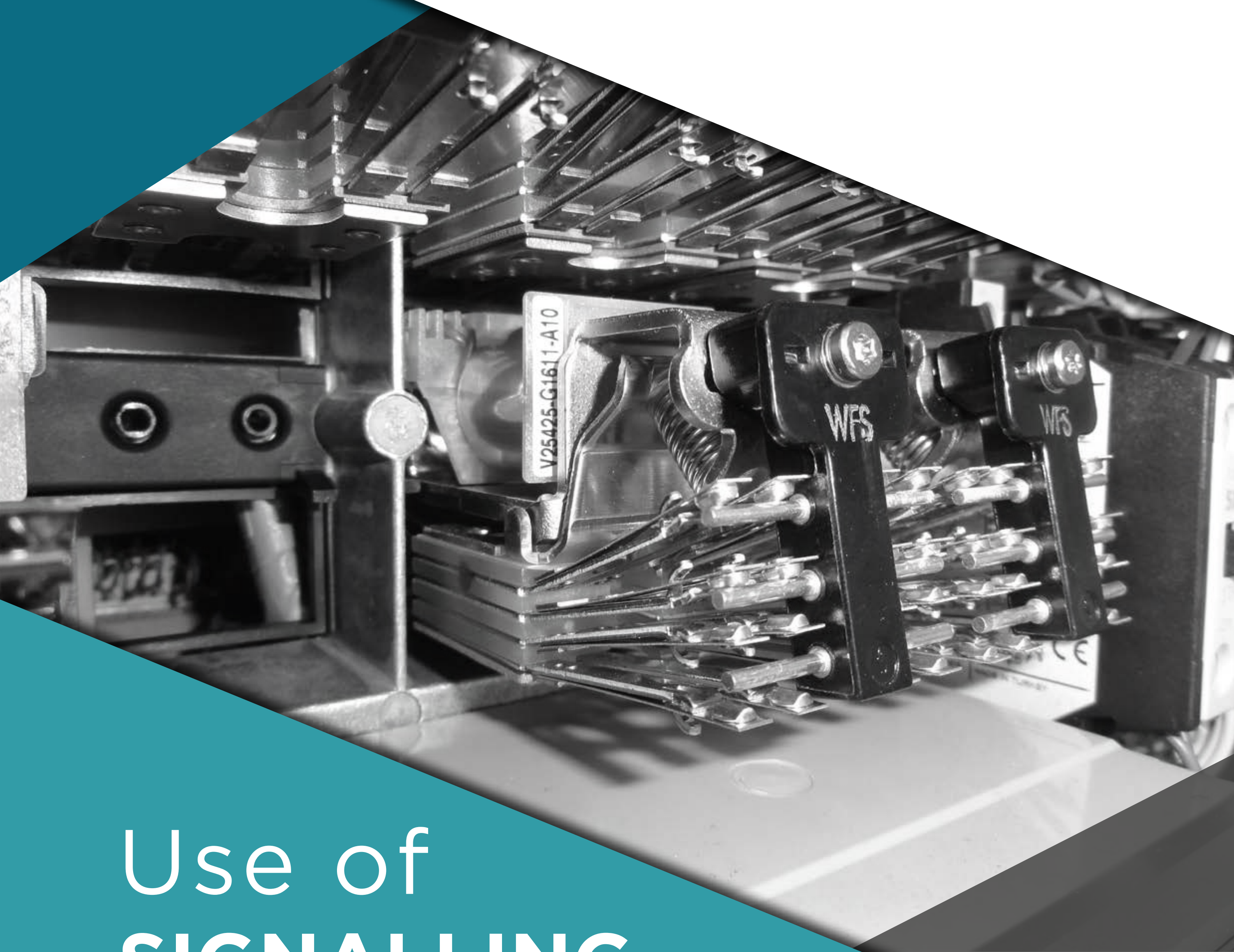

Use of **SIGNALLING RELAYS**

UIC Rail System Forum

Control Command Signalling & Operations

Signalling Expert Group

uic
INTERNATIONAL UNION
OF RAILWAYS

Please note

This document is a translation of a technical report originally written in German language and entitled “Einsatz von Signalrelais”. The translation has been prepared with great care; nevertheless, it is possible that some aspects of the report (e.g. technical terms) will give rise to differing interpretations in translation. In the event of any uncertainties, please refer to the German version of the technical report.

978-2-7461-2691-6

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With the following exceptions, all figures have been supplied by the individuals involved in the project.

- Figure 1 is based on figure 2.1.1 in [8],
- Figure 6 was taken from WIKIPEDIA,
- Figure 8 is based on figure 2.1.2 in [8],
- Figure 9 is based on figure 2.1.4 in [8],
- Figure 18 was supplied by J. Gerhardt, Chemnitz,
- Figure 33 was supplied by J. Gerhardt, Chemnitz,
- Figure 41 was supplied by the firm SELECTiQ,
- Figure 44 is based on the information in [17],
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- Figure 63 is based on figure 3.2.2 in [8],
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- Figure 75 is based on figure 16 in [21].

1. PREFACE

The UIC Signalling Expert Group (SEG) is a permanent expert group of the UIC RSF CCS & TLC sector. The expert group's objective is to expand the 'theory and technology underlying the control and safety of railway transport processes', to maintain the system-specific expertise and to engage in an exchange of experience between system experts.

The technical report 'Use of Signalling Relays' was drawn up by UIC SEG in collaboration with the system experts from a number of different infrastructure managers (IM). The aim of this report is to maintain the system-specific expertise required for the use of signalling relays in railway signalling systems, particularly with regard to:

- avoiding systematic faults in relay circuits,
- detecting random failures and
- providing maintenance fit-for-purpose.

This technical report will therefore treat the following themes:

- Introduction to relay technology (focusing on signalling relays),
- Faults and hazards to consider when using signalling relays,
- Tried and proven measures that eliminate/reduce hazards,
- Estimation of the efficacy of measures in dealing with given hazards,
- Demonstration of measures relating to given circuits,
- Basic theory and quantitative analyses,
- Testing relay circuits,
- Measures for maintenance,
- Use of other components.

This report is based on the results of the SEG project 'Use of Signalling Relays' (2013-2015). The following persons contributed to the SEG project and/or the drafting of the report (in alphabetical order):

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Paris, 16 December 2016

UIC SEG

2. INTRODUCTION TO RELAY TECHNOLOGY

2.1 The foundations of relay technology

Relays are electro-mechanical components that use an electrical control circuit to control several other electrical circuits. The following diagram shows the primary components:

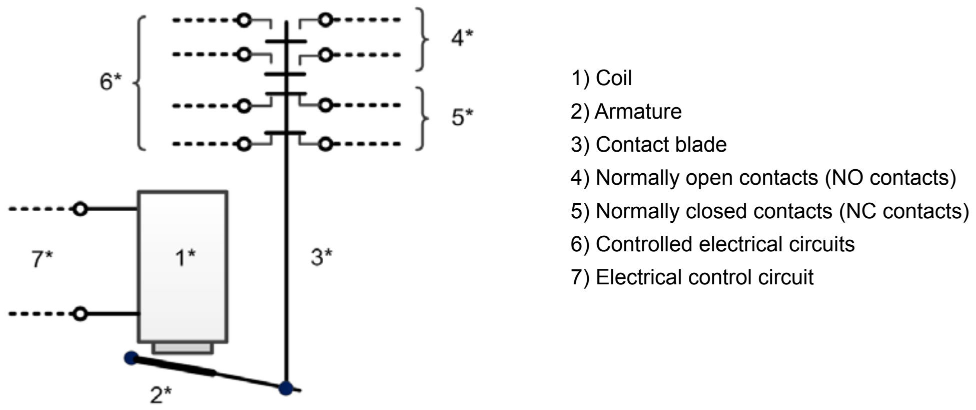


Figure 1: Basic structure of a relay in accordance with [8]

When current flows through the energising coil, a magnetic flux is produced, which acts on the armature. Coil core and armature are therefore made from ferromagnetic material (soft iron).

If the current flow is sufficiently strong (current ≥ energising current), the armature will pick up and the contacts controlled by the armature will change position. Normally closed contacts (NC contacts) will then interrupt their circuit, i.e. they will 'open' (NC contacts are therefore also referred to as 'contact breakers'). Normally open contacts (NO contacts) close their circuit (they are therefore known as 'contact makers'). In colloquial terms, the relay has now 'picked up'.

Please note: 'contact breakers' are otherwise known as '(NC) normally closed contact', 'break contact' or 'back contact'. 'Contact makers' are otherwise referred to as '(NO) normally open contact', 'make contact' or 'front contact'.

The armature remains in the energised position as long as the current flow through the energiser coil is strong enough (current ≥ holding current). Because of the mass inertia and the air gap between the energiser coil and the armature, the energising current will always be greater than the minimum current.

If the current flow falls below a certain value (current < de-energising current), the armature will drop. As a result, the NO contacts will 'open' and the NC contacts will 'close'. Depending on the type of relay, contact will be broken by gravitational force, by spring force or by a combination of gravity and spring force. In colloquial terms, the relay has now 'dropped'.

Compared to many other electrical components, relays have the following advantages:

- their high actuation threshold combined with their (relatively long) energising and de-energising times leads to them having a comparatively low sensitivity to interference voltages,
- the system-inherent preferred failure mode for relays supports the safe release/ locking of functions,
- knowledge of partial failure rates enables precise calculations,
- self- cleaning of the relay contacts increases availability and reduces maintenance costs,
- the capacity to test for critical properties enables long life cycles.

Compared to electrical components, relays have the following disadvantages:

- Higher acquisition costs,
- greater space requirement,
- greater energy requirement,
- higher maintenance costs (due to wear in particular).

2.2 Classification of relays

Relays can be classified according to their fundamental functional properties, specific applications and their safety-determining characteristics.

2.2.1 Classification according to functional characteristics

In accordance with IEC 60050-444 [2], a distinction can be made between 'monostable' and 'bistable' relays.

Monostable relays are characterised by the contact opening/closing behaviour of the relay contacts that follows the energising current. They can be combined as required with a contact-making and/or drop delay. A subgroup is formed by the 'elementary relays', where the actuation /drop delay is not used.

Bistable relays have a system-inherent memory effect, meaning that the 'energised position' of the relay is retained even after the energising source has been switched off (i.e., the 'closing' contacts remain closed even after being energised).

Please note: It is often not possible to definitively assign application-specific relays as monostable or bistable relays, because of their system-specific structure and mode of functioning they have an exceptional position. In individual cases they can also be used in combination with monostable and bistable relays (particularly to achieve technical fall-back levels).

2.2.2 Classification according to safety-determining characteristics

IEC 60050-444 [2] defines the following classes of relays: 'elementary relay' and 'relay with forcibly guided (mechanically linked) contacts'. IEC 61810-1 [3] defines requirements for 'all-or-nothing relays' (elementary relays).

Relays that are used in applications with exceptional requirements relating to functional safety must meet supplementary requirements. An important requirement in this context is in particular the use of 'forcibly guided contacts' according to EN 50205 [4].

Please note: The 'forced guidance' of contacts prevents make contacts and break contacts from being closed at the same time, enabling the sending of a message to indicate the switching condition of the set of contacts - an important precondition for the functional safety of circuits. A common term for relays with forced guidance is 'safety relays'.

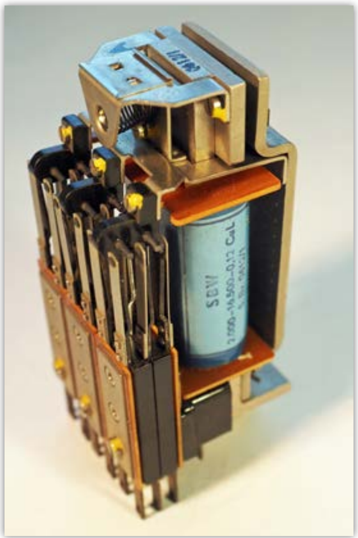


Figure 2: Relay without forced guidance of contacts (relay not shown in fitting position)

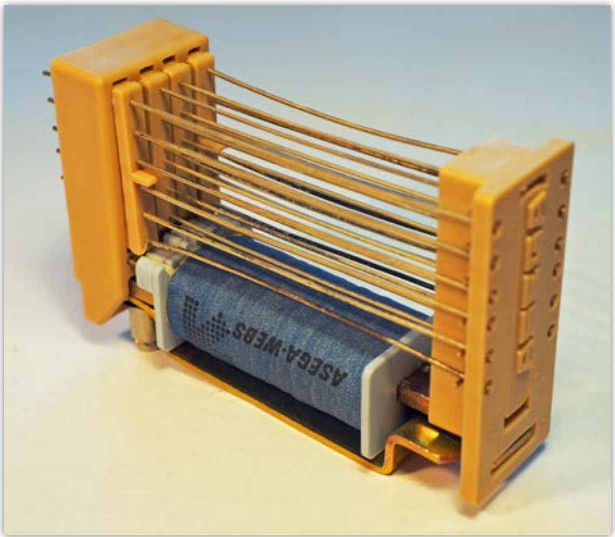


Figure 3: Relay with forced guidance of contacts

Relays that are used in signalling systems must meet the supplementary requirements of UIC 736 [1], EN 50578 [5] or IEC 62912 [6]. Such relays are also commonly referred to as 'signalling relays'.

Please note: the requirements governing forced guidance are defined and detailed in [1]. In accordance with [1], the forced guidance must ensure that all the NC contacts are open if a NO contact is closed, and that all the NO contacts are open if an NC contact is closed.

2.2.3 Classification according to specific applications

Application-specific relays are used for many applications. In this context, relays can, but do not necessarily have to meet the requirements for signalling relays according to [1], [5] or [6]. A typical example is given by relays that have been used in track circuits (TC) or block systems for decades.

2.3 Principles of signalling relays

Signalling relays have extremely stringent requirements relating to reliability and functional safety. Both have a major effect on the design of relays, the use of signalling relays and also on the environmental conditions to be guaranteed.

UIC 736 [1], EN 50578 [5] and IEC 62912 [6] specify requirements for signalling relays.

Please note: The requirements specified in [1], [5] and [6] are not identical. Appendix F contains an overview in this respect.

The following are some critical properties for signalling relays according to UIC 736 [1]:

- The forcibly guided contacts ensure that make contacts and break contacts are never closed at the same time.

- If a break contact remains closed when a relay is energised, no “normally open” contact (NO contact) may close even in the presence of 1.5 times the nominal current.
- If, when a relay opens, a NO contact remains closed, no NC contact (break contact) may close. The respective antivalent contact must in both cases still possess a defined residual opening.
- The effectiveness of forced guidance must be guaranteed throughout the application time. This is also the case in the event of a failure of individual relay components (whether or not the failure is caused by wear or fracture).
- Signalling relays must have a direct link between the armature and the contact members (indirect movement by other contact members is not permitted).
- The drop-down factor (K = de-energising/energising current) must remain within the defined tolerances throughout the application time.
- Signalling relays must meet the environmental conditions for railway operations. [1] therefore identifies the specific requirements relating to permitted vibrations, temperature range and dielectric strength.
- The minimum mechanical life of signalling relays is 10 x 10^6 switching cycles. The minimum life of relay contacts is 2 x 10^6 switching cycles (under permitted electric load).

Compared to elementary relays, signalling relays have the following advantages:

- Enlarged contact spaces combined with the ‘secured opening of contacts’ lead to ‘safe interlocking’.
- Forcibly guided contacts enable the secure testing of the system condition of relays resp. relay contacts.
- The exclusion of faults/failures as a result of ‘non-volatile characteristics’ leads to simplifications for the proof of safety of a circuit.
- Uniqueness protection of signalling relays prevents safety-relevant faults when relays are exchanged.

2.3.1 Classification of signalling relays

Taking account of the failures to be expected in each case, UIC 736 [1] specifies two types of signalling relay: Type N and Type C.

According to [1], type N relays are ‘*Relays that meet all the safety conditions themselves without support from other relays and without special checks to test their functioning in the circuit*’.

Please note: ORE Report A31 [7] defines a type N relay as follows: *‘A non-proved safety relay is a relay constructed and designed such that it fulfils any essential safety conditions without the assistance of other relay or special measures concerning the connections’*.

An essential characteristic for signalling relays of Type N is that it can be assumed with sufficiently high probability that no welding of NO contacts will take place. This is achieved by utilising ‘unweldable’ NO contacts (contact makers) or by using supplementary technical measures (e.g., the use of series contacts or a special designed fuse within the circuit) combined with a heavy-weight armature. Added to this, it is possible to exclude malfunctions that can normally be assumed to take place as a result of residual magnetism (remanence) or armature sluggishness by means of appropriate material selection and construction (if the defined application conditions are observed).

Type N relays therefore do not need to be tested for ‘de-energising’ (‘*not to be controlled*’).

Please note: In accordance with [7], relay contacts made from carbon or silver are *virtually unweldable*. Because a contact made from pure carbon has a shorter useful life than those made from other contact materials, sintered or impregnated contacts are usually used. [7] recommends using a minimum proportion of carbon of 15% for sintered contacts, and 40% for impregnated contacts. According to [7], a carbon content starting at around 5% determines the non-weldability of contacts.

A disadvantage inherent in the system for type N relays is their space requirement, their increased power requirement compared to the type C relay (incl. the larger core section resulting from this) as well as the increased energising and de-energising times.

Owing to their historical development, type N relays are only rarely used in German-language countries. However, in all other countries type N relays are very commonly used.

Type C relays are according to [1]: *‘Relays where the safety conditions are guaranteed by supplementary testing of the function of the circuit’* (C = ‘to be controlled’).

The functional test concerns in particular the drop-testing of the relay armature. As a rule, this takes place by means of circuitry measures (e.g., by means of a break contact for the relay concerned in the next contact-making electric circuit). Relay ‘drop failure’ will therefore be detected as a ‘functional failure’. No specific requirements exist for the weldability of the relay contacts themselves.

Please note: Since type C relays are to be drop-tested, the use of type C relays in contrast to type N relays will lead in the case of circuits with comparable functionality to a greater requirement of contacts (depending on the application case, between 20% and 50%, in rare cases up to 100%).

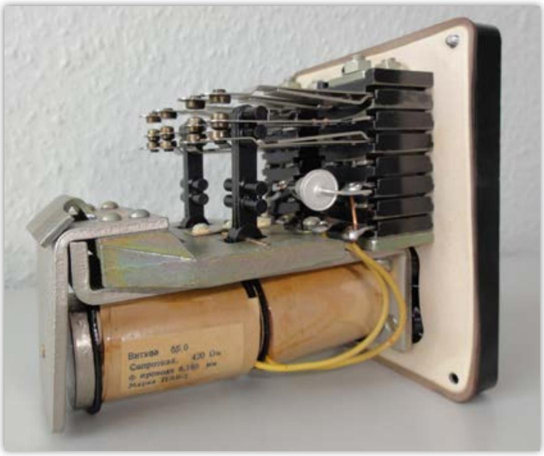


Figure 4: Relay type N according to [1] (Soviet design)

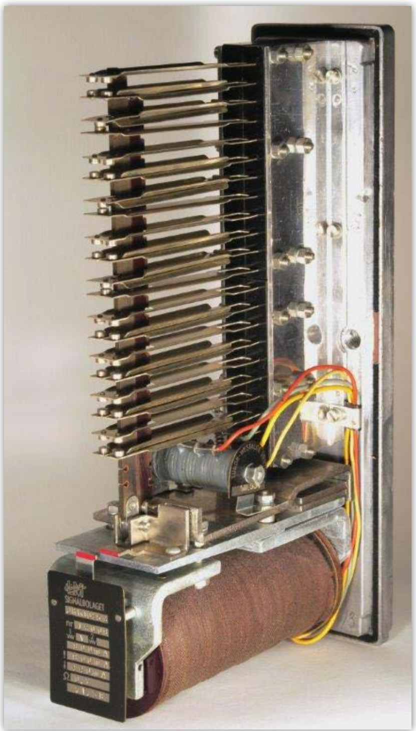


Figure 5: JRK relay type N

Please note: due to their design features, JRK-type relays may be considered as "spring type relays" which meet the requirements of [1] for N relays. Note, however, that such relays do not currently meet the requirements of [5] and [6] for N relays. For more details, see Appendix F.

