of humidity. Possibly harmful features should be listed to enable assessment, and then removal, isolation, or minimisation of their effects to occur during design and installation, and where adverse effects remain present, to allow for their presence by programmed maintenance or other monitoring during the life of the installation.

6.1 Interference

There are several sources of interference with programme operation which may cause unexpected operation.

Signals from a radio frequency transmitter may interfere with programme operation so that parameters such as distance or load are read wrongly. In these circumstances, operation of a lifting machine where load and distance are monitored continuously could vary from the designer's intention, possibly causing a hazard to the operator and other people nearby.

Electrical interference in a circuit may raise signal levels higher than wanted, so injecting spurious signals into logic. When electrical interference breaks through into voltage supply lines, momentary rises in voltage can exceed maximum component ratings, causing failure of integrated circuits and other components.

There are various options for defeating mains-borne interference, for example, applying suppression at source, or supplying the controller from a different power supply from the circuit in which the signals arise, or fitting an interference filter at the mains input of the programmable logic controller.

Users should be aware of sources of radiated and electrical interference and ensure that equipment vendors are also aware of conditions at the installation at the time of placing orders. There should be a list of potential sources of energy which may interfere with control systems. Sources may include electric fields around lift motor cables, energy radiated from welding machines, energy reaching the mains from semiconductor switching devices, radiant energy from electromagnetic heating systems, energy radiated by control and communication transmitters.

Design documents should list interference sources, and measurements, and assessments of whether the interference is likely to be significant.

Users should also be aware of features of the New Zealand electricity supply system such as frequency variation, the presence of harmonics, and the use of audio frequencies for signalling. Vendors should be able to assess how their equipment will perform in adverse conditions and advise on fitting control measures such as mains filters or radio frequency shielding.

Static electricity, which may be generated as easily as walking across synthetic floor coverings, may be discharged into electronic circuits, causing semiconductor components to break down partially. Failure may then occur at some later time, perhaps after a series of intermittent faults.

6.2 Software

Programmes can allow dangerous operation in unexpected ways, due to the assumptions on which they are written. For example, if low levels of hydraulic fluid in a machine call an instruction to hold controls at their present state, the machine may continue to run even if a guard is opened.

The “hold controls” instruction has priority over the result of “guard open”, which would normally be a stop instruction, perhaps because the programmer did not anticipate that the machine could run low on hydraulic fluid during operation.

There are two ways of improving safety when a machine is under programme control. The first is to wire the safety precautions in the traditional way, that is with limit switches at the guards wired to the control circuits of prime movers. Wiring of safety interlocks for emergency stops and other critical safeguards should be in a circuit outside the computer or programmable logic controller. The limit switches can be two-pole types with contacts to switch the control circuits, and a second contact set for signalling purposes. Signal contacts can be used for connection to the computer or programmable logic controller. Programmable logic controller operation follows operation of the safety circuit. Hard-wired safety circuits should be the method used with one-off controller systems.

In the second and more expensive system, independent programmers prepare code for two different controllers. This method is used for largescale automated process control, or for mass-produced machines, such as press brakes sold with dedicated controllers.

Outputs are continuously compared while the machine operates. The comparator circuit shuts down the machine if it detects a difference between the outputs of the

programmable logic controllers. The comparator circuit is a “watchdog”, and can detect software differences (that is differences in programme outputs), and differences in hardware outputs. Thus, failures affecting only one programmable logic controller can cause the machine to stop. The advantage of using different computers is that common mode failure, that is when the same fault affects both computers together to generate identical but faulty outputs, has a reduced probability of occurring.

The watchdog will not necessarily distinguish between a hardware and a software fault, but can stop machinery when it detects a discrepancy.

Control systems should shut down without failure to danger when supply power is lost or goes below safe limits; the operating system memory or user programme memory is corrupted; the operating system responds incorrectly.

7. INTERLOCKING APPROPRIATE TO THE HAZARD

Fig. 30 shows a graphical assessment of the degree of hazard presented by machinery to users. It is based on Appendix B of AS 4024.1 (Int) - 1992 *Safeguarding of machinery, Part 1: General Principles*. Using this method requires knowledge which will be added to with experience. There will be some degree of subjectivity in using the method, but describing the hazard has the advantage of concentrating the minds of those assessing hazards of machinery.

