Engineers' Relay Handbook

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Chapter 11
Special purpose relays
Part 1: Safety relays

Particular properties and benefits

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11.1.1 Introduction

Relays with forcibly guided contacts are a special type of relays. Colloquially they are often referred to as safety relays. Apart from the usually specified high product quality, they satisfy particular standard requirements.

These relays are primarily used in controllers to cope with safety-related tasks.
Among these are the protection of health, life, the environment, complex processes and capital equipment.

NOTE—Terms and standards in *italics* are described in 11.1.9 and 11.1.10, respectively.

11.1.2 What is meant by forcible guidance of contacts?

A forcibly guided contact consists of at least one NC-contact and at least one NO-contact with a mechanical device which prevents the NC- and NO-contacts from being closed at the same time. This requirement applies particularly for faulty conditions *(faulty condition)* over the entire life span, e.g. when a contact fails to open.

The consequence of this in a circuit is that an NC-contact that does not open can be detected by an open NO-contact. Correspondingly the same applies to an NO-contact whose NC-contact remains open (*identification of a failure*).
It follows from this requirement that the opening of a contact always precedes the closing of the antivalent contact, and that this under no circumstance occurs simultaneously the other way round.

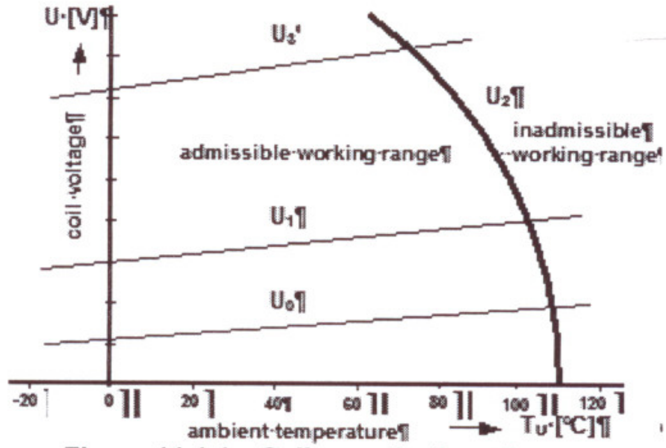

Figure 11.1.1—Coil energization diagram (exemplary presentation)

This means that the *'failure to open'* is detectable. This applies equally to both NC- and NO-contacts. For this failure to occur, the antivalent contact in question must have a minimum opening of > 0.5 mm or at least (2 x 0.3) mm in the case of bridge contacts. Apart from this, the possible causes of a faulty condition of the relay such as wear and breakage of components (especially springs)must be assessed and their effects kept under control by suitable design measures.

When a circuit is designed, the supply voltage must be considered in relation to the operation. The minimum value U_1 is required for the relay to respond. To avoid thermal overload, the value U_2 must not be exceeded.

For relays with forcibly guided contacts, there is a further voltage limit U_3. If an overenergization occurs in the faulty condition 'failure to open' of an NC-contact, a contact gap of at least 0.5 mm at the forcibly guided NO contacts must be maintained.

EN 50205 differentiates between contact assemblies according to the type of forcible guidance. Type A describes relays in which all contacts of the contact assembly are connected to each other by the forcible mechanical guidance. On the other hand, not all contacts of the contact assembly for type B relays are connected to each other by forcible guidance.

Relays with CO-contacts in safety circuits must also satisfy the requirements of standard EN 50205. This means that only one NC- or NO-contact may be used per CO-contact and that the CO contacts must be mutually forcibly guided. This is why

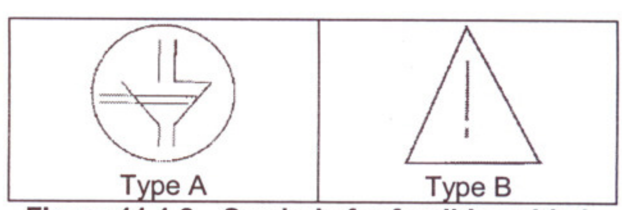

Figure 11.1.2—Symbols for forcibly guided contact assemblies according to EN 50205

only relays with at least two CO-contacts may be used for this type of application. They are also assigned to the forcibly guided category B.