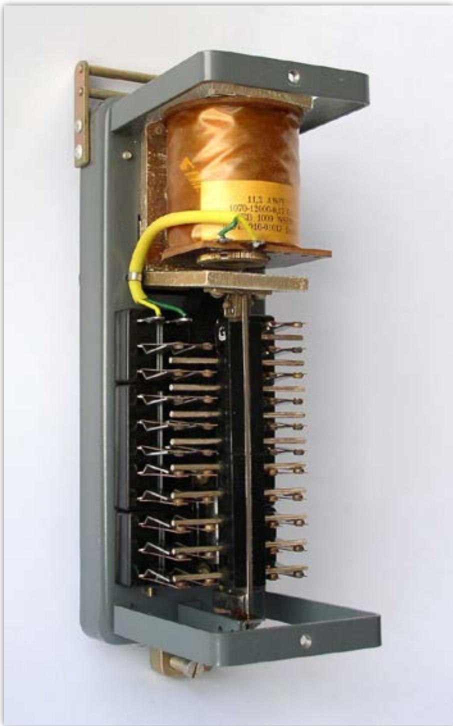


Figure 6: Relay type C according to [1] (normal relay, design II WSSB)

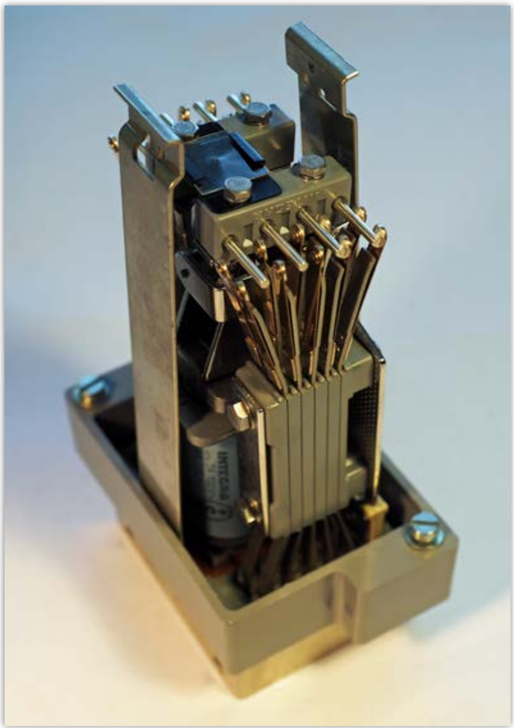


Figure 7: TM relay by SIEMENS Integra (relay not shown in fitting position)

2.3.2 A comparison of the principal characteristics of different classes of relays

The overview below is based on [8] and serves to compare the principal properties of relays of different classes:

type of relay	other relays	safety relay	signalling relay	
classification according to [1]	not defined (old: Class III)		type C (old: Class II)	type N (Class I)
armature drop test?	yes (but not normative required)		yes	no
armature usually drops as a result of	spring force		gravitational force and/or spring force	gravitational force and spring force 1)
forcibly guided contacts	no	yes		
NO contacts (make contacts)	weldable	may be weldable		not weldable
NC contacts (break contacts)	weldable	may be weldable		
when the NC contact is welded …	no normative requirements		NO contacts must not close 2)	
when the NO contact is welded	no normative requirements		analog as NC contact 3)	fault exclusion
spring supports	not required	may be present	required for all contacts	only required for NC contacts
types of contact	single or parallel contacts		single, series and parallel contacts	

Figure 8: A comparison of the properties of relay classes

1) According to [1], a combination of gravitational force and spring force is permissible; however, according to [5] and [6] armature drop may be caused by gravitational force only.

2) As stipulated by [1], [5] and [6], welded NC contacts must not cause any NO contacts to close. However, [1], [5] and [6] contain no requirements regarding the status of the other NC contacts (i.e. they may be "already open" or "still closed"). Theoretically, welded NC contacts ought to cause all the other NC contacts to break. If his is not possible for design reasons, the proof of safety document must make provision for covering the resultant hazards.

3) By extension, the points made in footnote 2 apply to welded NO contacts.

2.4 Functional principles of selected relay designs

2.4.1 Bistable relays

A bistable relay will usually attract in response to a short current (impulse) in the energiser coil. The return position (default position) is often achieved via a current in the opposite direction or via the actuation of a specific resetting device.

Different designs of bistable relays are used, depending on their application and safety requirements.

For control functions with very stringent safety requirements, interlocked relays are generally used. The memory effect of interlocked relays is caused by the mechanical interaction between two mutually independent relay systems. The diagram below shows the basic mode of action of interlocked relays.

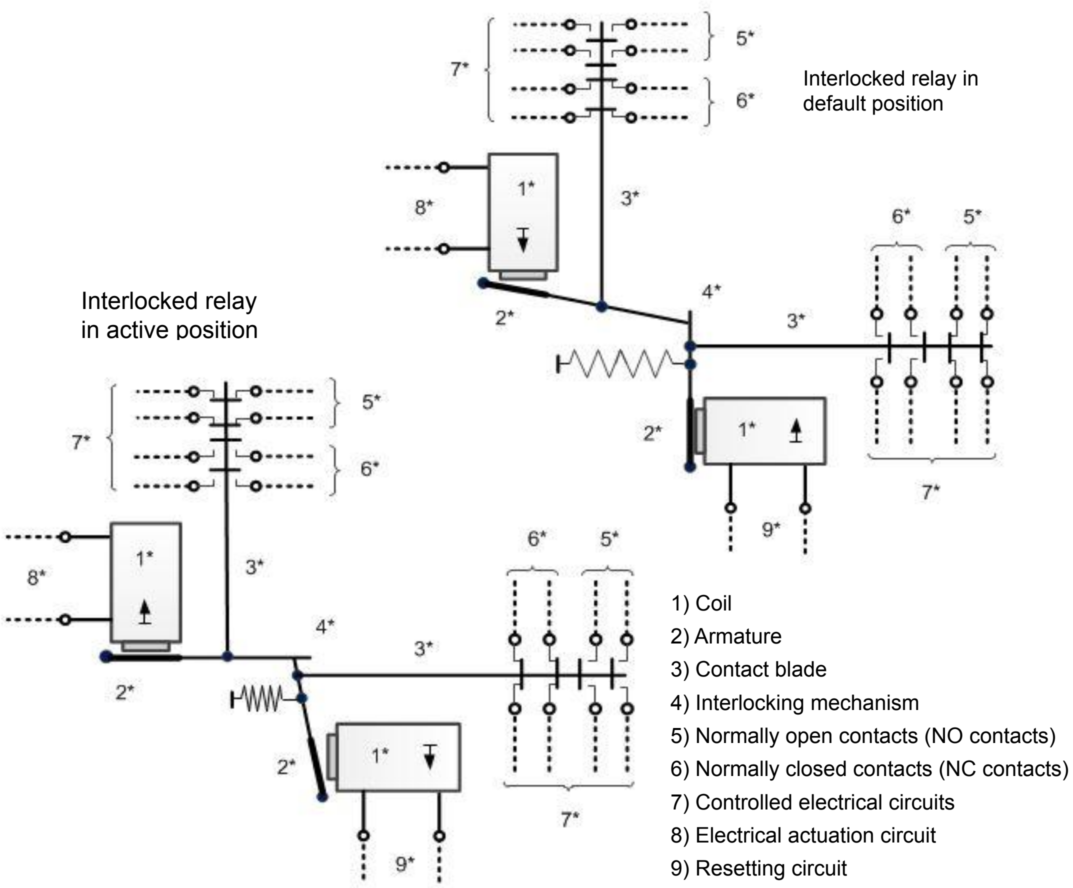


Figure 9: Basic mode of action of an interlocked relay according to [8]

Please note: An important property of interlocked relays is that on account of the design measures applied, the situation can be excluded where both relay systems drop at the same time. However, the simultaneous actuation of both relay systems cannot usually be excluded.

Based on the design characteristics, interlocked relays can be subdivided into two groups: ‘symmetrical’ and ‘asymmetrical’ interlocked relays.

Symmetrical interlocking interlocked relays generally consist of two subsystems with the same or similar number of relay contacts. In the case of *asymmetrical* interlocked relays, one of the two subsystems has only a comparatively small number of relay contacts.

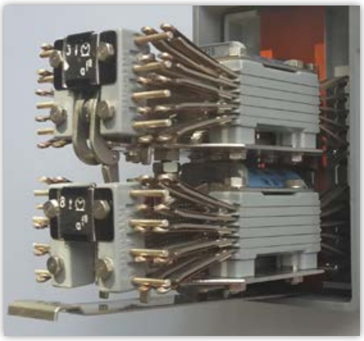


Figure 10: Symmetrical interlocked relay of the design TM Integra Siemens

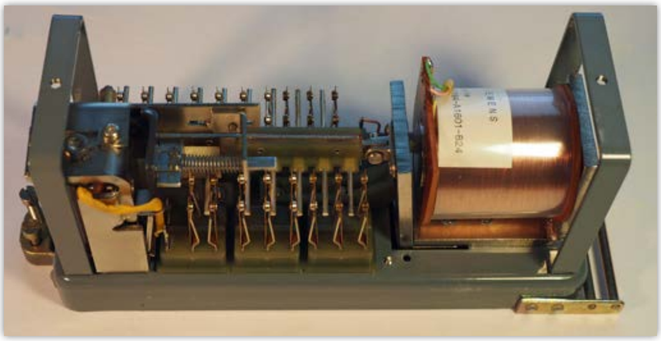


Figure 11: Asymmetrical interlocked relay of the design II WSSB (relay not shown in fitting position)

Please note: In connection with interlocked relays it should be noted that one subsystem is mechanically held in the default position. This results among other things in the active position where the NO contacts of a specific subsystem ‘open’ in functional terms, while the NC contacts ‘close’. It is therefore recommended to avoid using the terms ‘opening contact’ and ‘closing contact’ in the context of interlocked relays.

Magnetically latched relays, remanence relays and toggle relays are used for general memory functions.

The memory effect of magnetically latched relays is based on the use of permanent magnets, remanence relays work on the residual magnetism of their own armature systems.

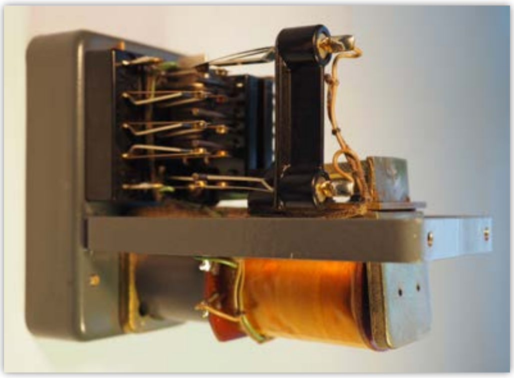


Figure 12: Magnetically latched relay of the design II WSSB

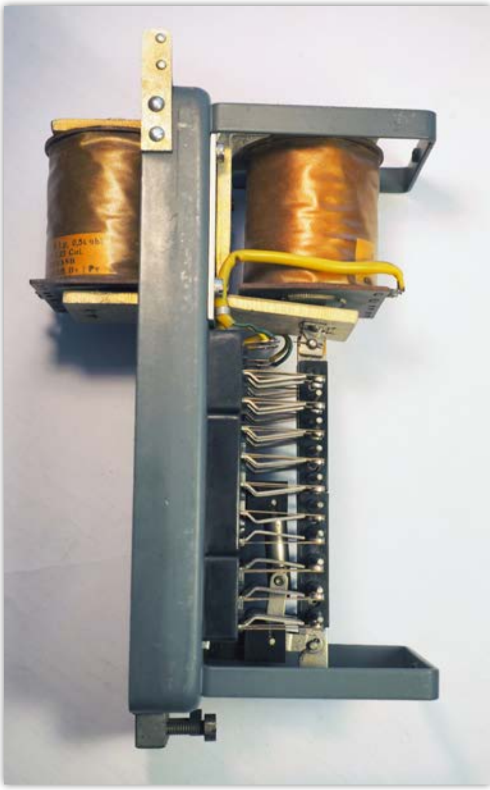


Figure 13: Toggle relay type II WSSB

The memory effect of toggle relays is based on the structural switching of an armature system between two coils. However, in contrast to interlocked relays, there is only one armature system. Toggle relays are therefore not used for ‘safe signalling’ functions, but are rather applied under the aspect of ‘energy saving’.

2.4.2 Motor relays

Motor relays work according to the principle of an asynchronous motor with a squirrel cage. The rotating field is produced by means of the spatially staggered arrangement of one control and one auxiliary coil fed from a common three-phase power network. The torque produced is dependent on, among other things, the amount of control current, auxiliary current and the phase differential of both currents. The phase shift should be 90° where possible.

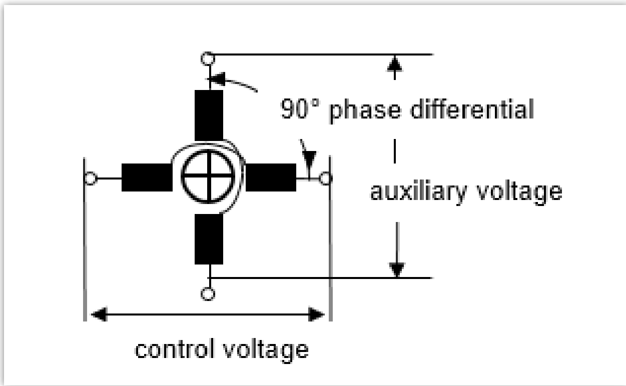


Figure 14: Mode of action for a motor relay

If there is enough torque, the rotor will turn (and with it the set of contacts) to the right or left. The rotation will be limited by the set of contacts. The NO contacts (make contacts) remain closed for as long as the resulting moment of torque is sufficiently large.

By displacing the phase position between the auxiliary and the control voltage by 180°, it is also possible to produce a negative moment of torque. This is utilised in three-position motor relays. In contrast to two-position motor relays, three-position motor relays have two separate sets of contacts (one each for the ‘right-hand’ and the ‘left-hand’ system).

Figure 15: Two-position motor relay of the design I WSSB (relay not shown in fitting position)

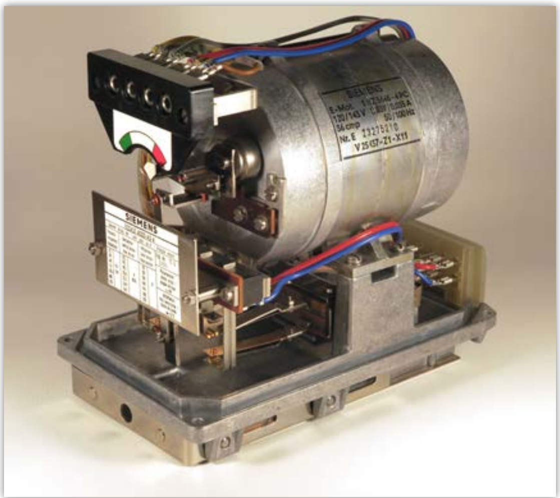


Figure 16: Two-position motor relay type SIEMENS

Two-position motor relays are mainly used in track circuits (TC), three-position relays in a phase code block for instance.

Please note: Due to the system-specific method of working of the TC (NC circuit) and the variable environmental conditions, TC relays are subject to extremely stringent requirements relating to de-energising safety. In addition, there are special circuitry measures (e.g., testing the route release sequence, TC power supply monitoring, etc.).

A major advantage of a motor relay according to [8] is *‘that due to its mechanical construction with unambiguous switching behaviour, it responds only to frequencies within a range of 2 Hz below or above its operating frequency (e.g., 42, 50, 100, 125 or 106.7 Hz); at slightly higher frequency deviations, the motor relay fluctuates as a result of floating phenomena and actually ceases to respond to deviations in excess of these’*.

Please note: In English-language areas the term ‘motor relay’ is also used for time relays, which function with a sequencer.

2.4.3 Vane relays

The method of functioning of a vane relay (also known as eddy-current or disc relay) uses the interaction of magnetic fields in a disc that can rotate. The resulting eddies apply a moment of torque to the disc (the vane).

Figure 17: Vane relay, Soviet design (relay not shown in fitting position)

As in the case of the motor relay, the torque produced is dependent on, among other things, the amount of control current, auxiliary current and the phase differential of both currents. The phase differential should be 90° if possible.

Please note: Relays with two coils are commonly referred to as 'two-element relays'. Relays with only one coil are commonly referred to as 'single-element relays'. Single-element relays are not used as track circuit relays, but as line relays.

2.4.4 Impulse relays (block relays)

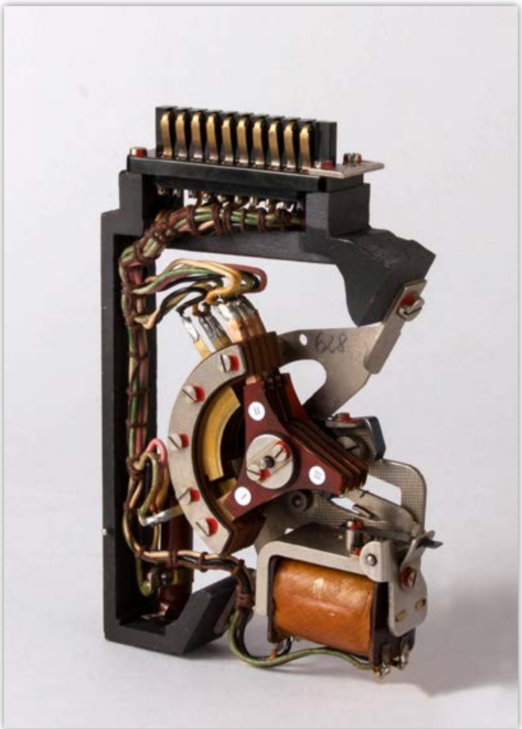


Figure 18: Impulse relay (block relay) of the design I WSSB

Impulse relays are preferentially used for the purpose of adapting to the still widely used AC block field in German-language countries. In practical use they are therefore often referred to as 'block relays'. Their mode of functioning uses an impulse relay previously widely used in telecommunications (the 'selector' switch).

Please note: The relay shown does not meet all the requirements of [1], [5] and [6].

2.4.5 Polarised relays

Polarised relays are DC relays that evaluate the direction of the energising current. They usually have three working positions: 'energised left', 'energised right' and 'de-energised'. These are therefore commonly also referred to as 'three-position relays'.

Biased relays are a specialised form of polarised relay. However, they only have two working positions: 'energised' or 'de-energised'. These are therefore commonly also referred to as 'two-position relays'.

Please note: polarised relays are mainly used in countries that apply the British signalling philosophy (e.g., in DC track circuits and block circuits). In German-language countries, polarised relays are only used for individual applications (e.g., in self-block 60).