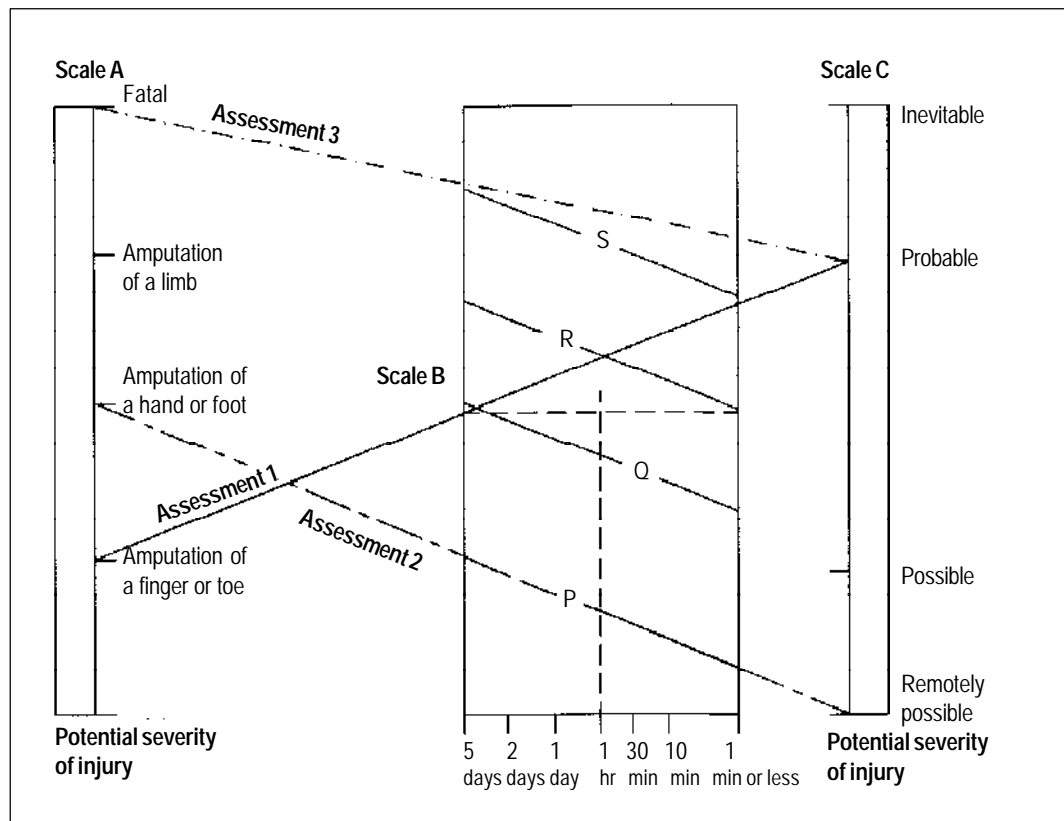


Fig. 30 Selection of an interlocking system based on AS 4024 (Int) — 1992

In this way the experience of machinery users, who have suffered from too easy access, can be applied in the design of interlocking systems. This design method requires an assessment of the hazard at the opening to potentially dangerous parts of the machine, assuming that the interlock has failed.

There are three factors to measure, which are:

- (a) Severity;
- (b) Frequency; and
- (c) Probability.

Measurement of potential severity requires a knowledge of the accident record for similar machinery and the fate of those who were caught in it. The assessor will have to observe the operation of the machinery and decide on its likelihood of piercing, crushing, shearing, or amputating anyone with the misfortune to get caught. Generally, if it looks potentially injurious, someone has probably been caught in a similar mechanism and was hurt or killed.

Frequency of approach is measurable in terms of duties.

- (a) Does product have to be lifted from the mould by hand every time the platen opens?
- (b) When does the attendant free the line if a bottle jams under the filling head?
- (c) How many times an hour does the stacking robot drop product which the attendant is supposed to clear?

It is almost guaranteed that if people can clean a machine without turning it off, or reach through moving parts to a grease nipple, or follow blindly when a supervisor teaches poor work habits, they will do so. Probability is less a matter of measuring what is sensible, and more a matter of imagining the worst case of an operator hurrying to fill an order and clean up before the end of the shift. Probability is not simply a matter of imagining that only the interlock fails, but also of assessing what people who work with machinery, with perhaps a limited understanding of what it does and how it works and of the meaning of terms like “force” and “power”, are likely to do when a fault appears in addition to failure of the interlock.

An example of interlocking selection is given in Fig. 30, where the loss of a finger or toe is probable if the interlock fails. Probability is the likelihood of injury occurring, and is the area where there is most likely to be disagreement.