Hereby forcible guidance of the contacts must not be confused with *direct opening action* as per *IEC EN 60947-5-1, Appendix K*.

Failure to open and *failure of insulation* are the only failures of significance in the context of our safety-relevant considerations.

Below, the function of forcible guidance is explained using failure to open in a clapper type relay.

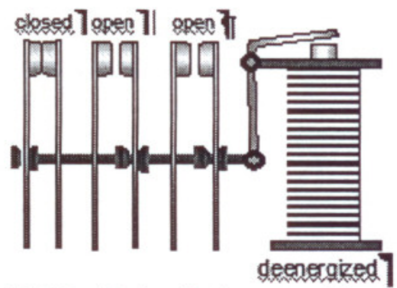

Figure 11.1.3—Relay in free position

Figure 11.1.3 shows the neutral condition of the coil (monostable). The relay is in the free position, the 2 NO-contacts are open and the NC-contact is closed.

Figure 11.1.4 shows the relay with an energized coil after the end of the switch-on process in a stable condition. The two NO-contacts are now closed and the NC-contact is open.

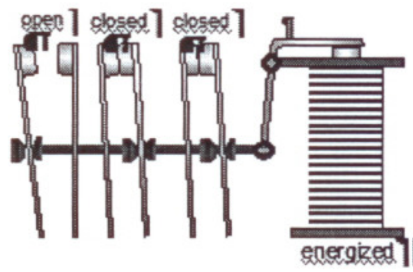

Figure 11.1.4—Relay in working position

Figure 11.1.5 demonstrates 'failure to open' after switching off of the energizing voltage at the coil: The middle contact (NO-contact) is welded. The contact springs are connected, to each other by the actuator and the NC- contact cannot return to its starting position. The NC-contact is used as a control contact and is therefore unable to close the feedback circuit; the failure is detected. The switching position of the second NO-contact is undefined since the contacts in the example do not open in a defined manner.

In the case of a relay without forcibly guided contacts the NC- and NO-contacts would be closed at the same time.

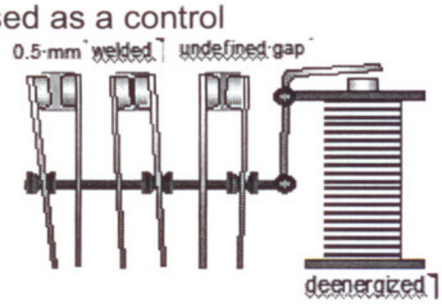

Figure 11.1.5—Relay in faulty condition, coil not energized

Figures 11.1.6 to 11.1.8 show relay executions with forcibly guided contacts.

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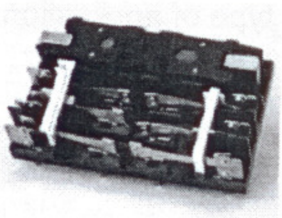

Figure 11.1.6—Relay with rotating armature (Panasonic)

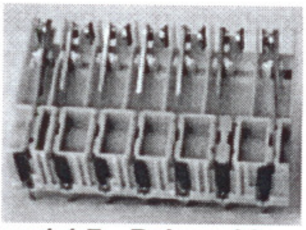

Figure 1.1.7—Relay with sliding armature (HENGSTLER)

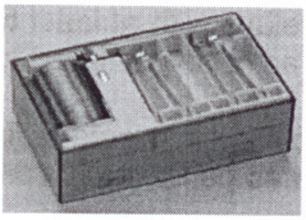

Figure 11.1.8—Relays with clapper armature (ELESTA)

11.1.3 Standards

Elementary relays, with forcibly guided contacts, that are used as components in safety applications must comply with the standard of safety relays *EN* 50205 as well as the general standards for elementary relays *IEC EN 61810-1*, *IEC EN 61810-2* and *IEC EN 61810-7.*

11.1.4 Failure types

Compared to relay failures in general, safety engineering differentiates between safety-relevant and safety-irrelevant failures. This is necessary for risk analysis.