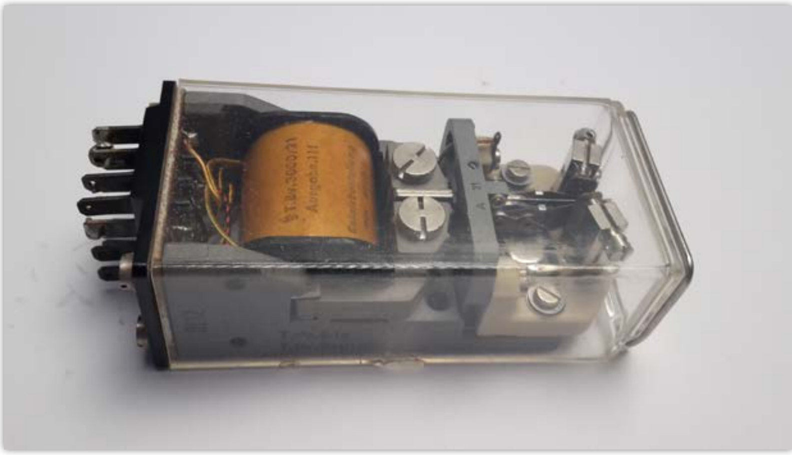


Figure 19: SIEMENS polarised three-position relay

Please note: The relay shown does not meet all the requirements of [1], [5] and [6].

2.4.6 Reed relays

Reed relays are a specific type of DC relay, in the case of which the magnetic field produced by a coil acts directly on the contacts. Reed relays therefore do not require an armature system. Depending on their application, reed relays use one or more (not forcibly guided) contacts.

Reed relays do not by definition meet the requirements of [1], [5] or [6]. They are therefore usually used only for specific (not safety-critical) applications.

a) Circuit board with reed relay b) Single switching element

Figure 20: Reed relay

2.4.7 Time relays (timer)

Time relays achieve a pre-defined pick-up and/or drop delay. Their mode of functioning uses, among other things, bi-metals, mechanical, pneumatic or electro-mechanical mechanisms. Electric/electronic circuits are also increasingly used.

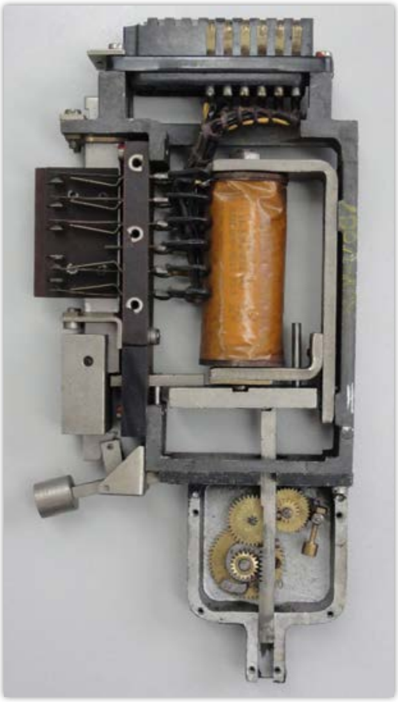


Figure 21: electro-mechanical time relay of the design I WSSB (delay unit open)

Figure 22: Electro-pneumatic time relay by Integra

2.4.8 Alternating current (AC) relays

Figure 23: AC relay type Kuhnke (relay not shown in fitting position)

For historical reasons (e.g., the use of primary cells for power), DC relays are mainly used in signalling systems. Relays that have an alternating current supply are therefore preferably only used on lines with DC traction and in specific applications.

An important feature of AC relays is the compensation of the magnetic field force development by structural measures (e.g., the use of passive damping elements).

Typical examples of their application are the vane relay and the motor relay. AC relays are also often used to control and monitor signals.

Please note: [1], [5] and [6] do not identify any specific requirements for AC relays.

2.4.9 Flashers

The preferred way of actuating flashing signal aspects is to use special flashing-indicator devices. “Thermo-flashers” and “alternating flashers” are tried-and-tested in service. Since both types use mercury, electronic circuits have been used exclusively in recent years.

Thermo-flashers work by means of the periodic heating of hydrogen, which leads to a change in the gas volume. This causes the mercury to move in its column, which in turn opens or closes contacts. The opening of the contacts cuts off the heat supply, whereupon gravity causes the mercury column to drop back to the starting position.

Alternating flashers work by means of the electro-dynamic effect of magnetic fields, which causes the contact system to move in a pendulum cycle. Mercury-based contacts are often used in such systems (see figure 25).

One major advantage of thermo-flashers over alternating flashers is that they have no moving mechanical parts. The design of thermo-flashers also provides them with a preferred failure mode. Generally, therefore, consumers are used which work on the same principle as NO circuits (see measure M201, M203 later on), i.e. if a thermo-flasher fails (e.g. due to failure of the heating coil), the lamps will remain dark.

The downside of both types of flasher is that installation must be as level as possible (see measure M441) and the presence of mercury requires them to be transported and stored in accordance with specific conditions (see measure M442).

Figure 24: S&H thermo-flasher

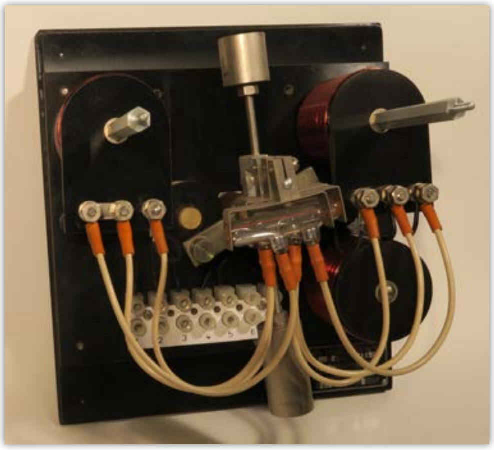


Figure 25: DSI alternating flasher

2.5 Use of signalling relays

2.5.1 History

The signalling relay designs used today are the result of more than 100 years of development. From a technical perspective, the following relay generations can be distinguished:

a. proprietary systems
b. relays and magnetic contactors
c. first generation signalling relay
d. second generation signalling relay

Some 150 years ago, the first systems working on an electro-magnetic basis were being used in railway signalling technology. A typical example are ‘bells’, the extensively used ‘instruments’ in English-speaking countries, and the ‘block fields’ often used in the German-language area. In addition, there were first relay designs that were used mainly from 1872 in track circuits (TC). These had a decisive influence on the development of relays, particularly the type N relay.

A significant step in this development according to [9] was the ‘Buchenan’ relay developed by the Hall-Signal Company in 1890. This was the first relay in which the armature acts indirectly on a contact spring via an insulating pen (made from ivory). The aim was, among other things, to prevent resp. detect the welding together of contacts as a result of the effect of lightning.

The next two decades were marked by the development of the TC relay. According to [12], AC relays were first used in England in 1901, and from 1910, vane relays were also available.

A distinguishing feature of the relays of these times was according to [10] the *'large coil space, low energy requirement (feeding from primary elements), and the voluminous design'.* In addition, [10] refers to a further special feature of the relays of the time: *"Since the relays were placed in shelves, this design was called 'shelf-type relay'. The connections were located at the top of a relay, so that their arrangement in the vertical direction took up a lot of space"*.

In the German-language area, developments took a different turn. According to [10], *'Long track circuits were not used until 40 years later because of the presence of iron sleepers in some places'. 'The use of electrical supplements to mechanical interlocking systems began sooner. The 'electro-mechanical' interlocking system as it is called today required more and more relays, called magnetic switches at the time'*.

A distinguishing feature of the magnetic contactors used from around 1890 in electro-mechanical interlocking systems is their design in the form of a locking magnet, i.e., different switching conditions were still being tested with the aid of mechanical locking devices.

Please note: The reason for using locking magnets in combination with a cam disc was, according to [11], the possible failure of the armature to drop as a result of magnetic remanence.

According to [14], AC relays were used for the first time for track vacancy proving in Germany after 1913, and in individual cases (e.g., in Leipzig station), disc relays as well. In 1919, Siemens & Halske started developing the two-position motor relay, and around 1925, the first DC relays were developed (both types of relay were used mainly in the automatic block 1928). In 1939, a new generation of two and three-position motor relays followed in a development by the VES Company.

It should be noted that the early designs of motor and disc relays and the DC relays were built as type N relays, meaning that they did not have weldable contacts.

Figure 26: VES two-position motor relay

Please note: Further developments of this time were according to [14] the ‘aperture relay’ used after 1926, which could indicate different colours per aspect based on movable colour discs, and the block relay used after 1938.

First generation signalling relays were developed around 1930. Decisive for the rapid expansion of the relay interlocking systems was according to [12], the development of the magnetically interlocked relay. The first relay interlocking was built as early as 1931 in Newport (Victoria, Australia).

In the German-language area, monostable ‘safety relays’ were developed first based on magnetic switches. Bistable safety relays followed later.

According to [14], the development of an interlocking system started in Germany in 1935 (according to [10] not until 1937). An important step forward here was the development of the signalling relay of design K44 among others. Owing to the war, the first relay interlocking was not taken into operation in Germany until 1948 in Düsseldorf-Derendof.

According to [16], the first interlocking system without mechanical interlocking was placed in service in Switzerland in 1941. This used safety relays of type TT by Integra/Signum for the first time.

Please note: It should be noted that the first relay designs as a rule met the critical (though not necessarily all the) requirements according to [1].

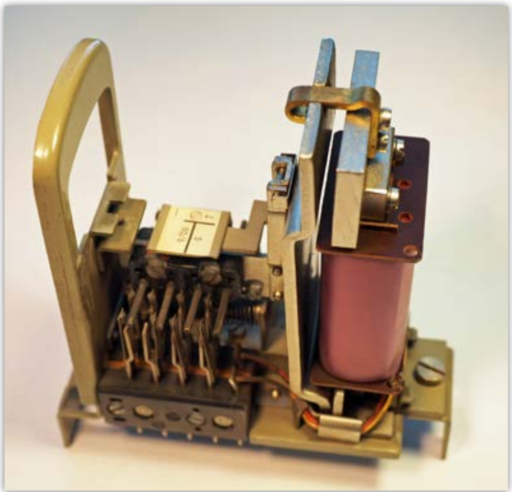


Figure 27: Relay design K44 (relay not shown in fitting position)

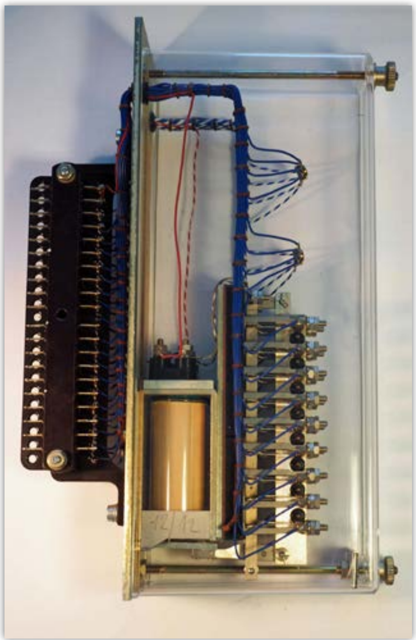


Figure 28: Safety relay type TT by Integra (new design)

Second generation signalling relays were used in operation from around 1950. Today they frequently constitute the basis of the relay interlocking systems in operation. Due to the historical circumstances and the normally used relay classes, their development was not uniform.

The aim of the developments in English-speaking countries was to reduce the dimensions of the relays according to [12] (shelf relays still had a construction volume of up to 1,200 cm^3).

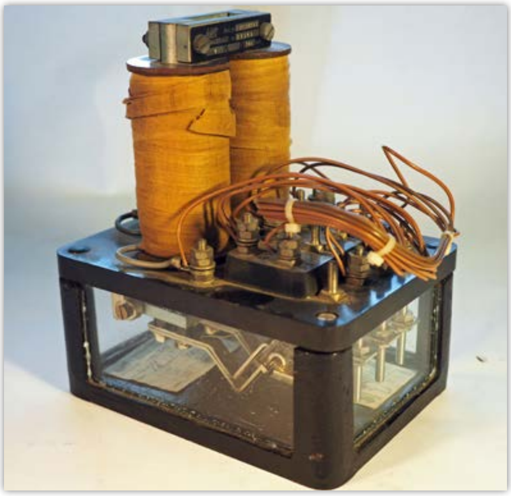


Figure 29: Swedish shelf relay of type JRC

Figure 30: Shelf relay (Russian design)

In the German-language area, in contrast, the focus was primarily on increasing the aspects ‘safety’ and ‘reliability’. Typical representatives of this relay generation are K50 relays made by Siemens.

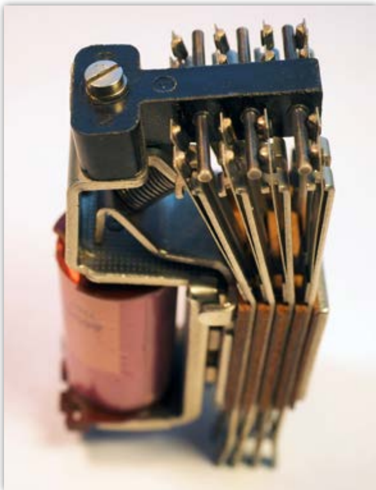


Figure 31: Relay design K50 by SIEMENS (relay not shown in fitting position)

Figure 32: K50 relay as part of a relay group

Please note: Although the WSSB relay design was developed virtually at the same time, it should be considered as the ‘last relay of the first generation’ as a result of its structural characteristics.

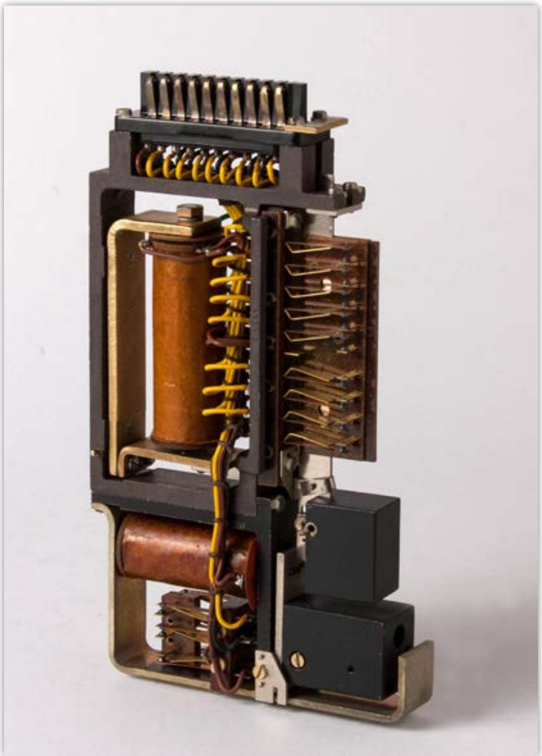


Figure 33: Interlocked relay design I WSSB

Based on experience with the first relay designs of the second generation, reliability and operating time were further optimised in the following years. Typical examples are the signalling relay 72 by SEL and design II relay by WSSB.

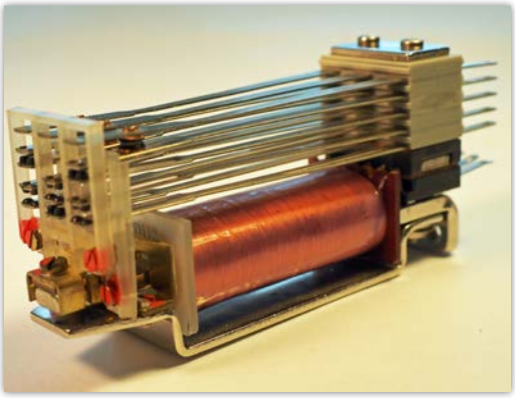


Figure 34: Relay design SEL L72

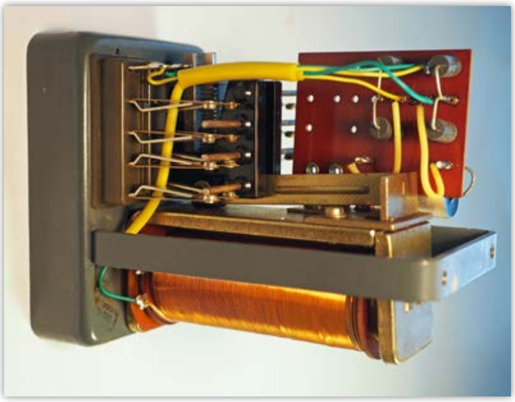


Figure 35: Small relay design II by WSSB

Please note: Figures 34 and 35 show special types of the relays concerned. In addition to normal contacts, relay SEL L72 uses high-voltage contacts, which were used in circuits for points, for instance. The small WSSB relay type II uses an additional mounting plate with diodes, which were used in signalling circuits, for instance.

One of the last signalling relay developments is the design III relay by WSSB. In particular the fixed contact elements used are innovative components: the armature acts on the contacts here (not the contact element).

Figure 36: Normal relay design III WSSB

2.5.2 Use of signalling relays in interlocking installations

In the German-language area, as a rule, individually mounted (usually pluggable) relays were used for mechanical and electro-mechanical interlocking systems as well as in special circuits in relay interlocking installations. The wiring was usually of the free wiring type.

Relay interlocking systems were initially also fitted with pluggable relays, though these were arranged in functional groups. The wiring was usually of the free wiring type or in the form of system-specific cables. A typical example of this are the interlocking-type WSSB GS II 64b relay groups.

With the development of geographically oriented circuits, the use of relay groups became standard for type C relays as per [1]. The wiring usually took the form of system-specific cables.

Please note: Signal boxes that use geographical circuits are often referred to in practice as ‘geographical circuit interlocking systems’.

In contrast to relay interlocking systems with conventional wiring, geographical circuit interlocking systems are provided with a series of system-specific characteristic features that have a decisive effect on both the Life Cycle Cost (LCC) and system availability.

The following are some of the strengths of geographical circuit interlocking systems (list is not exhaustive):

- reduced project requirements due to the use of element-specific relay groups,
- simplified adaptation of functionality to the changed operating requirements as a result of the use of (pre-defined) program cases and operating mode plugs,
- reduction of time requirement on commissioning / refurbishing (for instance by using pluggable system cables, operational and program plugs),
- reduced testing requirements as a result of the use of pre-tested relay groups and system cables,
- less stringent requirements regarding the qualifications of the project engineer and the acceptance inspector,

- simplified search for faults (for instance by the visualization of important status information).

The following are some of the disadvantages inherent in the system of geographical circuit interlocking systems (list is not exhaustive):

- within the scope of system developments, rising complexity leads to the tendency of rising costs (for instance relating to proof of safety),
- later changes to the system logic are generally only possible in small measure,
- the requirements regarding system management rise (example: relay group X may be operated together with relay group Y version 3, but not with versions 2 or 4),
- possible operating restrictions in the case of an exchange of relay groups with several sub-groups (e.g., a set of points with 4 switches),
- the tendency towards rising maintenance costs (a replacement relay group with non-pluggable relays costs more than an individual replacement relay),
- the implemented functionality can generally not be used in simple operating applications (e.g., small interlocking installations with simple operating conditions).

The number of relays used in electronic interlocking installations became reduced, partly because relays were only used for the purpose of securing ‘safe de-energising’ or for ‘galvanic separation’.

In countries that use the type N relay, the use of ‘plug-in relays’ has become standard. Relay groups were not practicable because of the dimensions of type N relays.

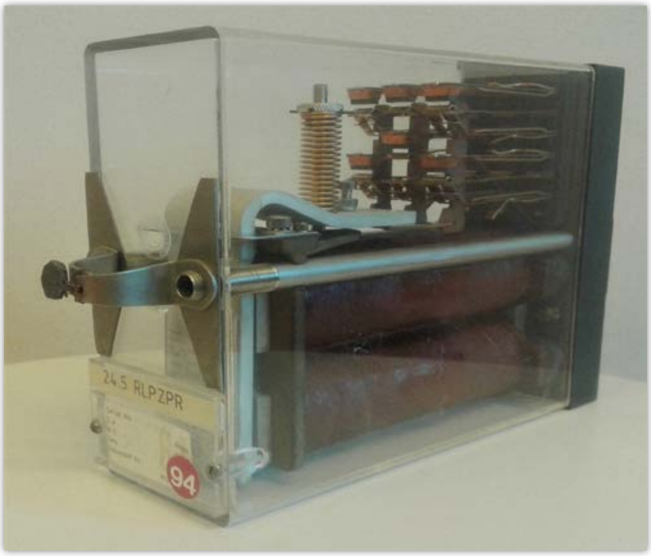


Figure 37: Plug-in type N relay of design B1

Figure 38: Plug-in type N relay (Russian design)

Because signalling relays are subject to wear, and due to the relatively high acquisition costs resulting from stringent requirements, normal relays (elementary relays) are also used in non-safety-critical applications.