There is an expectation that people working with machinery will be always objective and unhurried, and careful, but even these paragons have lapses. As the operator is required to approach the hazard once per hour, Type R guard operated power interlocking is appropriate for the initial assessment. Other considerations, such as experience of users, or technical considerations including the supply of adequately rated safety interlock switches, may result in some adjustment of the rating. (Assessment 1.)

Two other examples should help to demonstrate use of the system, which assumes continued use of the machine after the interlock fails.

In the second case, the amputation of a hand at a chain transmission is remotely possible, with a frequency of approach less than once per five days. Type P interlocking is therefore the first choice. (Assessment 2.)

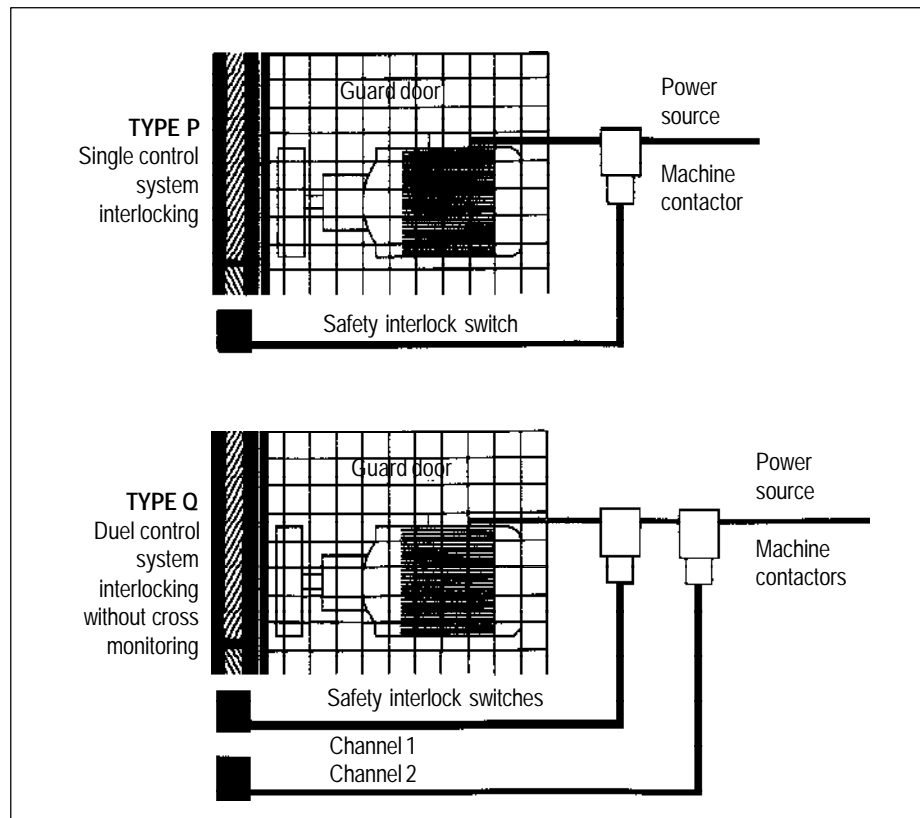


Fig. 31 Safety interlock switch arrangements — Types P, Q interlocking

In the third case, at an injection moulding machine, should the press platen close while the operator is between the press platen and the fixed part of the mould removing product, fatal injuries are probable.

Frequency of approach is once per 10 minutes. Interlocking system selection from Fig. 30 shows that type S is appropriate, that is with guard locking interlocking or dual control system interlocking with cross monitoring. This level of safety is illustrated in Fig. 32 (Assessment 3).

Adoption of a systematic approach to hazards of interlocking failure will only have a value if records are kept in a way in which information can be readily brought up to date.