11.1.4.1 Safety-relevant failures

Failure to open is a contact condition in which, contrary to expectations, a contact does not open. This is caused by contact welding or sticking.

Failure of insulation is the loss of breakdown voltage at the open contact, between the contacts of the assembly or between the contacts and the coil. (See paragraph 10 tables 9 and 10 in *IEC EN 61810-1*).

11.1.4.2 Safety-irrelevant failures

Failure to close means that contacts do not make contact. It is caused by wear of the contact pieces (contact burn-up), insulating pollution or that the minimum switching load is not reached, for example.

11.1.5 Application of relays with forcibly guided contacts

Relays with forcibly guided contacts behave deterministically, i.e. clearly foreseeable, also in case of failure. This means that systems with single failure safety and self-monitoring are easy to realize.

Typical applications are:

- Machine tools
- General plant and facility construction
- Process engineering
- Railways and signal engineering
- Medical devices
- Radio and telecontrol
- Fuel technology
- Mining and materials handling technology

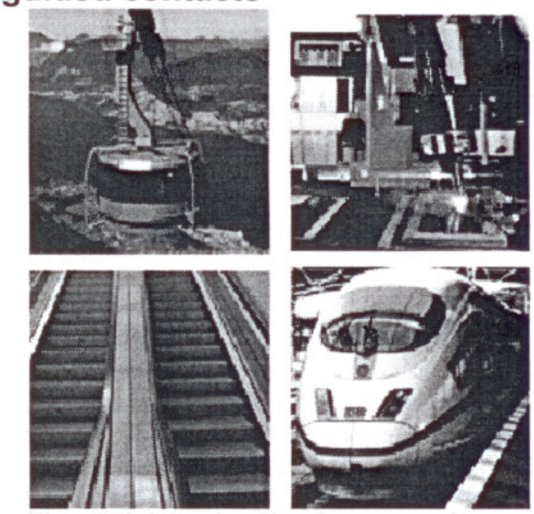

Figure 1.1.9—Application areas for relays with forcibly guided contacts

11.1.6 Remarks on the application of relays with forcibly guided contacts

It must be pointed out that relays of the type described here do not in themselves represent safety. The task of accomplishing safety is only fulfilled by the appropriate utilization of the special properties of the forcibly guided contact and a corresponding safety circuit. Hereby additional requirements must be met which do not directly relate to the relay.

Such additional requirements include, for example, unintentional breaking and bridging of power circuits within the control, or externally connected switching elements. This means that all elements involved in the operation must be considered and assessed in respect of their behavior in case of failure.

Direct wiring of contacts to protect them from cutoff arcs, for example, must be avoided. In case of failure, the arrangement protecting the contact can inadmissibly bridge the contact. The wiring must be assigned to the load to be switched in this case. Requirements from the standards for appliances and systems of the different application areas must be met additionally, e.g., *IEC 62103* and *IEC EN 60204-1*.

11.1.7 Wiring examples (in principle)

The mode of action in the circuit and thereby the

Advantage of the forcible guidance of contacts is demonstrated on the basis of the following wiring example. For simplicity's sake an example with three relays with a contact assembly of application type A is used. Solutions with only two relays are also widely used these days. The simplified example presented here features a 2-channel release circuit. The structure is 2-fold redundant. See Figures 1.1.10-1.1.13.

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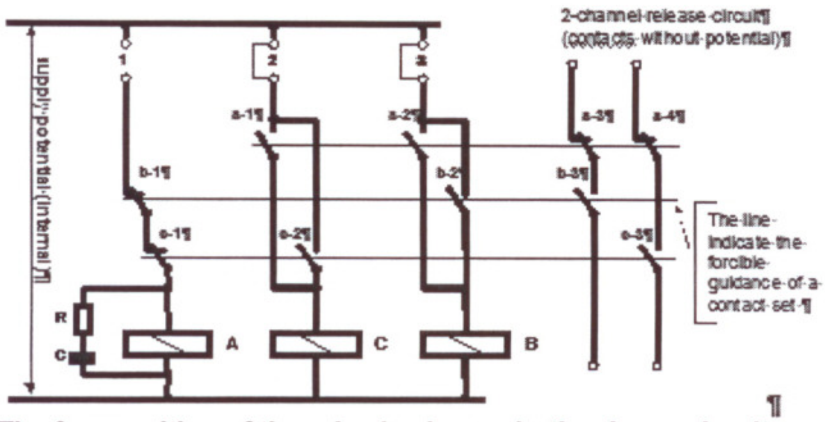