Figure 39: Delay unit type II WSSB with ‘elementary relay’ (relay not shown in fitting position)

Within the scope of the obsolescence strategy, ‘electronic relays’ are increasingly used that simulate the functioning of elementary relays (mono-stable as well as bi-stable relays) or specific types of relay (e.g., motor relays). Logical interlocking based on discrete electronic components and/or integrated circuits is used.

Figure 40: Electronic motor relay by SIEMENS

Figure 41: Solid state signalling relay made by SELECTiQ

Please note: Electronic relays do not meet the requirements of [1], [5] and [6].

3. RISKS AND MEASURES

3.1 Introduction

The use of relays in circuits with requirements regarding 'functional safety' demands an analysis of the risks associated with the use of relays.

This section therefore identifies the assumed faults / incidents together with the hazards resulting from this that are to be taken into account when using relays. In addition, measures are identified that eliminate or significantly reduce hazards.

The data in this section are based on:

- the acknowledged 'state of the art',
- the specific technical regulating system used by various infrastructure managers,
- many years of experience of system experts and
- the systematic evaluations of incidents or hazards.

3.2 Assumed failures and the resulting hazards

Appendix A identifies the fault / incident assumptions in connection with the use of relays, the possible consequences and potential hazards.

For the sake of simplification, the hazards are categorised as follows:

- a fault / incident that does not lead to a hazard (e.g., a random outage that is detected via a functional failure),
- a fault / incident that leads to a chance of potential hazard (e.g., a random outage that is not detected, or a combination of faults),
- a fault / incident that leads directly to a potential hazard (e.g., a potentially dangerous outage).

Please note: The data in appendix A are not exhaustive. Additional hazards that can result from special applications (e.g., relays switched in series) are discussed in section 4 'Frequently used applications'.

The faults / incidents are placed in thematic groups for easier readability.

- F100 contacts
- F200 relay system
- F300 insulation
- F400 power supply
- F500 maintenance
- F600 environment
- F700 other components

Please note: Parts of this section (e.g., fault groups F100 and F200) were derived from the measures identified in [1] in a 'reverse engineering process'. The aim was to assign a relevant hazard to every identified requirement from [1].

3.3 Tried and tested measures that eliminate / reduce hazards

Appendix B identifies tried and tested measures that eliminate hazards resulting from the use of relays in circuits with requirements for 'functional safety', or reduce these significantly.

These measures are placed in thematic groups for easier readability:

- M100 relay-related measures
- M200 circuit dimensioning
- M300 maintenance-related measures
- M400 other measures

Every measure is assigned the RAMS aspects associated with it. In addition, in the case of the safety aspect (RAM**S**), it is indicated whether the measure relates to type N and/or type C relays. If a measure is effective, this is marked with 'x'; if it is only 'conditionally effective' in contrast, or an 'option', it is marked with '(x)'.

Please note: The data in Appendix B are not exhaustive. Section 4 'Frequently used applications' discusses further measures that relate to special applications. Rarely used measures are expressly not named, as this would exceed the scope of this report.

3.4 Effectiveness of measures

Appendix C assigns one or more measures according to appendix B to the faults / incidents to be assumed according to appendix A. To simplify matters, a distinction is made between 'effective' and 'conditionally effective' measures. Faults / incidents are placed in thematic groups for easier readability.

Please note: The data in appendix C represent an extract from the 'impact matrix' drafted within the scope of work package B of the UIC SEG project 'Use of Signalling Relays'. Since this concerns Excel tables in the format DIN A0, appendix C uses a summarised version. A PDF version of the 'impact matrix' can be obtained from the members of the UIC SEG project.

The data in Appendix C demonstrate that the hazards resulting from the assumed failures / incidents are generally only eliminated or significantly reduced by applying a combination of measures.

As a matter of principle, the choice of measures for special applications is the responsibility of the user; essential measures are explained in the following section.

Please note: Appendix C also contains optional measures for certain faults / incidents. When selecting the measures, care should therefore be taken to prevent redundant (i.e., equivalent) measures being implemented.

3.5 Essential measures

The following describes the essential measures that must be taken into account in accordance with the 'state of the art' when using relays in circuits with 'requirements relating to functional safety'.

3.5.1 Use of signalling relays

One of the most important measures in circuits with 'requirements relating to functional safety', is the use of relays with forcibly guided contacts (i.e., safety relays).

The relays used in ‘safe signalling circuits’ must *meet* the requirements identified in [1], [5] or [6]. In this connection, it does not matter in the first instance whether these are signalling relays type N or C. However, the type of relay used will influence the circuit dimensioning.

If relays are used in ‘safe signalling circuits’ that *do not meet* the requirements identified in [1], [5] or [6], the associated faults according to Appendix A must be taken into account when assessing the safety of this circuit.

Please note: In the case of circuits ‘without requirements regarding functional safety’, relays are often used for cost reasons that do not or only partly meet the requirements from [1], [5] or [6].

3.5.2 Choice of relay contacts

The choice of relay contacts to be used in each application has a major effect on the useful life of the respective relay and therefore also on the LCC (see M117, and M119 up to M124).

Please note: Incorrectly dimensioned contacts can lead to hot contacts. In the ‘worst case’, components made of synthetic material (e.g., the forced guiding system) can become deformed.

Concerning the actuation of elements in the external part of the installation, note that for some relay designs the insulation strength to earth of some contacts is not evenly distributed, as described in [33]. Contacts with a high insulation strength should therefore be used for long cables of the trackside equipment.

3.5.3 Useful life of signalling relays

Relays that meet the requirements identified in [1], [5] or [6] possess a useful life, guaranteed by the manufacturer, of at least 10x 10^6 mechanical cycles resp. (in the case of permitted loading) at least 2x 10^6 electrical cycles (see M102, M115, M120, M121 and M122).

If the assured useful life (relating to switching frequency and/or operating time) is exceeded, it must be assumed that the ‘non-volatile characteristics’ assured by the manufacturer (e.g., the forced guidance of contacts) will suffer detriment as a result of wear and/or physical and chemical ageing processes.

Experience from practical use as well as relevant analyses have shown that the useful life assured by the manufacturer (depending on the type of relay) will in practice often exceed expectations by factors. This relates to the useful life of components of the relay system in particular, which is significantly longer than the useful life of the relay contacts (for details see Appendix D, ‘failure rates’).

Taking account of the above aspects, one or several of the following measures are usually applied when using relays beyond the operating time guaranteed by the manufacturer:

a. Cyclical refurbishing in accordance with the maintenance / repair strategy; the repair strategy is also adjusted if necessary on the basis of field data and relevant analyses.

   Please note: a refurbished relay is generally considered ‘as good as new’.

b. Additional tests combined with extended field monitoring.

   Please note: The testing frequency and the stringency of testing operating time may be adjusted if necessary.

c. Analysis of a representative random sample in combination with extended field monitoring.

3.5.4 Circuit dimensioning - NO circuit

According to the ‘Theory of transport safety technology’, it is always necessary to utilise the ‘higher quality condition in energetic terms’ for the release unit (e.g., a relay) for the release of a safety-relevant function.

Since the ‘higher quality condition in energetic terms’ of a relay refers to the ‘dropped armature system’, safety-relevant functions will be released ‘by a current flowing’. To this end, NO contacts (make contacts) will generally be utilised for elementary relays.

The locking of safety-relevant functions will therefore logically take place as a result of the ‘absence of current’ (M202), i.e., in the case of an elementary relay by means of the de-energised (more stable) end position.

For ‘safe signalling circuits’, the NO circuit (M203) will therefore preferably be used.

3.5.5 Circuit dimensioning - NC circuit

Interlocking systems that monitor system condition (e.g., monitoring of the end position of points) often use the ‘NC circuit’ (M204).

Please note: one of the advantages of the NC circuit is the immediate (i.e., rapid) system response to interlocking installations set up in this way.

If NC current circuits are used in the form of safety-relevant ‘release functions’ (e.g., in track circuits), supplementary measures (see M205) are required to eliminate resp. reduce significantly any hazards resulting from the fault group ‘drop failure’ (F230).

3.5.6 Circuit dimensioning – drop test (type C relays)

As it is not possible to exclude the situation in which contacts become welded together, relays type C must be tested for their dropping capacity during the switching process (M207).

Please note: the drop test is basically also to be performed for type C relays with memory effect.

The drop test can take place by direct means through the contacts of the relay concerned or indirectly via the contacts of other relays (which are controlled by the relay being tested).

A typical example for an indirect test is the drop test on track circuit relays (NC circuit). For functional reasons, the drop test in this case generally takes place via the ‘test for route release sequence’. For details, see chapter 4.4.3.

If a drop test cannot be performed in normal operation for functional reasons (e.g., in connection with the monitoring of track circuit supply), the maintenance strategy must be adapted accordingly (see M427 and also M313).

3.5.7 Circuit dimensioning – mandatory sequence: ‘release only after locking’

If safety-critical functions are functionally dependent, the dependencies concerned must be tested accordingly in the circuit.

If, for instance, the release of a function requires the prior locking of another function, it must be ensured that the locking action takes effect before the release takes place (M213).

Typical examples for M213 are 'determining the route' (e.g. locking of point operation and also 'conflicting' routes) ahead of signal staging as well as the exchange of safety-critical information between systems which are independent of one another (e.g. the direction of travel on the track or the locking of departure signals prior to activation of the block section).

Please note: In connection with block systems, M213 is colloquially referred to as 'block change' ('Verschlusswechsel') in German block systems.

3.5.8 Circuit dimensioning - 'locking via current flow'

Wherever possible, 'locking of a safety-relevant function via current flow' must be avoided. If the NO circuit has to be applied in response to functional or circuitry conditions in order to 'lock a safety-relevant function', the relay concerned must be tested as to its locking position (M206).

Please note: In order to be able to dispense with the measure 'locking via continuous current flow', relays with a memory function are used (M208). A typical example of their application are the repeat locks used in German interlocking installations. So an interlocked relay will block all proceed signals at a 'one-acceptance block' before the 'train-on-line' information can be given (combination of M206, M208 and M213). The proceed signals remain closed until the block has returned to the default position.

3.5.9 Circuit dimensioning - use of relays with memory function

Relays with memory function are preferably used to lock safety-relevant functions, in individual cases also to save energy.

In practice, several types of relay are used that all have different failure rates depending on their design. For 'high-standard safety-related functions' (e.g. management of block direction) only interlocked relays are usually used. Magnetically latched relays and remanence relays are generally only used for 'normal control functions' (toggle relay are generally no longer installed into new systems).

When using relays with memory function, it should be noted that many relay designs have asymmetrical failure rates. To lock safety-relevant functions, the more stable end state must therefore always be used (M209).

3.5.10 Circuit dimensioning - Use of interlocked relays

When using interlocked relays, account must be taken of the fact that both sub-systems may be in the 'energised' position as a result of the type of construction. However, it is not possible for both sub-systems to 'drop' at the same time. From this we can derive that the NO contacts in the two sub-systems can both be closed at the same time.

When using an interlocked relay, care must therefore be taken in the circuit to ensure that the right contacts are applied both for 'locking a function' and 'releasing a function' (M210). In addition, the actual locking action must be proved (M211).

Please note: Measures M210 and M 211 can be combined.

In practice, measures M210 and M211 are implemented in different ways, depending on whether *symmetrical* (see, for example, figures 10 and 42) or *asymmetrical* (see, for example, figures 11 and 33) interlocked relays are used.

If *symmetrical* interlocked relays are used, M210 and M211 are met if:

- back contacts (NC contacts) are used to 'lock functions' from the 'sub-system that switches first' (i.e., back contacts of the sub-system that is energised) and
- back contacts (NC contacts) are used to 'release functions' from the 'sub-system that switches last' (i.e., back contacts of the sub-system that drops).

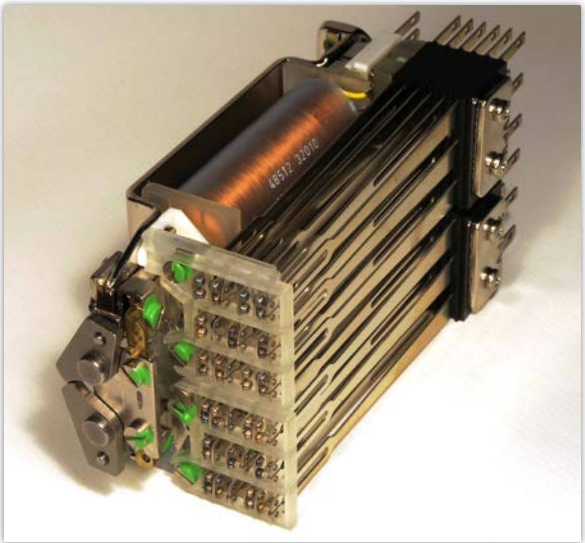


Figure 42: symmetrical interlocked relay L72 made by SEL

Since in the case of *asymmetrical* interlocked relays one of the two sub-systems may not have sufficient NC contacts available, 'locking of functions' and 'release of functions' are generally achieved using contacts from the same sub-system. Two frequently used circuit variants are described below.

- Variant A: 'Change of default position of sub-systems'

  In the default position, the first sub-system is in this case mechanically locked. The locking action is initiated by actuating the second sub-system. NO contacts from the first sub-system are generally used to 'lock functions', NC contacts from the first sub-system are used to 'release functions' (M210). Any drop failure of the first sub-system (corresponds to a locking failure) is detected via the missing 'release of function' (M211).
- Variant B: 'Subsequent inspection of the locking action'

  In the default position, the second sub-system is in this case mechanically locked. The locking effect is initiated by actuating the first sub-system. NC contacts from the first sub-system are used to 'lock functions', NO contacts from the first sub-system are used to 'release functions' (M210). As in the event of drop failure of the second sub-system (here this would correspond to a locking failure) it may not be possible to detect this. Current-saving contacts are generally dispensed with in this case, i.e., the coil in the first sub-system remains permanently energised during the 'locking action'.

  Please note: Since M211 is only met 'indirectly' in this case, the switching variant B will usually not be used for 'high-standard safety-related' interlocking systems.

In order to prevent mistakes within the scope of construction, assembly and maintenance, the corresponding default position must be defined and documented for every interlocked relay. This is the case particularly when using switching variant A ‘change of default position’ for asymmetrical interlocked relays.

Please note: Since interlocked relays are operated in pulse action, the energy supply is usually switched off after the sub-system concerned has been actuated. The NO contacts of the other sub-system in each case should be used as current-saving contacts.

3.5.11 Circuit dimensioning - use of remanence relays

When using remanence relays, care should be taken to ensure that the ‘more stable end state’ is the ‘dropped relay’. NO contacts (contact makers) should therefore always be used to release a safety-relevant function, and NC contacts (break contacts) to test the locking action.

The length of the actuation / de-energising impulses must be suitably dimensioned to ensure that the soft iron core is sufficiently magnetised.

According to [33], a remanence relay’s coil may not be activated in parallel with a capacitor, since this will create a resonant circuit which will weaken the magnetisation of the soft iron core.

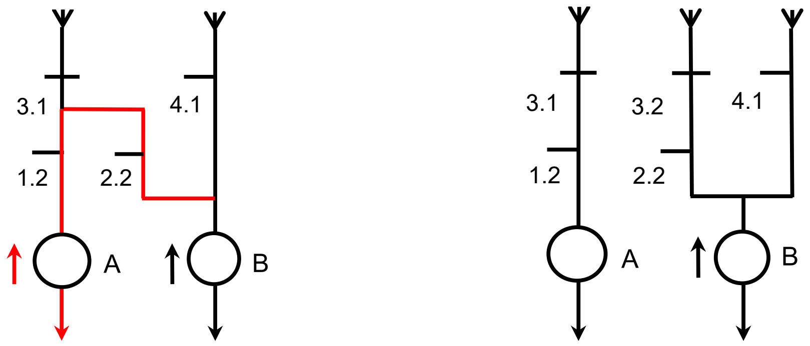
Please note: In order to avoid overheating, some remanence relay designs may not be permanently energised, as described in [33].

3.5.12 Circuit dimensioning - use of magnetically latched relay with external memory function

When using magnetically latched relays with external memory function (e.g., a permanent magnet), care should be taken to ensure that the ‘more stable end state’ is normally the ‘energised relay’. NC contacts (break contacts) should therefore normally be used to release a safety-relevant function, but NO contacts (make contacts) to prove the locking action.

3.5.13 Circuit dimensioning - deterministic circuit logic

When designing the switching logic, care should be taken that so-called ‘zig-zag’ circuits resp. ‘parallel circuits’ are avoided (M212 and M251).

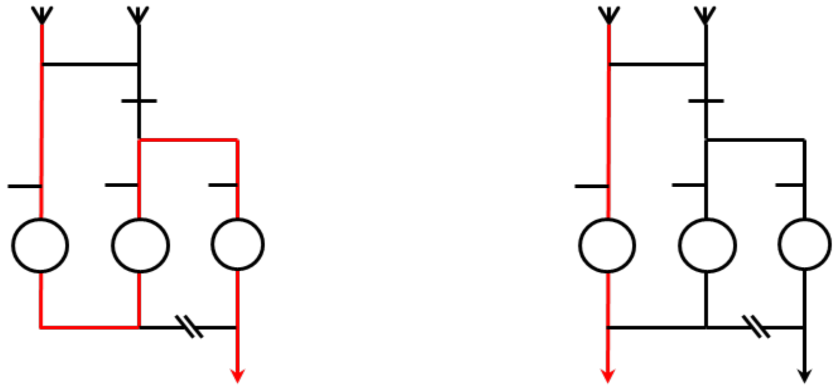


a) Relay A is energised “out of turn” due to double use of contact 3.1

b) Same function as in a), but no double use of contact 3.1

Figure 43: Deterministic circuit logic - use of contacts

The connection of the relays to the negative terminal should by preference be constructed as a ring feeder (M252). The following diagrams visualise the problems; they are based on relevant data provided in [17].



a) 'Zig-zag' circuit as a result of random interruption of negative terminal connector

b) same circuit as b), but negative terminal connector as a ring feeder here

Figure 44: Deterministic circuit logic – negative terminal as ring feeder as per [17]

Please note: When designing the circuit logic, it is also important to ensure that the switching sequence of the separate relays takes place in a causal fashion (in this case a circuit diagram can be made). Switching sequences that are not causal should be avoided.

3.5.14 Circuit dimensioning - Arrangement of contacts

When arranging the contacts these are preferably to be placed between the supply source and the relay coil (M231). The arrangement of contacts between the relay coil and the negative terminal is only permitted if M251 and M212 are observed.

3.5.15 Maintenance measures

The test and maintenance measures specified by the relay manufacturer must be observed (see for instance M304 up to M307). Only approved inspection and test devices and tools may be used (see M421 up to M423, M425). The maintenance staff must have the necessary qualifications for this (M426).

Relays and relay groups must be protected during transport and during storage (M442).

The use of silicone-containing cleaning agents / components must be avoided (M310).