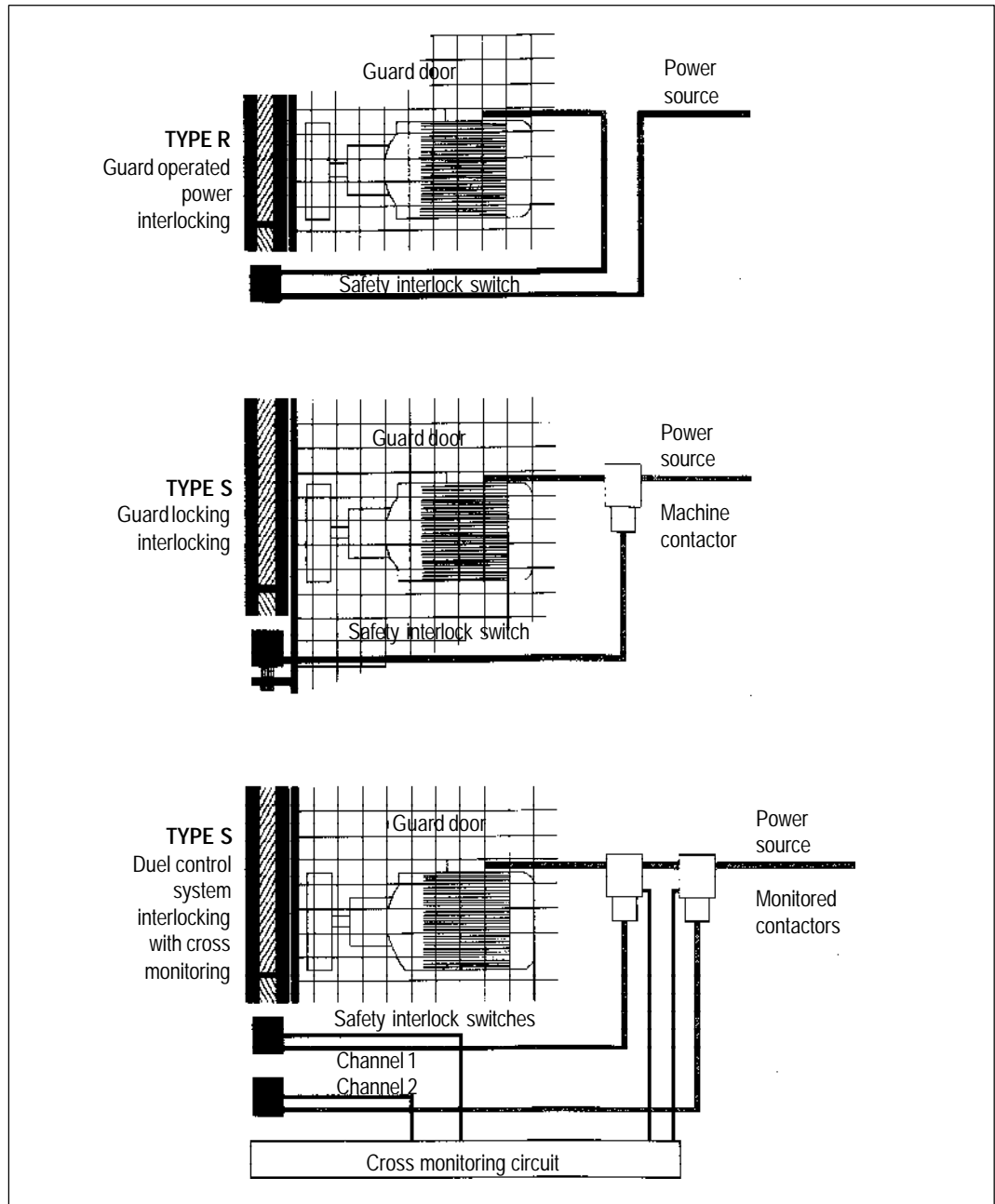


Fig. 32 Safety interlock switch arrangements—Types R, S interlocking

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GLOSSARY

Actuator: Part of a switch which is moved by an outside force.

Alternating current: Electric current which, over time, varies regularly in amplitude and sign.

Ampere: One ampere is that constant current which, if present in each of two parallel conductors of infinite length and one metre apart in empty space, causes each conductor to experience a force of 2×10^{-7} newtons per metre of length.

Amplitude: Size or quantity.

Atmosphere: Air and its contents. Pneumatic systems exhaust to atmosphere.

Average value: Equivalent value of steady direct current which will heat a resistor. The amplitude of d.c. may change, for example following rectification of a.c., but the sign will always be the same.

Belt conveyer: Moving continuous flexible carrier of goods.

Breaking: Opening an electric circuit.

Capacitor: Device for storing electric charge on metal plates separated by an insulating medium.

Chocked: Secured from movement by mechanical stops.

Closing: Completing the current path of an electric circuit.

Coil: Insulated wire wound about a former to carry current and produce an electric field.

Contactors: Device which closes one or more electric circuits.

Contacts: Parts of a switch which open and close to control the flow of current.

Current: Flow of energy through an electrical conductor.

Direct current: Current which flows in only one direction.

Direct-on-line: Switching the supply directly on to the motor. There may be an upper power limit specified for motors which may be started this way.

Electric: Charged with electricity.

Electrical: Powered by electricity.