Figure 1.1.10—The free position of the relay is shown, both release circuits are interrupted. The connection points marked 1, 2 and 3 indicate the positions at which the external switching elements must be looped in. For simplicity's sake these points are bridged here.

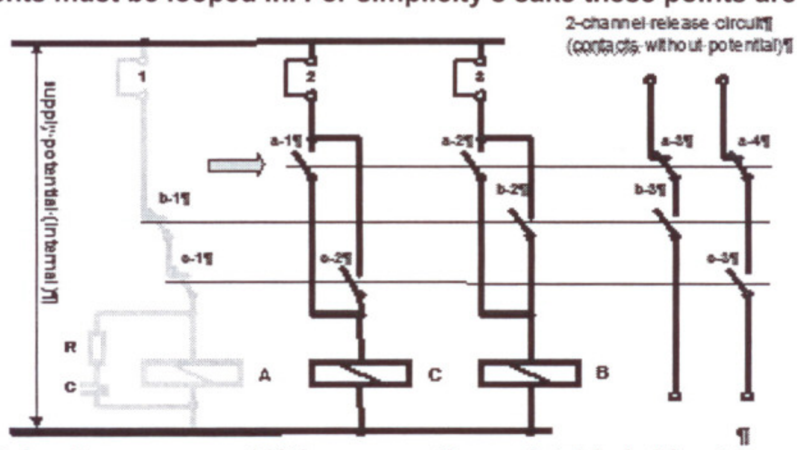

Figure 1.1.11—Relay A can respond if the connection point 1 is bridged by external contacts. At the same time, capacitor C is charged via resistor R (the capacitor serves later for the release delay of relay A).

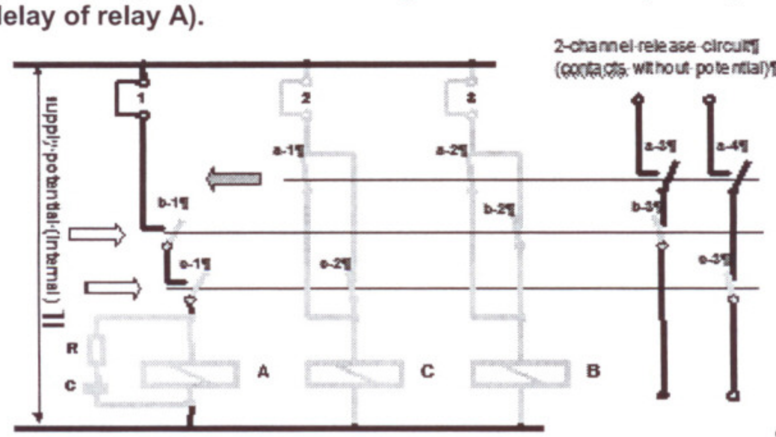

Figure 1.1.12—When relay A is activated, relays B and C respond via the contacts a-1 and a-2. Immediately beforehand, the two NC-contacts a-3 and a-4 in the release circuit are opened. Contacts b-3 and c-3 close after relays B and C are activated. Simultaneously, contacts b-1 and c-1 are opened and the current supply to relay A is switched off. For this to happen with a delay, the release is briefly delayed by the discharge of capacitor C. Closing

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also at the same time are contacts b-2 and c-2, by which the self-holding current circuit for relays B and C is closed.