Please note: Silicone-containing material in combination with high ozone concentrations, reduced contact cleaning and load-free switching leads to the development of SiO_2 mono crystals on the relay contacts. Since the crystals act like diodes, temperatures can increase locally, which, in the worst case, can impair forced guidance.

The state of the core / cable insulation must be tested cyclically (M301).

Please note: Chemical processes lead to damage to the core insulation after 15 up to 20 years. In this connection account should be taken of the following fault patterns:

- brittle core insulation: the insulation chips off (particularly at bending points), the violet and red wires are usually the first affected,
- some of the softening agent leaks out (these drops can be electrical conductors).

If line circuit breakers (LCB) or motor circuit breakers (MCB) are used as a safeguard, it should be noted that the circuit breakers can resinify after about 10 years. Practical experience has shown that the LCB and MCB concerned still become activated, but can no longer be switched on again. It is therefore recommended to test LCB and MCB within the scope of cyclical maintenance (this also concerns replacement parts).

3.5.16 Maintenance measures for the power supply

When supplying power to track circuits, care must be taken when using a redundant power supply (e.g., redundant frequency inverters) that the switching logic does not negatively impact the monitoring of the supply voltage (see F403 resp. M271).

If the power supply cannot be placed close to the relay installation, a voltage drop due to the length of the supply cable must be taken into account when setting the supply voltage.

In geographical circuit interlocking systems featuring geographical linking of many relay groups by system cables, the voltage drop per relay group must be taken into account. If the voltage drop is excessive, the following measures can be examined:

- increase in supply voltage,
- several feeds per geographical linking cable,
- supply at centre of geographical linking cable (so-called ‘central supply’).

3.5.17 Other measures

Relays may only be mounted / operated in the position permitted according to the manufacturer’s specifications (M441).

4. FREQUENTLY USED APPLICATIONS

This section explains applications that are commonly used in practice, but that are not ‘essential measures’ in the meaning of the preceding section.

4.1 (Elementary) relays switched in series

Relays switched in series are commonly used in many different types of interlocking designs. They are also used in the following applications, for instance to:

a. evaluate low and high-ohm circuits or switching stages,
b. realise switching stages (or phases) while at the same time minimizing the the number of control contacts,
c. multiply contacts while at the same time minimizing the number of control contacts for repeater relays.

Please note: A typical application relating to a) is the four-wire interlocking widely used in German-language countries to turn and monitor point machines. As a rule, relays are switched in series here to monitor point position and detect trailed points. An example relating to b) and c) is provided by the signalling control circuit for the interlocking type Integra Domino 69 (see section 5.1).

When relays are switched in series, the following aspects must be taken into account, particularly for application cases b) and c):

- the first relay is connected directly to the supply line,
- the second relay is connected directly to the return conductor,
- the control contacts are located between the two coils,
- both relays have the same or virtually the same coil resistance, designed for half the supply voltage.

The diagram below illustrates the principle to be applied:

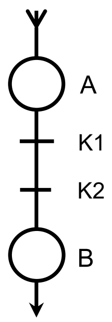


Figure 45: Relays switched in series

Please note: For relays A + B, the ‘essential measures’ identified in section 3.5 must be implemented. This concerns measures M201 through M203 and M207 in particular. The type of circuit means that measure M231 on the other hand can be used only for relay B in application cases b) and c).

4.2 Principles of contact multiplication

If the number of available relay contacts is insufficient, the following alternatives are usually examined:

- use of a different relay contact set
- use of a different type of relay (with more contacts)
- relays switched in series (for contact multiplication)
- use of repeater relays

The selection of a suitable set of contacts for the intended application is a common measure. It should be noted that the choice of a set of contacts can have repercussions for the relay coil used or the relay switching behaviour.

In many designs of interlocking systems, relays with a different number of relay contacts are used (see, for example, figures 6 and 35). In contrast, the later exchange of a relay for one with more contacts is more likely to be exceptional.

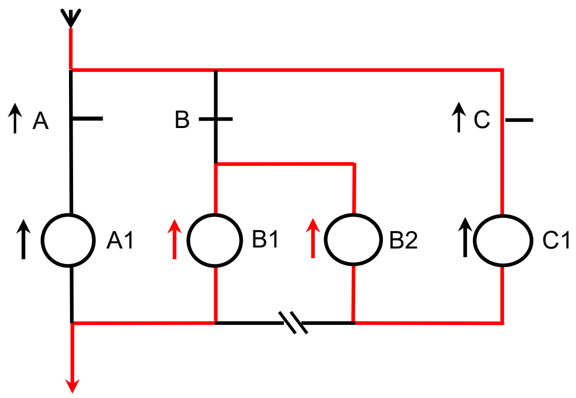
Switching relays in series for the purpose of contact multiplication is generally already planned at the system design stage. Switching relays in series is not really suitable as a measure for achieving subsequent contact multiplication.

The use of repeater relays is the measure commonly used. Frequently used switching variants will therefore be detailed in the following.

4.2.1 Parallel switching with elementary relays for contact multiplication

Parallel switching of additional elementary relays should be avoided wherever possible (see Appendix B, measures M251 and M212). If parallel switching is unavoidable, measure M252 should be applied. This applies to both NO and NC circuits.

Please note: If there is an interruption in the return conductor, in the worst case, the relays in adjacent circuits may receive untimely energisation. Figure 46 shows an example of this.



Please note: In figure 46, relay B2 was switched parallel to relay B1 to achieve contact multiplication. If there is an interruption at the negative terminal both relays may receive untimely energisation (wrong side failure).

Figure 46: Parallel switching according to [24], simplified representation

4.2.2 Parallel switching from additional elementary relays to remanence relays

In the case of remanence relays, care should be taken that the more stable condition is that of the de-energised relay (M209). For locking tasks, NO contacts should therefore be used. The locking action that takes place when there is a power outage is tolerated.

If, for the purpose of contact multiplication, an elementary relay is used parallel to the pick-up coil of a remanence relay, it cannot be excluded according to [24] that the self-induction voltage produced when the elementary relay switches off will unlatch the remanence relay in an untimely fashion. To prevent this, it is usual to switch a diode in series to the pick-up coil of the remanence relay.

If, for the purpose of contact multiplication, an elementary relay with a double coil is switched parallel to the force-down coil of a remanence relay, it cannot be excluded according to [24] that a voltage is induced in the first coil of the supplementary relay when the second coil is energised that will cause the remanence relay to drop. This can be prevented by controlling the supplementary relay separately or by switching a diode in series to the first coil of the supplementary relay.

Please note: The failure of a diode in this case does not as a rule lead to a hazard situation.

4.2.3 Cascade switching of elementary relays for contact multiplication

Cascade switching is the most frequently used circuit for contact multiplication. In this context, the following principles must be observed according to [24]:

- *'In NO circuits, all relays must be checked to establish their default position'* (M207).
- *'In NC circuits, the default position is generally checked indirectly via the last relay in the cascade'*.

In addition, the delay caused by the cascade switching of the relays is to be factored into the circuit design.

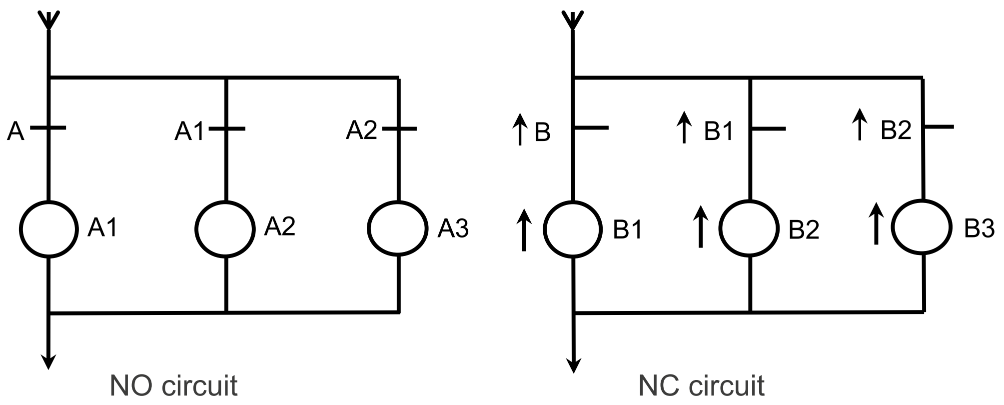


Figure 47: Cascade circuit for elementary relays according to [24], simplified representation

Please note: In NO circuits, the requirements for the wiring and testing of a supplementary relay can be reduced by switching the supplementary relay as first relay in the cascade.

4.2.4 Cascade circuit for interlocked relays

If interlocked relays are used as repeater relays (for interlocked relays), these relays should be switched in cascade. Consistency of contact positions for interlocked relays must be checked in the circuitry according to [24].

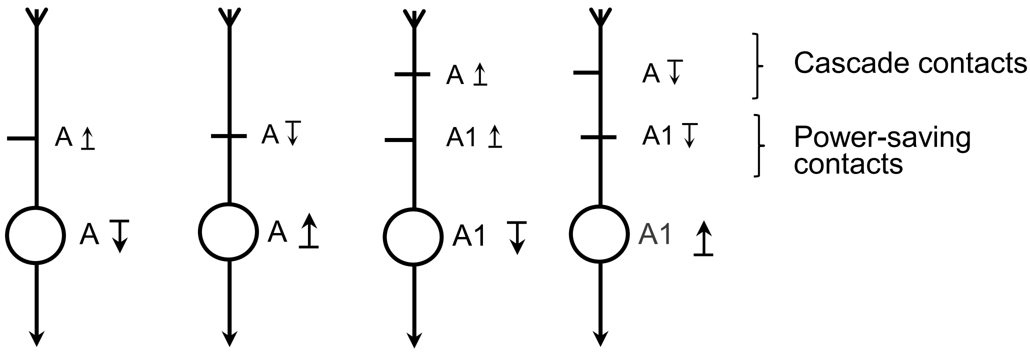


Figure 48: Cascade circuit for interlocked relays according to [24], simplified representation

Please note:

- Figure 48 shows one possible variant of a cascade circuit. A number of others are also tried-and-tested in service and are widely used.
- All relays in the cascade are to be proved according to [24] for their default position.
- According to [24] and [26] in NO circuits, the requirements for the wiring and testing of a supplementary relay can be reduced by switching the supplementary relay as first relay in the cascade.
- If the use of repeater interlocked relays is planned at the design stage [26], care should be taken to ensure that the locking actions take place through the first relay in the cascade, releases, on the other hand, through the last relay (see also M213).
- Normally NO contacts are used as power saving contacts according to [24] (aim: late switching off).
- When using cascaded interlocked relays, care should be taken to apply the correct timing in the circuit according to [24]. For visual displays, as a general rule, the contacts of the first relay are therefore used in a cascade of interlocked relays.
- According to [26] the contacts of the last interlocked relay in the cascade are used to check whether all the interlocked relays are still in the default position. The contacts of the first interlocked relay are used to check whether the interlocked relays have departed from the default position.
- When exchanging bi-stable relays, care should be taken to avoid disturbances (in the worst case hazards) by checking that the relays used are in the original switching position. This applies particularly to the repeater relay, which may not be in the same place.

4.3 Change of polarity

As a protective measure against stray voltages, changing the polarity of the supply voltage has proven effective (see appendix B, measure M255).

Please note: Because of the high expenditure, measure M255 is generally only used in high quality signalling circuits. In addition, it should be noted that M255 implicitly demands the implementation of measure M254. In the case of more recent circuits, the above reasons therefore mean that generally only redundant contacts (see for example M233 and M234) and/or redundant circuits are still used.

4.4 Control and monitoring of elements in the external installation

The control and monitoring of elements of the external installation often represent a challenge for the design of the respective circuit due to environmental conditions to be observed, operating distance and the respective safety requirements. In the following sections, information is therefore provided in this respect.

4.4.1 Unipolar vs bipolar switching

The number of relay contacts used to trigger field elements (per function) generally depends on a combination of several criteria. The list below contains some important criteria, but a detailed description is expressly not given at this stage, since this would exceed the scope of this report.

Criteria for decision-making for unipolar resp. bipolar switching.

- requirements for the tolerable hazard rate (THR) of the respective function,
- number of available return conductors,
- environmental conditions (e.g., electrified sections, type of traction, etc.) and
- operating distance (and thus the height of the assumed interference voltage),
- feed concept (e.g., IT feed concept with monitoring),
- earthing concept (e.g., mono or bi-lateral earthing of the cable sheath),
- requirements for person, material and fire protection,
- required availability.

Please note: The bipolar switching has become established as ‘state of the art’ (particularly on electrified lines). An exception is the method of control with the most restrictive signal aspect (e.g., ‘stop’), which is generally unipolar.

4.4.2 Measures against wire short-circuits or stray voltages

If a short-circuit between wires can lead to a hazard situation, a measure or a combination of the following measures will normally be applied.

Separate return conductor

If multiple information items are transmitted, separate return conductors should be used in accordance with the ‘state of the art’. Using shared return conductors must be taken into account in the proof of safety document.

Wires in separate cables

Although in theory this measure should be effective, it is rarely used in practice, as it has cost-related consequences (e.g., relating to design and cabling) and also negative effects on maintainability.

Earth-free circuits

To protect against stray voltage effects (e.g., as a result of core short-circuits or interference voltages), earth-free circuits are usually used (IT feed concepts) to control field elements.

If a hazard caused by an earth or wire short-circuit cannot be excluded in an earth-free circuit, the earth-free situation is generally monitored. This can be done (for instance in older installations) by performing cyclical manual tests or using insulation monitoring devices.

When using several insulation monitoring devices (in one and the same installation), care must be taken that simultaneous insulation tests do not lead to a hazard situation or false alarm. The use of insulation monitoring devices must therefore be taken into account in the proof of safety document.

Please note: The earth-free situation in IT feed concepts is also monitored in connection with the aspect 'person protection' (particularly on electrified lines).

4.4.3 Measures in connection with track circuits (TCs)

TCs work according to the NC circuit (M204). In order to reduce or eliminate the risks attached to this, traditionally one or more of the following measures are applied:

a. evaluation of the occupation sequence of a TC
b. logical linkage of the occupation sequence of several TCs
c. use of additional rail-based contacts (treadles)
d. use of type N relays
e. current-supply monitoring

In many interlocking and block section designs, route release is based on an automatic analysis of the TC occupancy sequence. In modern interlocking designs, there is logical linkage of the occupancy sequence for several TCs.

Please note: Measure b) presupposes that a route consists of several train detection sections or that supplementary release criteria (e.g., point-action treadles) are used.

Any occupancy disruptions detected (e.g. due to a failure to de-energise) mostly affect route release. One major advantage of this is that it will also detect excessively-high supply voltages.

As an alternative to the aforementioned measures, track circuits based on type N relays may be used.

Since, in the worst case situation, a short interruption of the TC power supply (e.g., a defective contact) simulates a train journey (and therefore may mask the above measures), the TC power supply is usually monitored by technical means (M271). In case of need, a suitable safety response is triggered (e.g., blocking of route clearance).

Please note: The monitoring location and the distribution of TC voltage have a major effect on the effectiveness of measure M271. If redundant power supply components are used to feed the TC (e.g., redundant frequency converters), it is also to be ensured that a redundancy switch does not mask the monitoring of the TC feed.

4.4.4 Control and monitoring of signal aspect 'stop'

Control of signal aspect 'stop' corresponds from a theoretical switching viewpoint to measure M206 'locking via current flow'. Since most of the assumed faults will prevent the flow of current, the correct display of signal aspect 'stop' will usually be tested in the circuitry. In this connection there are theoretically the following approaches to finding a solution according to [17]:

a. *At the point when the start signal shows the 'proceed' aspect, the target signal must indicate 'stop'.*

b. *At the point when the start signal shows the ‘proceed’ aspect, the target signal must indicate (or must have indicated) ‘stop’ after the last ‘proceed’ aspect of the start signal.*

c. *The stop aspect is considered so safe, that a ‘faulty remain on proceed’ is not assumed’* (e.g., by using two mutually independent contact criteria or applying a type N relay).

4.4.5 Measures to combat signal aspect distortion

If, as a result of the failure of a signal lamp, a non-permissible ‘proceed’ aspect is shown, the required signal aspect or combination of signal aspects will be tested in the circuitry involved. If required, a suitable safety response will be triggered (e.g., the display of a restrictive signal aspect).

4.4.6 Flashing signal aspects

Concerning the actuation of flashing signal aspects, care should be taken to ensure that a failure of the flasher (e.g. due to the contacts’ failure to energise or de-energise) cannot lead to an overly-permissive signal aspect being shown. Generally, a combination of the following measures is used to prevent this:

- fault-tolerant signalling (system-inherent avoidance of the failure’s impact)
- use of flashers with a defined preferred failure mode
- use of highly reliable flashers
- technical monitoring of flashing signal aspects (including response to any failures of this sort)
- visual display of flash cycle of flashing signal aspects on control desk or monitor

The measure(s) deployed will depend on the application in question, the associated safety requirements, and the “state of the art”.

In selecting flashers, attention must be paid to the requirements surrounding the circuits controlling the signal lamps or the indicators on the control desk (e.g. requirements concerning reliability or functional safety with regard to safety integrity). Replacing a flasher or rebooting the system cannot be allowed to lead to a dangerous situation.

Operational requirements (e.g. the flashing frequency, duration of display of the relevant signal aspect, or signal aspects permitted) must also be factored-in. This presupposes that said requirements have been defined and communicated ahead of time.

Please note: some railways use different frequencies for flashing signal aspects (e.g. a “fast” flash and a “slow” flash). Flashing frequencies around 1 Hz are fairly widespread. To avoid confusion, many railways define maximum limit values for the tolerable deviation in flashing frequency. Generally, higher flashing frequencies are better tolerated than low ones (which could potentially be confused with steady lights).

If the flashing signal aspects are monitored using a relay wired in series to the signal lamp, note that if alternating current is used and no further measures taken, this monitoring relay will wear out very quickly. In modern interlocking designs, therefore, “holding circuits” are often used; these prevent the monitoring relay to oscillate.

Please note: The measures taken to avoid the monitoring relay to oscillate are to be detailed in the part of the proof of safety dealing with signal control. This concerns, inter alia, the impact of any potential rise via the N conductors of the feed transformer.

4.5 Transmission of information between 'safe signalling' systems

In transmitting 'safe signalling' information, allowance is to be made for the potential impact of resistive, inductive and capacitive interference. The efficiency of the protective measures taken is to be indicated in the proof of safety for all hypothetical operating situations.

4.5.1 Correct system set-up

If relays are used to transmit information (e.g., status information and/or commands), care must be taken that the relays are not located on the same side as the feed for the circuit concerned.

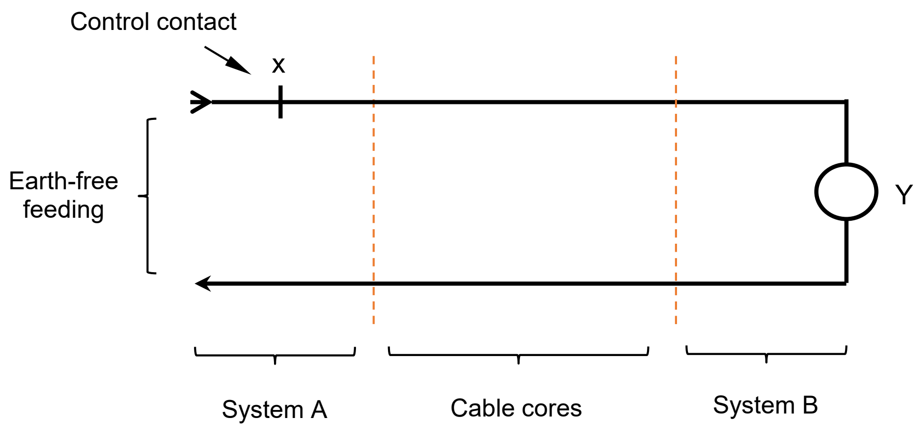


Figure 49: Transmission of information according to the rules (simplified representation)

The background of the above measure is the fact that the proof of safety usually assumes short-circuits in cables in the external installation, while excluding them in the internal installation. The following figure visualises an example in this context as well as the potential consequences of an incorrect system set-up.