Electricity: Phenomena caused by electric charge, which causes bodies carrying like charges to repel each other, while bodies carrying opposite charges attract each other. Electric charge is caused by an excess of electrons for negative charge, or a deficit of electrons for positive charge.

Electronic: Circuit where small amounts of current are used to control much larger currents.

Energy: Work done when the point of application of a force moves.

Extra low voltage: Any voltage normally exceeding 32 volts a.c. or 115 volts d.c.

Fast blow fuse: Usually a cartridge fuse which operates at 1.2 times the nominal current.

Ferrite: Ceramic magnetic oxides which have magnetic properties. They are insulators.

Hazard: An activity, arrangement, circumstance, event, occurrence, phenomenon, process, situation, or substance (whether arising or caused within or outside a place of work) that is an actual or potential cause or source of harm.

Humid: Damp.

Hydraulic: Using oil under pressure as a means of doing work.

Inching: Predetermined movement of machinery for each actuation of a control.

Inductive: Causing magnetic flux by passage of current through a conductor.

Infrared: Heat radiation within the range 400 nm to 4000 nm. nm = nanometres
= 10⁻⁹ metres

Ingress: Entrance to an enclosed space.

Input of an electric circuit: The part of a circuit which receives a control signal. It may include filters to restrict amplitude and frequency of the signals received.

Integrity: Design for predictable operation.

Interlocking: Means of restricting operation of machinery by control circuits.

International Protection (JP) ratings: Degree of protection provided by enclosures for electrical equipment. AS 1939-1986 provides a statement for use in New Zealand.

Limit switch: Switch which detects the limit of movement.

Livened: Connected to a source of electric current.

Logic: System of determining output signals from combinations of input signals.

Machineable polymer: Substance made from long chain molecules which can have its shape altered by turning or tapping.

Magnetic permeability: Property of a substance which determines how easily it will form a magnetic flux.

Milliamperes: Thousandths of amperes. 1 mA = 10⁻³ A

Monitoring: Verification of the operation of a circuit. When operation is different from that expected, protective measures are switched into operation.

Normally closed: Switch contacts which are closed when the switch actuator is under no pressure.

Normally open: Switch contacts which are open when the switch actuator is under no pressure.

Nylon: Long chain polymer.

Oscillator Circuit which produces a signal regularly varying in amplitude over time.

Oxidation: Formation of an insulating layer of metallic oxide.

Permeability: Property of a substance which determines how easily it will form a magnetic flux.

Permittivity: Value of the insulating medium between plates of a capacitor in determining quantity of charge held.

Pitot head: Means of reading air velocity by sensing pressure differences.

Platen: Part of a press which moves under pressure to form a product.

Plunger: Switch part which moves when the actuator causes it to.

Pneumatic: Using air under pressure as a means of doing work.

Power: Rate at which work is done or electrical energy is converted into work.

Pressure: Force per unit area.

Prime movers: An engine, motor, or other appliance which provides mechanical energy derived from steam, water, wind, gas, gaseous products, compressed air, the combustion of fuel, or any other source.

Programmable logic controller: An electronic device which continuously accepts inputs from field devices and sensors and controls outputs, in accordance with an internal programme. Device which accepts a series of programming steps to perform logical functions.

Pull cord: Cord which operates a latching switch to stop motion.

Reflective target: Object which reflects sufficient light to allow a receiver to determine whether a target is present or absent.

Resistor: Circuit element which dissipates heat.

Resonant: Oscillation at a specific frequency.

Retroreflector: Reflector using glass or plastic prisms to return light to a receiver

Slow blow fuse: Fuse which allows current flow in excess of the nominal value to continue. As much as 10 times the nominal value for a few milliseconds.

Solenoid: Electric coil whose flux causes movement of a ferromagnetic core.

Specular: Reflective, especially from a metal surface.

Spurious: Unwanted and likely to cause unwanted operation.

Squirrel cage: Rotor named for its shape.

Starting: Means of connecting an electric motor to a circuit. Considerations are: starting current; starting torque; inertia of rotor; control electronics required; possibility of braking.

Stiction: Force holding electric contacts together.

Surveillance: Review of operation of machinery.

Switch: Device by which a small amount of force, which may be mechanical or electrical, is used to allow the flow of a much larger force, for example, electric current, into a circuit.

Tank: Receiver for hydraulic oil.

Temperature: Measure of the hotness or coldness of a body.

Torque: Force tending to rotate the body on which it acts.

Velocity sensor: Device which senses speed of an object or fluid.

Voltage: Potential difference between two points in a circuit.

Welded: Connection of two solids by the liquefaction, followed by solidification of material which joins them.