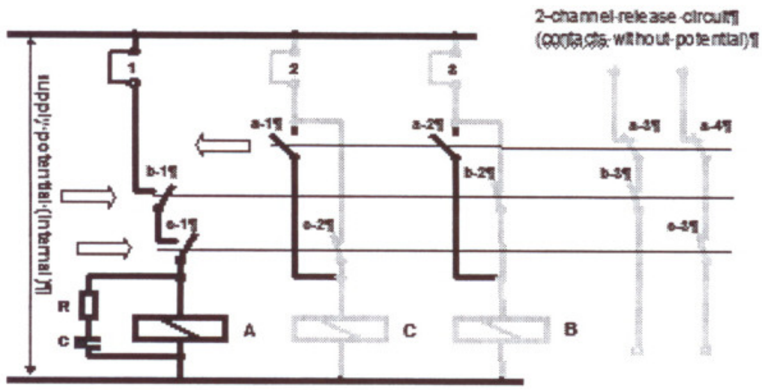


Figure 1.1.13—With the release of relay A to the free position, contacts a-3 and a-4 in the release circuit are also closed.

Forcible guidance of contacts enables failure-safe functions in a simple and straightforward way, i.e. clearly and economically. The result is that, due to the forcibly guided contacts, at least one of the contacts a-1, a-2, b-1 or c-1 does not close so that a renewed switching-on is prevented by at least one channel of the two-channel release circuit

a) Contact a-3 in the release circuit suffers a failure to open. The result is that, despite excitation of relay A, the NO contacts, because of the forcible guidance of the contacts a-1 and a-2 with a-3, cannot cause the relays B and C to respond. The contacts b-3 and c-3 in the release circuit remain open. The same applies if contact a-4 in the release circuit suffers a failure to open.
b) Contact b-3 in the release circuit suffers a failure to open. The result is that contact b-1 in the response circuit of relay A, because of the forcible guidance of contact b-1 with b-3, remains open. Relay A cannot respond, and thereby the relays B and C cannot respond either. The same results also if contact b-2 in the self-holding circuit for relay B suffers a failure to open. The same applies if contact c-3 in the release circuit suffers a failure to open, or contact c-2 in the self-holding circuit for relay C, respectively.
c) Contact a-1 in the response circuit for relay C suffers a failure to open. The result is that the contacts a-3 and a-4, forcibly guided with a-1, remain open in the release circuit. The same applies if contact a-2 in the response circuit for relay B suffers a failure to open.

d) By looking at line interruptions, dry joints and thereby also interruptions in the coil of the relay's operating mechanism as further failure possibilities, they all generate an effect of the same kind which does not represent a hazardous faulty condition. The release circuits are interrupted. In practice the principle circuit example is typically somewhat extended. The release circuits contain a further contact in each case, namely contacts b-4 and c-4. The effect of this extension is that an individual release circuit suffering from failure to open will also interrupt the current circuit.

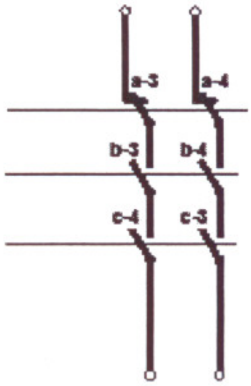


Figure 1.1.14—Extended release circuits

11.1.8 Summary

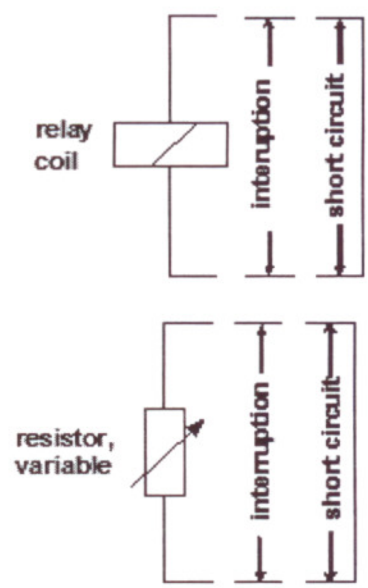
Relays with forcibly guided contacts designed according to *EN 50205* are innovative and reliable components with which safety engineers can develop and produce fail-safe controls or appliances. Like relays in general, relays with forcibly guided contacts can safely separate potentials and rigorously withstand of transient voltages. The contacts themselves cope reliably with wide ranges of contact loads.
This means that relays with forcibly guided contacts can make an economically important contribution towards the protection of health, life, the environment, as well as facilities and equipment, processes and capital assets.