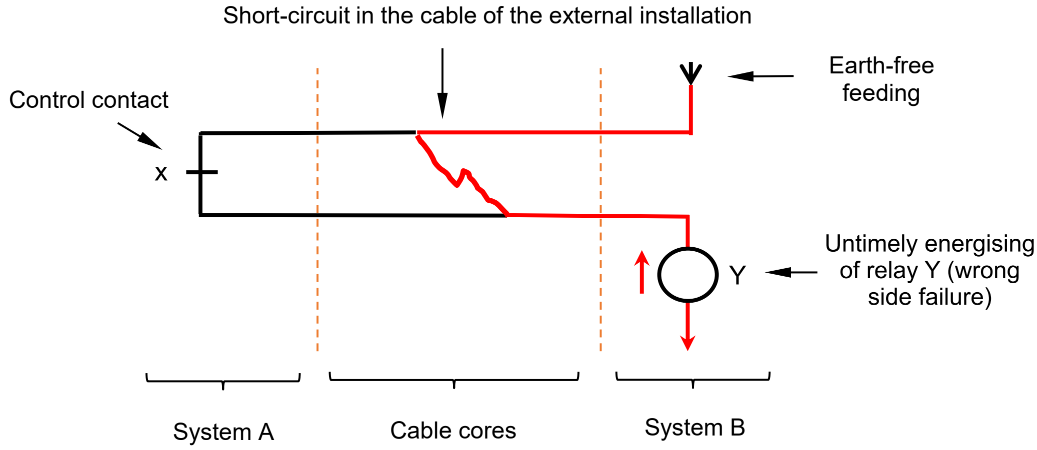


Figure 50: Non-compliant transmission of information

4.5.2 Antivalent transmission of information

'High quality' signalling information (e.g., safety-relevant commands or interlockings) are usually transmitted in an antivalent manner. Antivalence of information must be checked in the circuit concerned.

Please note: In the past, relay-based transmission systems were occasionally used to save cores (e.g., relay circuits based on 2 out of 5 codes).

4.5.3 Short-circuit switching

Short-circuit switching is a special form of bipolar turn-off. This is usually only used for the transmission of 'high-quality' signalling information.

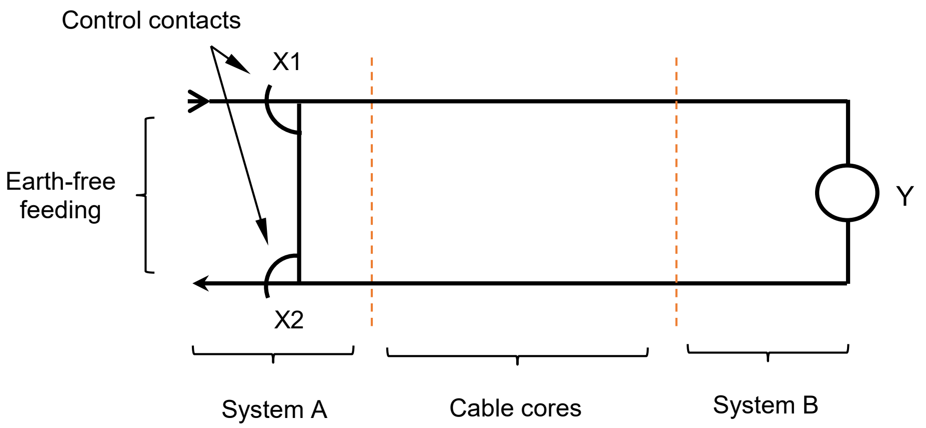


Figure 51: Short-circuit switching according to [26]

Please note: In practice, short-circuit detectors are also used, in which, in the case of a fault, a fuse is triggered (M253). However, this presupposes the application of measure M254.

5. DEMONSTRATION OF MEASURES RELATING TO REAL CIRCUITS

The aim of this section is to demonstrate the application of the measures listed in sections 3 and 4 in real circuits. To obtain a better understanding of the examples cited, information is also given on the functional interlocking process.

5.1 Signal control interlocking system Domino 69 (SBB/CFF/FFS)

Relay interlocking systems of the type Domino 69 (Do69) were developed especially for smaller stations without shunting routes, this concerns a track plan and locking system. Do69 represents a low-cost alternative to the geographical circuit interlocking systems used extensively by SBB/CFF/FFS of the type Domino 67 (Do67).

Figure 53 shows a schematic extract from the signalling circuitry of interlocking systems of the type Do69. This is based on the fundamental circuit for signal control of a Do69, but contains some significant simplifications. Therefore, supplementary information will be provided wherever necessary in terms of functionality.

5.1.1 Functional process (simplified representation)

When a route is set (e.g., from signal A to track 3), the points that are still in the wrong position for the route concerned are automatically set in the required position (the functionality concerned is not shown in figure 53).

Relay SZ (signal-time relay) energises when the following conditions are met:

- all the points on the route concerned were correctly controlled or are already in the correct position,
- the track clearance sections of the route are not ‘occupied’ (the contacts concerned are not shown in figure 53),
- the target signal displays ‘stop’ or ‘emergency stop’ (see contacts for relays SRH and SRNH),
- no opposing route is set,
- the one-pull signal lock is in the default position.

Via a NO contact of relay SZ, relays SA1 and SA2 become energised for contact multiplication, as a result of which relay SZ energises automatically for 6 up to 8 seconds. At the same time, a contact in relay SA2 circumvents the key contact of signal A, as a result of which the route is ‘memorised’.

Please note: If the points do not reach the monitored position in time, the ‘memorised’ route is automatically deleted by relay SZ de-energising.

Via a NO contact in relay SA1 in the circuit of signal-activation relay 1, relay SS1 now energises, provided the following conditions are met:

- the start and target keys are back in the default position,
- the points concerned are in the correct position and ‘monitored’,
- the track clearance sections of the route and the ‘non-profile-free’ flank protection are not ‘occupied’ (the contacts concerned are not shown in figure 53),
- the target signal displays ‘stop’ or ‘emergency stop’ (see contacts of relays SRH and SRNH),
- no opposing route is set,

- the ‘stop’ aspect (as a result of a train running) is in the default position.

When relay SS1 is energised, the first sub-system of interlocked relay WV energises and this locks the points concerned. Via the NC contact of the second sub-system of interlocked relay WV, relay SS2 can now energise, provided the above conditions are still being met and the ‘special interlockings’ have been activated (e.g., in the event of insufficient overlap).

Via a NO contact of relay SS2, the first sub-system of interlocked relay SW now energises, as a result of which the one-pull signal lock becomes active. Then the pertinent signal aspect is displayed (the functionality involved is not shown in figure 53).

Please note: one-pull signal lock resumes the default position again only on route release (the functionality concerned is not shown in figure 53) and the point locks have been released again.

5.1.2 Circuitry measures applied

Measure	Explanation
M201, M202	All relays in the circuit function according to the NO circuit.
M203	In addition to the energising of various relays, the switching of signal aspect also requires a change of interlocked relays.
M204	The monitoring of the points installation takes place according to the NC circuit.
M207	All relays are tested for de-energising (not all parts of the respective functionality or circuitry are shown in figure 53).
M208	To lock points and one-pull signal lock, interlocked relays are used.
M210	Interlocked relays use the NC contacts of the ‘first switching’ sub-system to ‘lock functions’ and the NC contacts of the ‘last switching sub-system’ to ‘release functions’.
M211	In the case of interlocked relays, the start of the locking action is indirectly tested via M210.
M212, M251	The circuit is constructed in a deterministic manner.
M231	With the exception of relay SA1, all contacts are arranged between the feed source and the relay coil.
M234	Redundant contacts forming part of the point-monitoring relays are used in the circuit for one-pull signal lock 1 and 2.

Figure 52: Signal control Do69, implemented measures

Please note: With the exception of relay SZ, only signalling relays of type C according to [1] are used. For this reason it was decided not to list all relay-related measures (M101 up to M199).

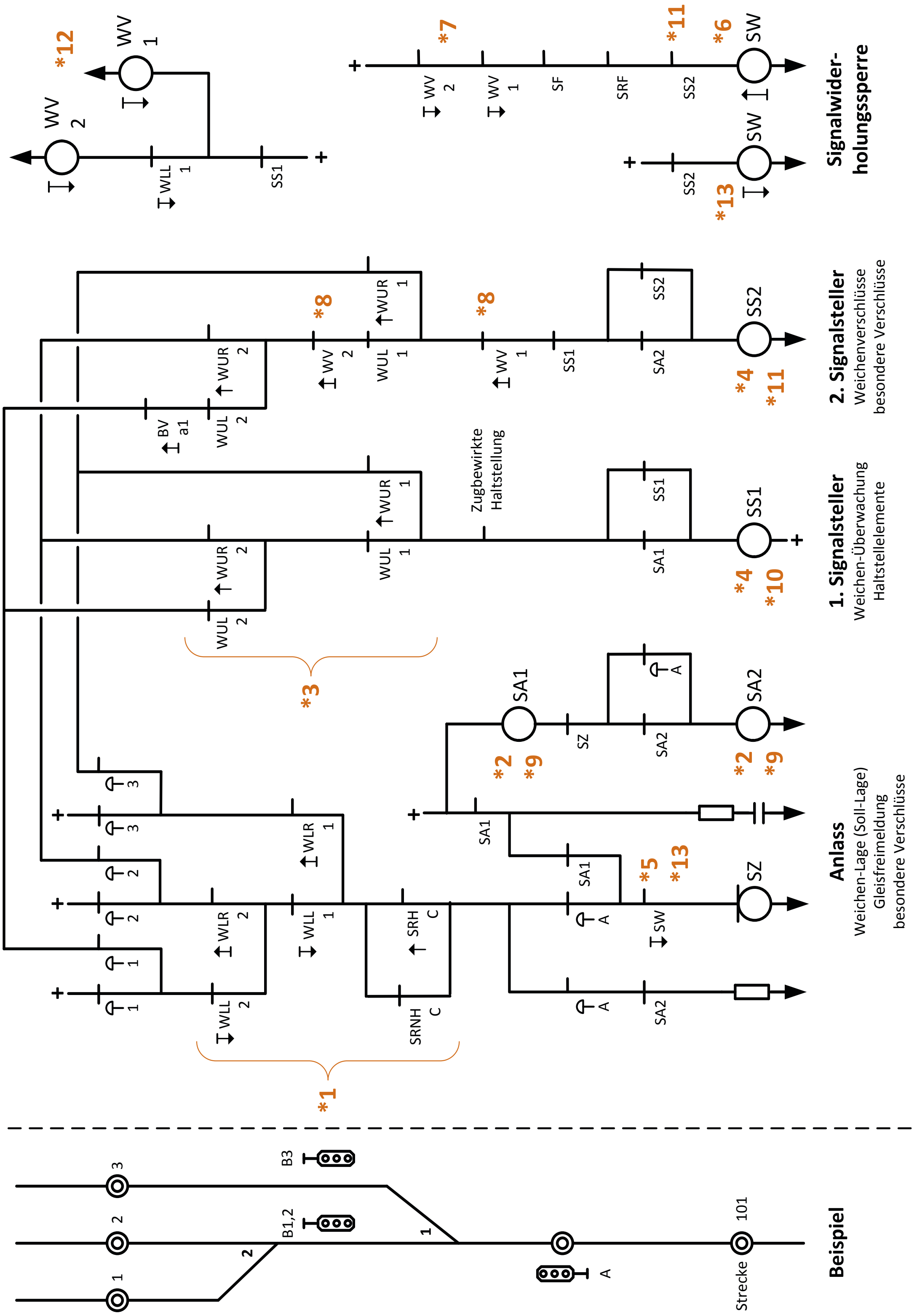


Figure 53: Signal control Do69 (simplified representation)

Explanation of the notes on the circuit:

Hint	Explanation
*1	Route dependencies (point checks performed [1]), see functional process).
*2	Two signalling relay in series, reason: contact multiplication.
*3	Route dependencies (continuous checks performed [2]), see functional process.
*4	Signalling relays in series, reason: double utilisation of contacts.
*5	The energised sub-system of interlocked relay SW locks relay SZ (M210).
*6	The de-energised sub-system of interlocked relay SW is tested in the signalling circuit (release of the signal release return conductor not represented).
*7	The energised sub-systems of interlocked relay WV locks the second sub-system of interlocked relay SW (M210).
*8	The de-energised sub-systems of interlocked relay WV release relay SS2 (M201, M210).
*9	The drop test (M207) for relays SA1 and SA2 takes place in the circuit ‘signal release return conductor’ (not represented).
*10	The drop test (M207) for relay SS1 takes place in the SZ circuit (not represented).
*11	The drop test (M207) for relay SS2 takes place in the circuit of the second one-pull signal lock sub-system.
*12	The drop test for the first sub-system of interlocked relay WV takes place during point control (not shown).
*13	The drop test for the first sub-system of interlocked relay SW takes place indirectly via the locking of relay SZ.

Figure 54: Signal control Do69, notes on the circuit

Please note:

1. The expression ‘point checks performed’ is used by SBB/CFF/FFS to describe a one-off test of criteria linked to aspects of signal dependency. If the criterion concerned is later no longer met, *no* safety response will take place.

2. The expression ‘continuous checks performed’ is used by SBB/CFF/FFS to describe a prolonged test of criteria linked to aspects of signal dependency. If the criterion concerned is no longer met after the first check, a safety response will take place.

5.2 Signal control Siemens Dr S interlocking (Finland, FTA)

The relay interlocking system design developed by the former Finnish State Railways of the type Siemens Dr S has been in use since the late 1950s. Until the end of the 1980s, Dr S systems were standard interlocking systems for small and medium stations with raised transport volumes in addition to type Ganz Domino 55 (Integra). Most interlocking systems of the type Dr S are remote controlled; there are now only about 60 in use (of a total of around 330 interlocking systems on the Finnish railway network).

The basic design described here has been in use since the late 1960s, in the last 15 years it has been developed further in terms of switching safety and also in light of new functional requirements. All the circuits of this type of interlocking system are fitted with relays type C design K50 (elementary relays and interlocked relays).

Figures 56 and 57 show a schematic extract from the signalling circuit for Siemens Dr S (FIN) interlocking systems; figure 58 shows the associated time sequence for the circuit.

5.2.1 Functional process (simplified representation)

If the start and target buttons are applied for the desired route (e.g., from signal P901 to track 001), the respective button relays (ST P901 and T 001) are the first to energise (the respective functionality is not represented in the diagrams).

In the circuit ‘route setting and acceptance testing’, the remaining requirements for setting the route concerned are then tested:

- the release relay (relay ‘A p901’) is in the default position,
- the down-proving relays for track sections (relays ‘Ab’) are in the default position,
- the test relay for the route interlocked relay (relay ‘pü’) is in the default position,
- no opposing route was set,
- no release for local control area was issued.

Please note: Relay ‘pü’ monitors the default position of the route interlocked relay for the routes in the respective station area that are mutually exclusive (the circuit concerned is not shown in the figures). Since this relates to safety-relevant monitoring functions, relay ‘pü’ is used in an NC circuit.

If all conditions are met, the first sub-system of the auxiliary interlocked relay p901/001 energises and then controls the main locking relay p901/001 that sets the route. At the same time, opposing routes are blocked. When the second sub-system of the main interlocked relay p901/001 de-energises, the first phase of route setting is complete.

At the beginning of the 2nd phase of route setting, the first thing tested is whether as a result of the change of interlocked relays p901/001, relay ‘pü’ has de-energised (with a drop delay of around 2 seconds). If this is the case, the conditions for signal control and route locking are tested in the circuit ‘locking/monitoring’.

Signalling relay P901 is energised when the following conditions are met:

- the points in the route concerned are in the required position; their final position is monitored; they are locked,
- key release instruments are in the default position (i.e., ‘key not released’); the key is monitored,
- the track sections in the route are ‘free’,
- flank protection (points, signals) is provided and monitored,
- the target signal for the route to be set shows a signal aspect (i.e., the target signal is ‘not dark’),
- an advance train is not immediately behind the target signal for the route to be set.

Via NO contacts for signalling relay P901, the first winding of the route-setting relay p901 is then actuated, leading to the setting of the route.

Please note: In order to increase availability of the ‘Signal set to stop”’ function, the ‘Ha’ (stop position) relay, signal relay P901 and the route-setting relay p901 are powered via the same fuse (see section 8.6).

Via the NO contacts of signalling relay P901 and the setting relay p901, the respective ‘proceed’ aspect is then actuated. The choice between the signalling aspects ‘proceed’ and ‘proceed 35’ is made via the contacts located within the lamp circuit of the route interlocked relay concerned. Via the NC contacts of the reduced speed route interlocked relay, additional tests are run to establish that a non-permissible signal aspect is not being actuated (e.g., by means of the false actuation or contact-bridging action of the higher-speed route interlocked relay).

When the lamp monitoring relay has energised (green or green/yellow), the red lamps are finally switched off.

Please note: The switching of the proceed aspects takes place in a bipolar manner using the contacts of signalling relay P901 in the feed line and return conductor. In contrast, switching the stop aspect takes place in an unipolar manner using the contacts of various relays in the feed line.

5.2.2 Circuitry measures applied

Only signalling relays type C according to [1] are used. Therefore, the list does not mention relay-related measures (M101 up to M199).

Please note: Measures in brackets mean that these have not been realised to the full extent.

Measure	Explanation
M201, M202	All relays in the circuit function according to the NO circuit (exception: relay pü).
M203	In addition to the change of interlocked relays, the switching of signal aspect also requires the signalling relays to energise.
M204	Monitoring of points position and key locks takes place in a NC circuit.
M205	The pü relay monitors the default position of the interlocked relays in a NC circuit. Since this concerns a release function, the relay is drop-tested in the circuit (failure to energise is detected as a functioning fault).
M207	All relays are proved for de-energising (not all parts of the respective functionality or circuit are shown in the figures).
M208	To lock the points and the route, interlocked relays are used.
(M210)	In most cases, with interlocked relays, the contacts of the sub-system that de-energises in the default position are used to ‘lock functions’, while to ‘release functions’, the contacts of the sub-system that is locked in the default position are used.
M212, M251	The circuit is constructed in a deterministic manner.
M213	Whole route locking takes place only after route setting (locking of ‘opposing’ routes).
M231, M232	All contacts are arranged between the feed source and the relay coil (with the exception of the route-setting relay and signalling relay; here measures M212 and M251 must be observed).
(M233)	In the route-setting circuit (acceptance testing), the NC contacts of the opposing route are arranged partly redundant on both sides of the relay coil. Signal lamp circuits that allow a train to run have redundant signalling relay NO contacts on both feed lines (in a new signalling group or with a supplementary circuit for the old ones).
(M252)	Connections to the negative terminal are mainly constructed as ring feeders.

Figure 55: Signal control SpDrS (FIN), measures applied

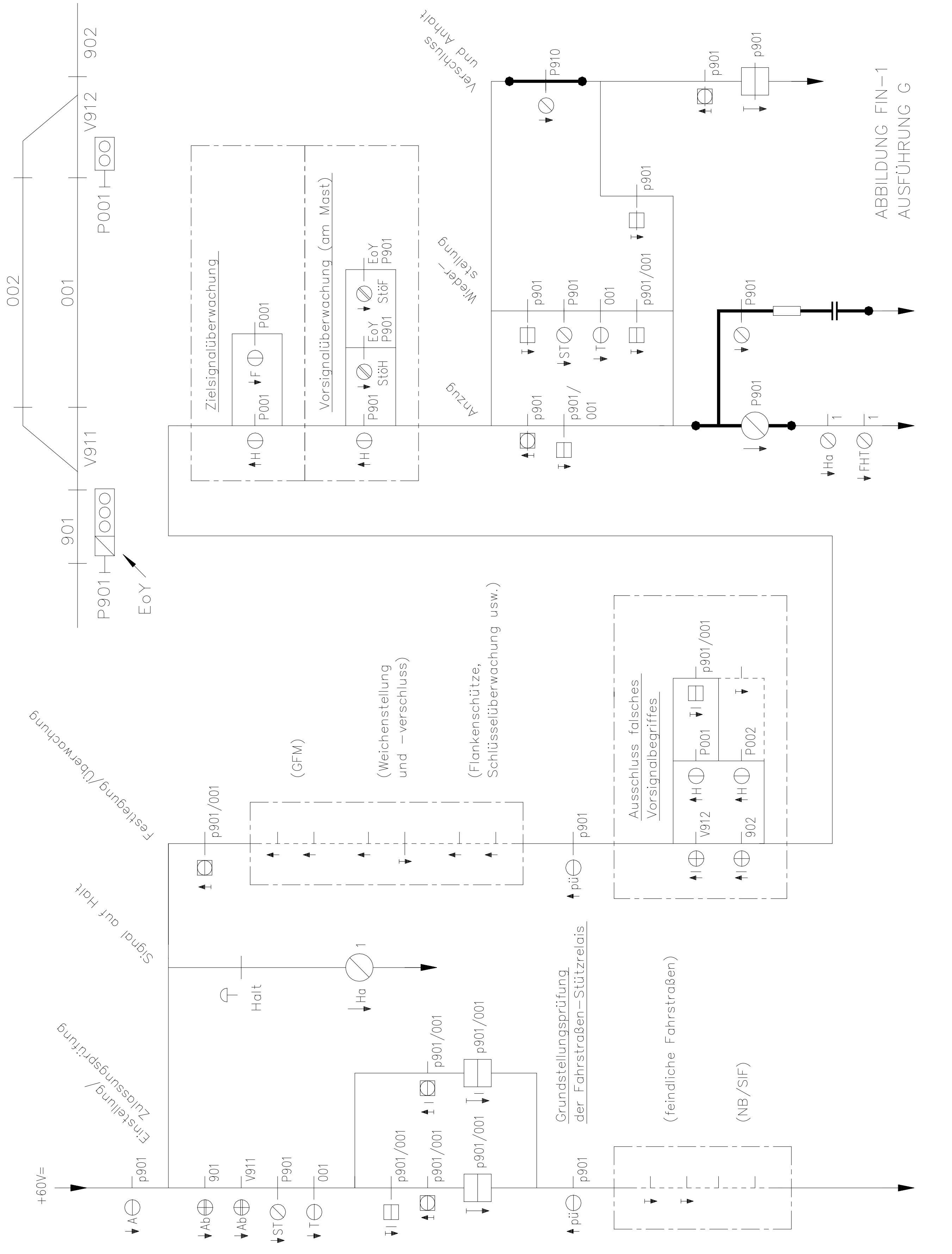


Figure 56: Signal control DrS (FIN), simplified diagram - part 1

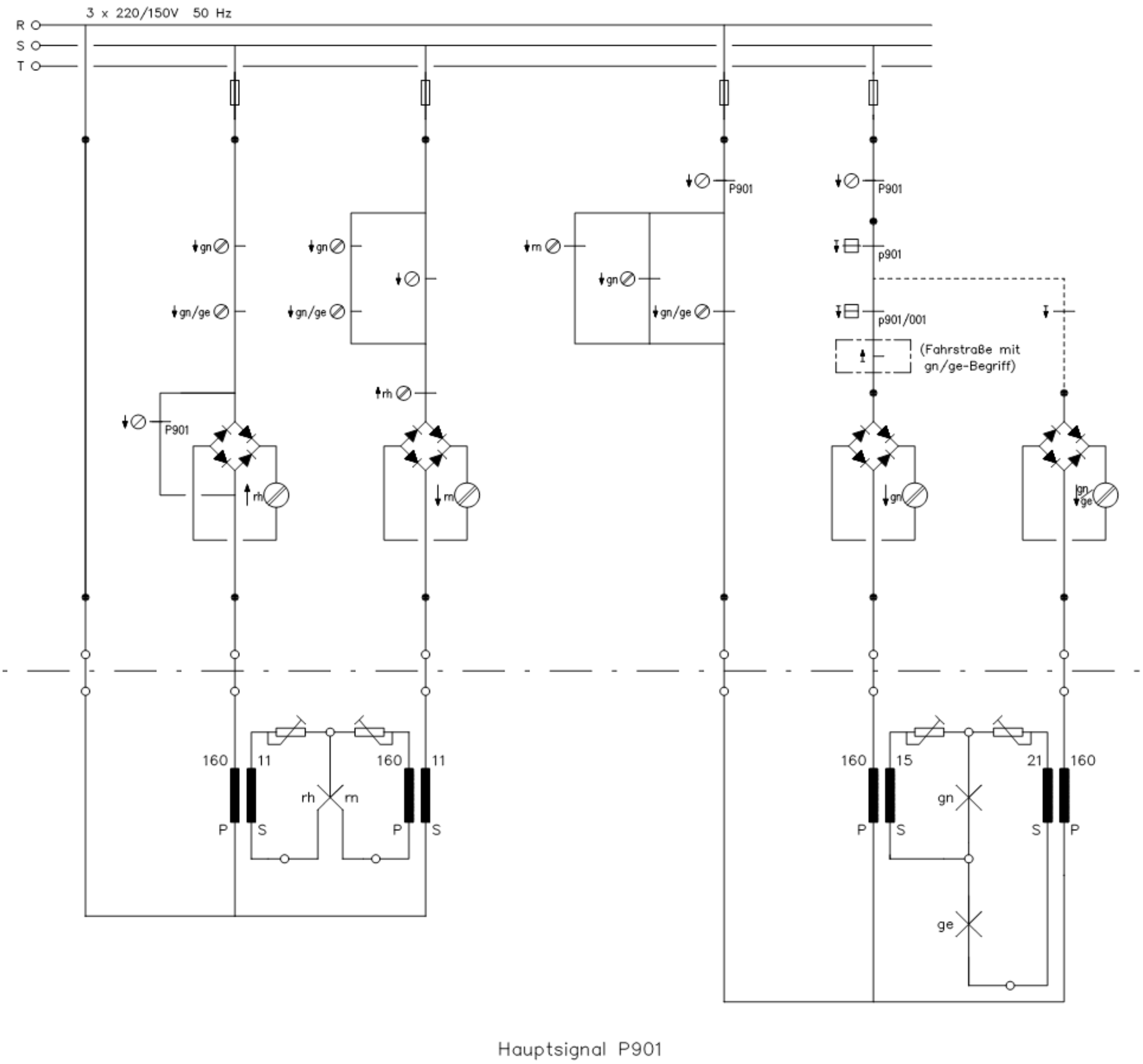


Figure 57: Signal control DrS (FIN), circuit time secquence diagram

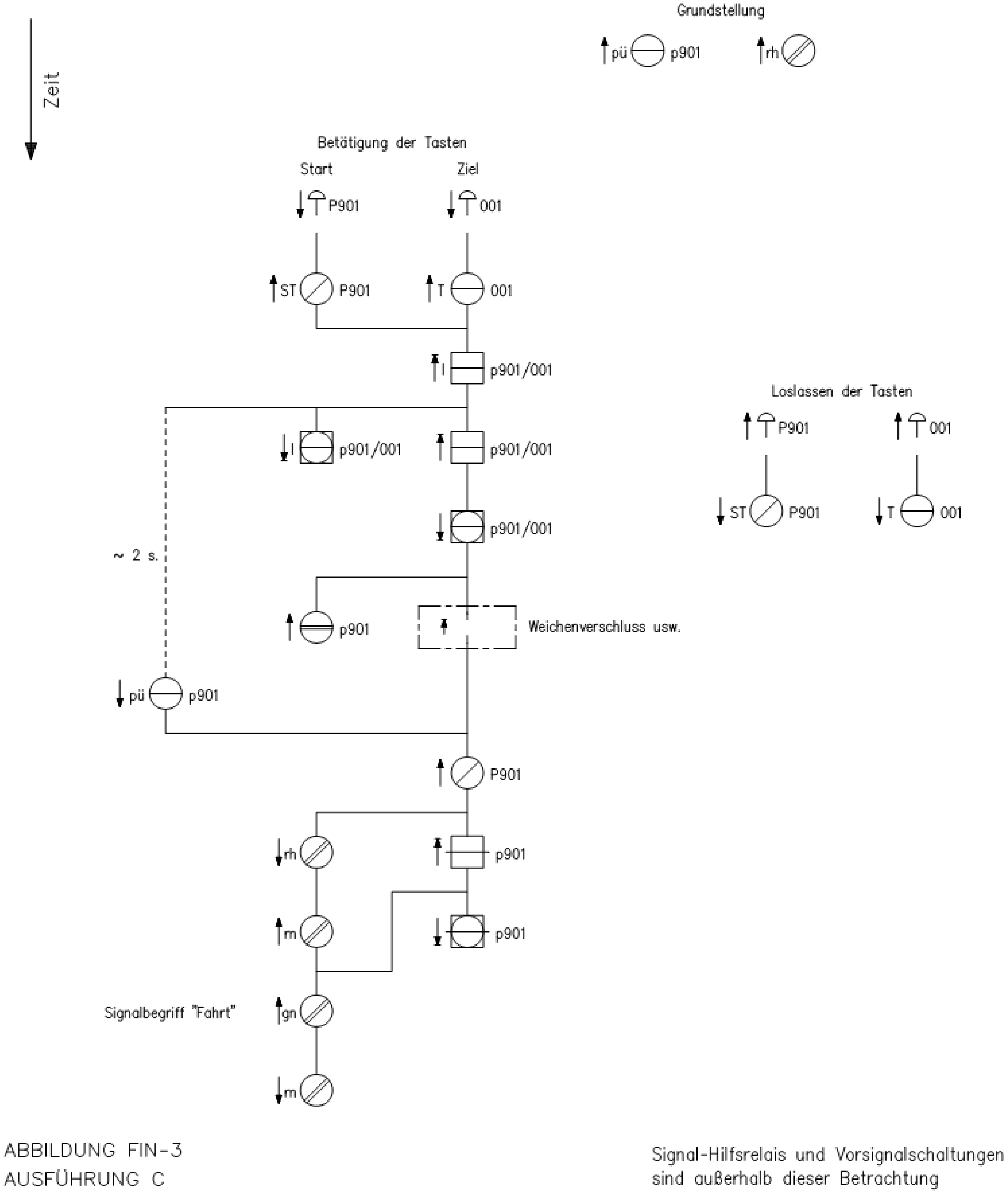


Figure 58: Signal control DrS (FIN), circuit time secquence diagram

5.3 Signalling control with simplified panel interlocking Siemens 1980 (ÖBB)

Relay interlocking systems of the type simplified track interlocking Siemens 1980 (VGS80) were developed especially for smaller stations without humping routes/ shunting routes, this concerns signalling control interlocking systems. These are a low-cost alternative to the geographical circuit interlocking system of the types Lorenz (SpDrL) and Siemens (SpDrS) used extensively at ÖBB.

Figures 60 and 61 show a schematic extract from the signalling circuitry of interlocking system type VGS80.

Please note: The figures are based on the fundamental circuit for signalling control for a VGS80, but contain some significant simplifications. Wherever this is necessary from a functional point of view, supplementary information will therefore be provided.

5.3.1 Functional process (simplified representation)

If a route is to be set (e.g., from signal A to track 3), all the necessary points in the route, overlap and the flank protection must first be placed in the correct position by the operator.

The FAP relay (route setting tester) in the circuit for acceptance testing energises when the following requirements are met ('point' check):

- all points of the respective routes must have the required position and a monitored end position (monitoring of points is not shown in figures 60 and 61),
- no specific interlocking functions are activated (e.g., routes in the opposing direction).

Via a NC contact of relay FAP, the feed for relay FPA (acceptance tester relay) is interrupted and relay FPA will only remain in the energised position for a limited period of time via an RC circuit.

Please note: The combination of FAP and FPA allows relay FAP to be proved for energising and de-energising in the circuit for route locking relays. The energising proving for relay FAP takes place in the course of the actuation process of the single-route-locking relays. If relay FAP fails to de-energise, then relay FPA can no longer energise, which prevents the actuation of the single-route-locking relays. The energising and de-energising proving for the FPA relay takes place in the circuits of the single resp. cumulative route-locking relays.

Via the NO contact of relay FAP, the interlocked relay 'route locking relay' (FSV) at the same time becomes active for the respective route, provided FPA is still energised. **Please note:** The other system's current-saving contacts, usual in interlocked relays, are located here between the relay coil and the negative terminal.

After relay FPA drops, with one contact of interlocked relay FSV's de-energised sub-system, the interlocked relay 'cumulative route locking relay' (FVS), becomes active.

Via the interlocked relays FSV, or FVS's contacts, the interlocked relays 'point locking relays' (WFV) now become active. The default position of relays WÜR and WÜL are proved in the process (the respective contacts are located between the relay coil and the negative terminal.

Please note: This locks the points concerned.

With interlocked relay WFV's contact for the de-energised sub-system, the relays 'points monitor right' (WÜR) or 'points monitor left' (WÜL) are made to energise (depending on the position of the points, see contact for WLR relay), provided the points have a monitored end position and are not trailed.

When the locking sub-system in the default position for the FSV and FVS relays has dropped and the points monitorrelays WÜR or WÜL have energised, all the conditions for energising the 'route monitor relay' (FFU) are met. The conditions are monitored 'continuously'.

Please note: the WFV interlocked relay is also monitored - but the information that WFV has fully re-actuated is transmitted into the circuit via relays WÜR or WÜL.

When the FAP relay energises and with the (ongoing) button pressure at the start signal, the signal actuating relay (SHA) energises, provided the one-pull signal lock (SWR) is in its default position.

Please note: the SHA relay is used at exit routes to store button pressure until the conditions for a signal staging are met (e.g., the default position of the line block or track clearance).

Via the NO contact of relay FFU in the circuit of the 1st signal-activation relay, the relays 'main signal-activation relay 1' (SHS1) or 'main signal-activation relay 2' (SHS2) energise, provided the following conditions are met:

- the start and target buttons are still depressed or start button actuation was stored (SHA relay),
- the points concerned are in the correct position and monitored,
- the track clearance sections of the route (clearance marker incl. cover for buffer overhang and train extension) are 'not occupied' (the contacts concerned are not shown in figure 60),
- no specific interlocking are activated (e.g., routes in the opposing direction),
- the target signal must have shown 'stop' at least once after the last 'proceed' display.

Please note: Whether SHS1 and/or SHS2 energise depends on the speed to be indicated (SHS1 = 40 km/h, SHS2 = 60 km/h, SHS1 + SHS2 = Vmax).

After SHS1 and/or SHS2 have energised, the 'main signal-activation relay 3' (SHS3) can now energise via the NO contact of the relay concerned, provided the following conditions are met:

- The start button and SHA are again in the default position.

  Please note: A test for 'release' of the target button does not take place here, however, the buttons are monitored in a different circuit.
- The points concerned are in the correct position and monitored,
- the track-clearance sections of the route (clearance marker incl. cover for buffer overhang and train extension) are 'not occupied' (the contacts concerned are not shown in figure 61),
- no specific interlocking functions are activated (e.g., routes in the opposing direction),
- the target signal must have shown 'stop' at least once after the last 'proceed' display,
- the one-pull signal lock (SWR) is in the default position.

Please note: The contacts for relay SHN between the relay coil of relays SHS and N are used by the operator to set a signal at “stop” manually.

Using the NO contact of relay SHS3, the signal repeat lock (SWR) is then brought into its active position.

Please note: The signal repeat lock only returns to its default position when the respective relays have returned to their default positions on route release (the respective functionality is not shown in figures 60 and 61).

5.3.2 Circuitry measures applied

Only signalling relays type C according to [1] are used (design K50 - normal, locking and magnetically latched relays). For this reason it was decided not to list all relay-related measures (M101 - M199).

Measure	Explanation
M201, M202	With the exception of relay FPA, all the relays in this circuit function according to the NO circuit.
M203	In addition to the energising of various relays, the switching of signal aspect also requires a change of interlocked relays.
M204	The monitoring of the points installation and track-clear proving take place according to the NC circuit.
M207	All relays are tested for de-energising (not all parts of the respective functionality or circuitry are shown in figures 60 and 61).
M208	To lock the route and the points and to secure one-pull signal lock, interlocked relays resp. magnetically interlocked relays are used.
M209	The more stable state (resp. preferred failure mode) is not used to clear the signal aspect in the signalling circuit.
M210	In the case of interlocked relays, the correct contacts to ‘lock a function’ or ‘release a function’ are used.
M211	The interlocked relays are tested to establish the start of the locking function. **Please note:** Only symmetrical interlocked relays are used.
M212, M251	The circuit is constructed in a deterministic manner.
M231	With the exception of relays FSV, WFV, SHS1/SHS2/SHS3 and the pick-up winding of interlocked relay SWR, all contacts are arranged between the feed source and the relay coil.
M234	In the circuit for relays SHS1/SHS2/SHS3, the redundant contacts of relays WÜR/WÜL and FFU are used.