11.1.9 Terminology

fail-safe: Ability of a safety unit to remain in a safe condition (fail-safe) or to directly change into another safe condition if a certain failure occurs (deterministic behavior in case of failure).
failure: A failure is the inadmissible deviation of an actual condition from the reference condition.
A failure results if a specified function no longer exists, whereby the following applies: failures with a common cause are to be regarded as 1 failure, i.e. follow-up failures are included.
exclusion of a failure: An exclusion of a failure is possible if the occurrence of a failure effect can be prevented by suitable measures. Forcible guidance of contacts in accordance with *EN 50205* guarantees that NC-contacts and NO-contacts cannot be closed at the same time. The failure 'spring breakage', like the failure 'failure to open', however, cannot be excluded. Possible exclusions of failures of different components are listed in the Table 11.1.1.
identification of a failure: By designing circuits carefully, failures will produce predictable effects. Such a behavior makes the failure detectable, i.e. necessary measures can be clearly deducted.

failure safety (single failure safety): Safe engineering is feasible. Engineering free of failure is utopia. The acceptance of possible events of failure is a prerequisite. As far as the effect of a failure is concerned, single failure safety is normally demanded. This means that after an individual failure has occurred, the agreed safe function is given. Hereby the simultaneous occurrence of two independent failures not is assumed. Should a risk of this type exist, then monitoring cycles (cyclic self-supervision, tests) must take place as frequently as necessary for the above assumption to be complied with. In its effect, the occurrence of a failure must not impair the safety, i.e. a device's or a system's deterministic behavior. The system must provide functional safety in a failure-tolerant manner. The cyclic self-supervision serves to reveal the failure.

effect of a failure: The effect generated by the occurrence of a failure.



Let us look at the winding of a relay operating mechanism. In principle the same possibilities for failures are given as in the case of an ohmic resistor. A shorted coil changes the value of the resistor, it decreases at will, a short circuit can even occur. Resistance rises to infinity if the conductor is interrupted.

These failures affect the function of the relay. Responding is rendered more difficult or made impossible in case of a shorted coil; the contact assembly does not reach the working position. If the relay is in working position when the failure occurs, this position is maintained or the contact mechanism changes to the free position. The appropriate circuit technique makes these failures detectable. The release circuits are either interrupted or not closed in the first place. The failures assumed here can also occur when the components are wired together. An interruption can be caused by a dry joint, just like a short circuit by a failure in a capacitor. Certain failures can be excluded. In this case one refers to the exclusion of a failure in 11.1.11.

failure modes and effects analysis (FMEA): The study of consequences of failure events for the purpose of assessing risks.

NOTE—In safety engineering, failures that may impair safety and cannot be detected are not allowed to impair the safety. This applies also to the accumulation of such failures.

All the assumed failures mentioned lead to a condition which does not impair the safety-technical function. Hereby, however, relays must not be seen as isolated components. Instead, the wiring technique and the way in which it is implemented must be included, so that failures are detected with each switching cycle (See *test.*) at the latest.

faulty condition: Condition of one item with failures at the time of inspection. The condition is subject to a failure of a system or device without impairing the safety.
release circuit: Output contact circuit of a device with safety-related function, whose closing takes place only after it has been tested and confirmed that the function of the device is as intended.
failure of insulation: Failure of insulation can be excluded, provided that the rules of insulation coordination are used as the basis for dimensioning. The standards for the corresponding devices and systems that describe the requirements applicable to the deployment in question must be observed, e.g., *IEC 62103/EN 50178* and *IEC 60204-1*. For the relays per se, *IEC EN 61801-1* applies in this context.
failure to open: Contrary to expectation, a closed contact doesn't open. This is possible with both NC- and NO contacts.
redundancy: In engineering, it is the extra effort that is not directly required for the function of a system, the parallel connection of two systems so that the function is maintained even if one system fails. In standardization, it is the application of more than one device or system or part of a device or system to ensure that another one is available to perform this function in case of a malfunction (*IEC/EN 60204-1*). In automation a two-fold redundancy (two-channel feature) is very common. If the two systems yield different results, an undesirable condition is the result.
homogenous redundancy: Redundancy that employs identical means. In everyday life, wearing two belts or two suspenders simultaneously would be a homogenous-redundant system. Your pants would stay up even if one of the two holding devices failed.
diverse redundancy: Redundancy in which the means are non-uniform. In everyday life, the wearing a belt and a suspender simultaneously would be a diverse-redundant system to hold up your pants even if one of the two holding devices failed. Belt and suspender are unequal means. NC- and NO-contacts are diverse contacts. The series connection of NC- and NO-contacts is a diverse-redundant contact chain. By means of the order of contact actuation, the contacts are also assigned a certain strain (simultaneous closing or opening must be avoided). In the above-discussed connection example this is given for the contacts in the release circuit. The order for closing the release circuit is as follows:

- NC-contact opens
- NO-contact closes
- NC-contact closes.

In this order of actuation, the NC-contact is responsible for the switch-on process. If the power circuit is interrupted, by opening the NO-contact, the latter becomes responsible for the switch-off process.

test: Process of testing whether or not a certain function exists when the test is performed. One also refers to cyclic testing, if this process is repeated, prior to each activation.

direct opening action: To ensure a contact separation as a direct result of a defined movement of the operating part of the switch via non-spring-loaded parts, e.g., not dependent on a spring (*IEC EN 60947-5-1*).

11.1.10 Standards

EN 50205: Relays with forcibly guided (mechanically linked) contacts
IEC EN 60204-1: Safety of machinery – Electrical equipment of machines–Part 1: General requirements
IEC EN 60947-5-1: Low-voltage switchgear and control gear–Part 5-1: Control circuit devices
IEC EN 61810-1: Electromechanical Elementary Relays–Part 1: General and safety requirements
IEC EN 61810-2: Electromechanical Elementary Relays–Part 2: Reliability
IEC EN 61810-7: Electromechanical Elementary Relays–Part 7: Test and measurement procedures
IEC 62103/EN 50178: Electronic Equipment for use in power installations
ISO EN 13849-2: Safety of machinery – Safety-related parts of control systems–Part 2: Validation

11.1.11 Failure exclusion table

Apart from relays, other components are used in power circuits of relevance to safety. Failure exclusions are admissible for these components subject to certain conditions. The basis for this, are for example physical circumstances (capacitors do not display a strong increase in capacity in case of failure, i.e. the fault 'increase of capacity' can be excluded) or also design circumstances (cement-coated wire resistors or coiled metal film resistors may suffer from an interruption as a failure, but the failure 'short-circuit' can be excluded).

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ISO 13849-2, among others, also deals in its appendices with safety principles, lists of failures and exclusions of failures. Table 11.1.1 provides an overview.

Table 11.1.1—Failure exclusion table

Component	Assumed failure	Failure exclusion	Remark
Printed circuit board	Short circuit between wiring paths	Yes, particular assumptions	Air gaps and creepage distances must correspond at least to the insulation coordination, see applicable basic standard such as e.g. IEC 62103
	Interruption of wiring paths	No	
Electrical contact	Failure to close	No	It must be prevented in principle that conductive parts coming loose can bridge the contact.
	Failure to open	No	
Electrolyte capacitor	Interruption	No	---
	Leakage current	No	
	Short circuit	No	
	Capacity increase	Yes	
	Capacity decrease	No	
Wire resistor	Interruption	No	Single-layer wire coil, cemented, glazed or embedded
	Short circuit	Poss. within limits	
	Resistance increase	Yes	
	Resistance decrease	Poss. within limits	
Semiconductor diode	Interruption	No	The correspondingly same applied to all semiconductor components
	Leakage current	No	
	Short circuit	No	