Figure 59: Signal control VGS80, implemented measures

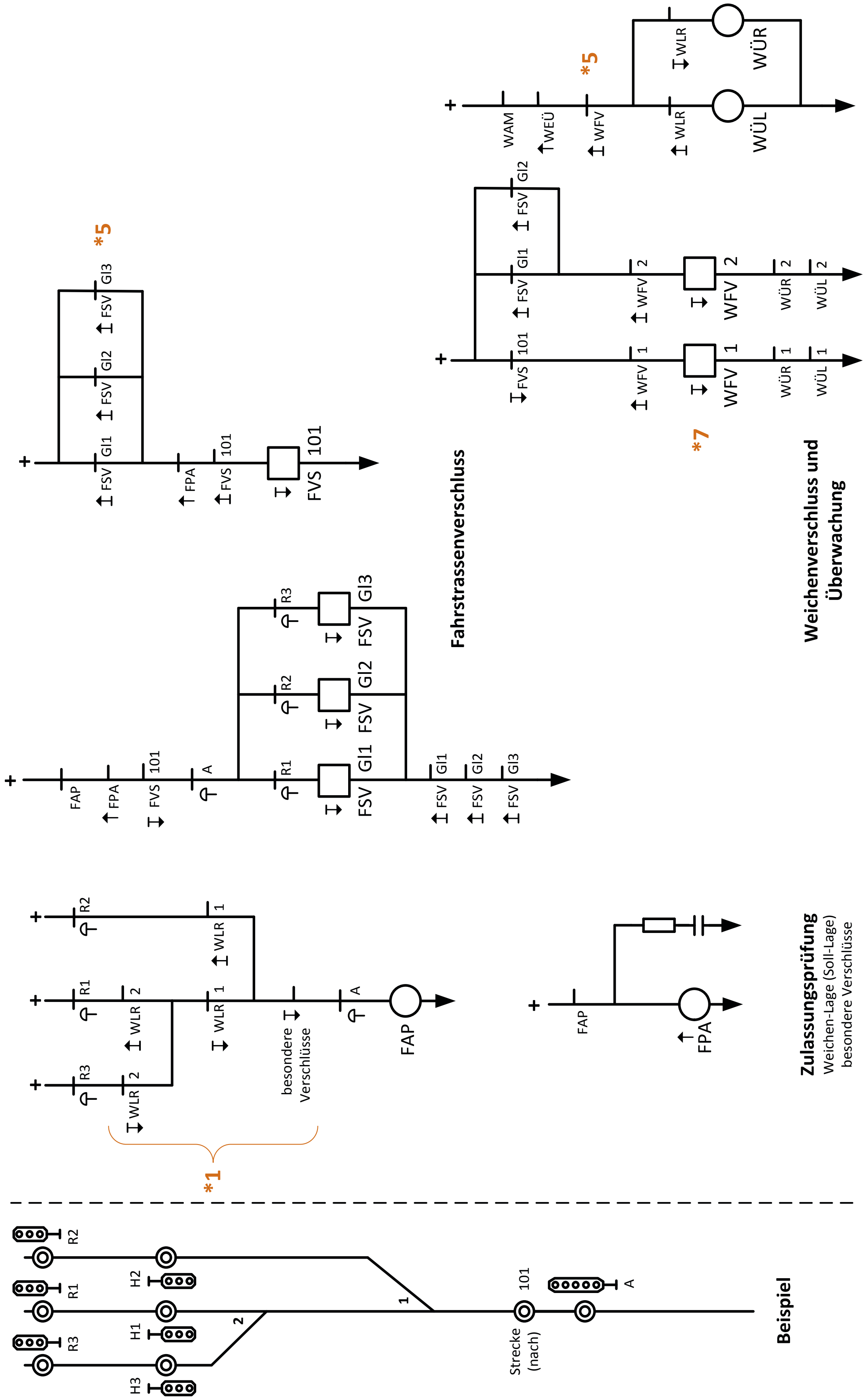


Figure 60: Signalling circuitry VGS80 (simplified representation), Part 1

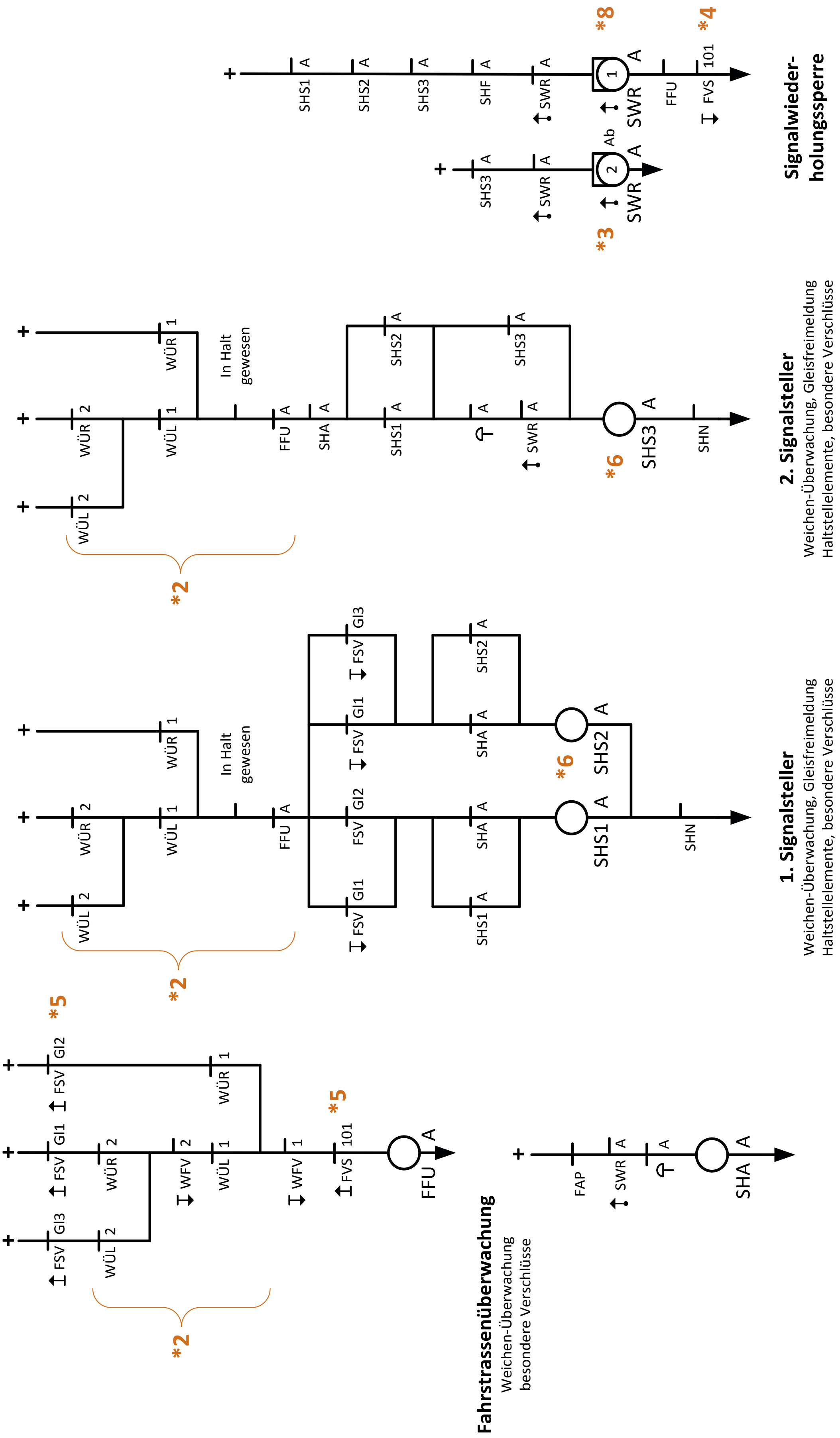


Figure 61: Signalling circuitry VGS80 (simplified representation), Part 2

Explanation of the notes on the circuit:

Please note	Explanation
*1	Route dependencies (point checks performed[1]), see functional process).
*2	Route dependencies (continuous checks performed [2]), see functional process).
*3	The de-energising of the magnetically latched relay SWR is tested in the signalling circuit (release of feed line for clear aspects not shown).
*4	The energised sub-systems of interlocked relay FVS lock the pick-up winding of magnetically latched relay SWR (M210).
*5	The de-energised sub-systems of interlocked relay WFV release relay WÜR/WÜL (M201, M210/M211). Similarly, FSV releases FVS / FSV and FVS releases FFU.
*6	The de-energised proving (M207) for relays SHS1/SHS2/SHS3 takes place in the pick-up winding SWR.
*7	The de-energised test for the energised sub-system of interlocked relay WFV takes place within the scope of point control (not shown).
*8	The energised test for magnetically latched relay SWR takes place in the SHA and SHS3 circuit.

Figure 62: Signal control VGS80, notes on the circuit

Please note:

1. The expression ‘point checks performed’ is used by ÖBB to describe a one-off test of criteria linked to aspects of signal dependency. If the criterion concerned is later no longer met, *no* safety response will take place.
2. The expression ‘continuous checks performed’ is used by ÖBB to describe a continuous test of criteria linked to aspects of signal dependency. If the criterion concerned is no longer met after the first check, a safety response will take place.

6. THEORETICAL FOUNDATIONS

The aim of this section is to provide an introduction into the ‘theory of railway signalling’ whilst also explaining tried and proven interlocking safety methods. Finally, the effectiveness of the selected measures is demonstrated within the scope of quantitative analysis.

Please note: The explanations in this section are based on the methodology used in the course ‘technical traffic cybernetics, specialisation railway signalling’ given at the University of traffic engineering Dresden by Prof. Dr.-Ing. Fenner and Dr.-Ing. Lorenz. The explanations make it possible – particularly for people trained in other specialised areas – to gain an insight into the ‘theory of railway signalling’.

6.1 Introduction

Because railway passengers, in contrast to individual transport, have no influence on the safety of the transport process, the risk acceptance of passengers is generally very small. The risk of accidents linked to railway travel (particularly in the case of trains that travel at high speed) must therefore be kept as small as possible. At the same time, passengers demand maximum punctuality.

For this reason, traditionally, extremely high demands are made on the safety and availability of railway signalling systems. However, normally there are no requirements that specify that accidents must be ‘excluded at all cost’. The reasons for this are given in [8]:

- *‘When designing, operating and maintaining railway signalling systems, human errors can be limited, but not (totally) excluded’.* We can add to this that it also applies to the aspect ‘inspection’.
- *‘The majority of technical failures cannot be excluded during the operation of railway signalling systems’.*
- *‘Human errors and technical failures can... lead to hazardous situations, which, though they must be highly improbable, cannot be totally excluded’.* We wish to indicate at this point that these ‘hazardous situations’ usually correspond to ‘hazards’.
- *‘Hazardous situations can lead to accidents in certain circumstances that are not always avoidable and whose consequences cannot always be precisely estimated’.*

For the above reasons, in accordance with [8], the *‘risk-free transportation of passengers... is theoretically and technically impossible’.*

6.2 Basic system requirements

The basic requirements for railway signalling systems can be derived from the following phase diagram:

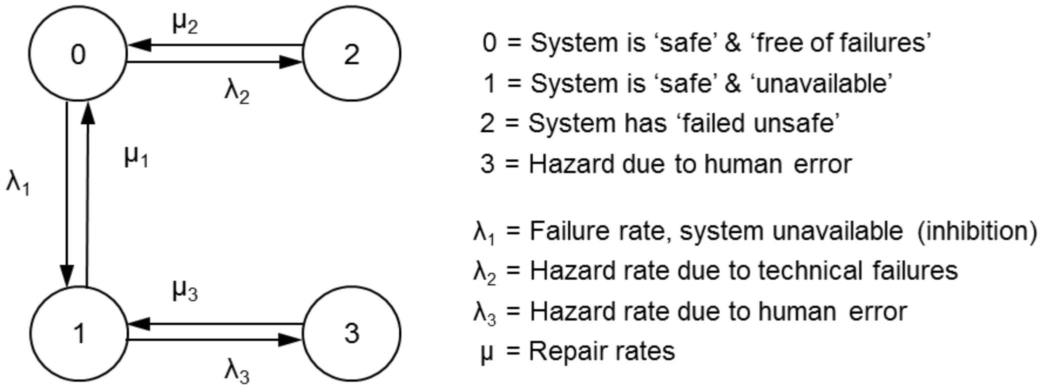


Figure 63: Phase diagram according to [8] (simplified representation)

We assume the axiom that the signalling system was taken into operation 'safe and free from failures' (system condition 0). However, this presupposes according to [8] that *'all functions of the signalling system were specified and implemented free from faults'.*

For the signaller there is at this point no necessity to intervene in the transportation process with safety-relevant services.

When developing signalling systems, measures must be identified in order to control failures. It is particularly important in this context that failures and faults are converted with a high probability into a 'safe system condition' (1), but only with a very small probability into the 'hazardous condition' (2). According to [8] this corresponds to the 'fail-safe principle'. In addition, it must be safeguarded that the assumed failures / faults do not jeopardise the safety integrity of the signalling system. The next section contains details.

Please note: Because very high demands are made on the availability of safety systems and adopting the 'safe system condition' (1 = safe but not available) often results in immediate hazards for railway operations (e.g., by passengers descending from a stationary train), modern safety systems normally have different types of integrated 'fault tolerances' (e.g., a 2-out-of-3 system structure).

The 'hazardous system condition' (3) can be reached through faults made by the signaller or by mistakes made during maintenance. For this reason it should always be attempted to keep $\lambda 1$ as small as possible and $\mu 1$ as high as possible.

6.3 Functional safety

Functional safety for safety-relevant functions in a signalling system must be demonstrated in the functional proof of safety document. According to [8] 'functional safety' is present

1. *'If the safety requirements specification covers all safety-relevant functions appropriately and completely,*
2. *all safety-relevant functions are correctly implemented in the interlocking signalling system so that when it is commissioned it appropriately fulfils the safety-relevant functions in the failure-free condition, and*
3. *these functions cannot be lost following commissioning.'*

When constructing signalling systems, measures must therefore be taken against systematic failures as well as malfunctions resulting from random failures / faults. The efficacy of the measures must be demonstrated in the proof of safety document.

It should further be ensured that requirements are linked to safety-relevant functions regarding their 'level of safety' (here in terms of 'safety integrity'). As a logical consequence we can derive from this that in addition to the respective function itself, failures / faults will also affect the safety integrity of a function. The following diagram shows the connections.

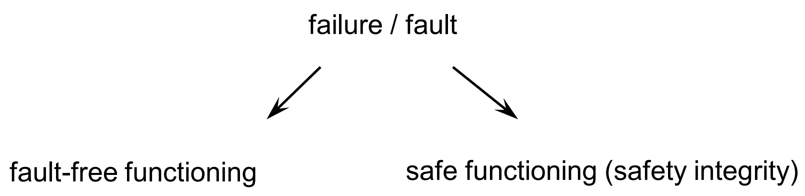


Figure 64: Effects of failures and faults

As the term 'safety' is defined resp. interpreted in different ways in the separate specialised disciplines, the following sections will explain this term briefly.

6.3.1 Definition of 'safety'

Safety as a function of risk

There is a widespread notion that 'safety is a condition in which risk (R) is no greater than a defined threshold risk'. Risk is generally defined as the product of the frequency (H) of the occurrence of 'an incident that leads to damage' and the 'extent of the damage to be expected when the incident occurs' (S), (i.e., R = H * S).

Please note: A system-inherent disadvantage of the approach described above is according to [8] that determining the (accepted) threshold risk requires quantitative findings.

Safety as the 'absence of non-acceptable risks'

A further approach is provided by EN 50129, which has proven its worth particularly in the construction of modern signalling systems. EN 50129 defines safety as the *'absence of non-acceptable risks'*. From this we can derive according to [8]:

- that in addition to *„non-acceptable risks that must be excluded, there are also acceptable risks that need not be prevented'*,
- that safety-relevant functions *'(should) offer exactly the degree of safety required to prevent the creation of non-acceptable risk'*,
- that safety targets can be derived from 'non-acceptable risks' from which in turn safety requirements can then be derived for the components used.

Please note: The risk that can be tolerated in each respective application case is derived from a set of factors, which we will not discuss in detail at this point however.

Safety as the 'condition of an observation unit'

Because in older proof of safety documents there are often no findings relating to 'acceptable risks', the terms 'safety' according to [8] is used in the following meaning:

'Safety is the condition of a unit under observation in which it meets identified requirements at a given point in time that eliminate hazards resp. accidents'.

Safety as a function of hazard probability

In mathematical terms, 'functional safety' is given (i.e., R (t) = 1) when no hazard occurs resp. the probability of one occurring is very small resp. negligible (i.e., Q_{gf} (t) –> 0). This is the mathematical interpretation:

$$R(t) = 1 - \sum_1^j Q_{gf}(t)$$

Where R (t) = safety and $\sum_1^j Q_{gf}$ = sum of the hazard probabilities

Please note: R can be expressed both as a time or actuation-related function.

Signalling safety

According to [8] safety-related systems have attained a very high level of safety (depending on the state of technological advancement). *'This was possible without the precise determination of the threshold risk... by specifying without exception all incidents (technical failures, interference disturbances) that are not permitted to lead to hazard situations'*. Clearly, the term 'safety' in signalling systems was also interpreted in a different way. The term 'signalling safety' is usually used here.

Signalling safety according to Mü 8004 [19] *'is the capacity of a properly operated, maintained and handled signalling installation to prevent any hazards resulting from functional failure in a pre-determined period of use, to the extent dictated by the state of the art, even in the presence of component failure and interference effects in an signalling installation considered free from faults when first activated'*.

6.3.2 Safety target of safety systems

Signalling systems must prevent any hazards resulting from malfunctions due to failures / faults in keeping with the respective 'state of the art', yet not exclude them (absolutely). This presupposes that failures / faults resp. the resulting malfunctions are detected. Non-detected failures / faults are therefore 'potentially dangerous'.

Ergo sum, the primary safety target of signalling systems is to protect against 'potentially dangerous failures / faults'. In other words: signalling systems serve to protect against hazards (but not to prevent totally faults which may cause hazards nor to prevent incidents). The following diagram shows basic connections.

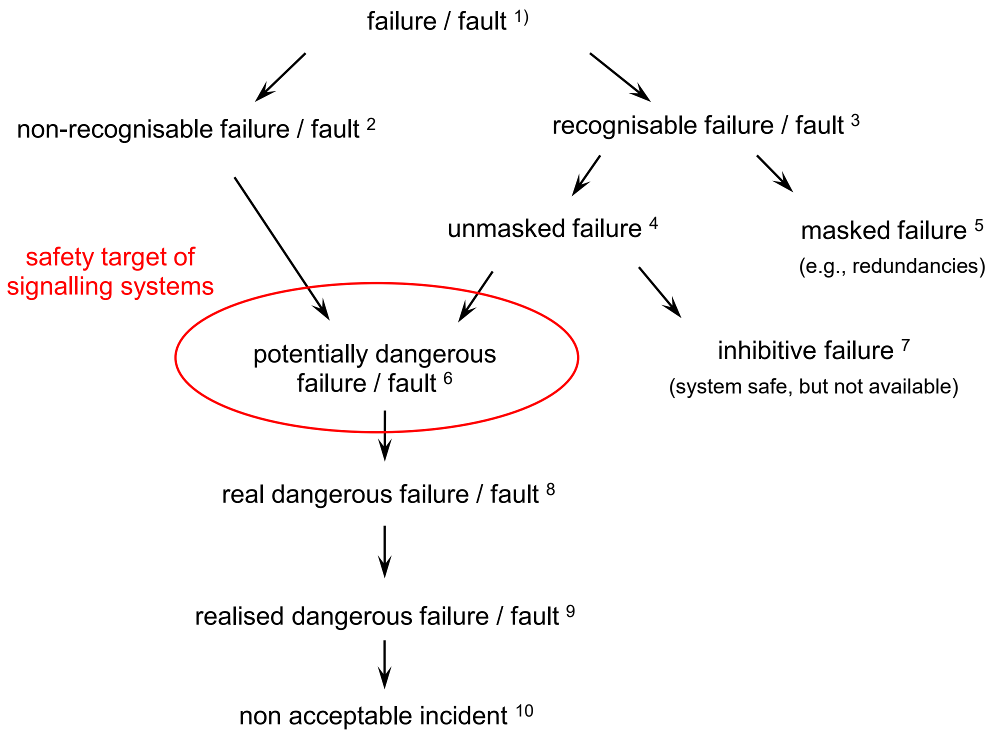


Figure 65: Safety target of railway signalling systems

Notes relating to figure 65:

1. A failure or fault occurs. Example: 'Welding of NO contact for signal relays type C' (see appendix A, fault F101).
2. The failure/fault is not detected at all or not in a timely fashion (e.g., due to lack of measures or a second failure occurring at the same time).
3. The failure/fault is detected by a measure relating to circuitry for instance (e.g., by using a signalling relay according to [1] combined with measure M207 'drop test' according to appendix B).
4. The function concerned was not implemented in a redundant manner, the failure will with high probability therefore lead to a malfunction resp. a hazardous state.
5. The function concerned was implemented in a redundant manner, the failure therefore does not lead to a malfunction resp. a hazardous state (e.g., due to measures M233 - M238 according to appendix B).
6. Failures that are not detected resp. not controlled[1] are by definition 'potentially dangerous' as they can affect safety-relevant functions and/or the safety integrity of a signalling system. This state must therefore be avoided.
7. A system is in a 'safe condition' (safety integrity is guaranteed); however, the function concerned is no longer available (functional failure).

   Please note: This corresponds to the system state ① in figure 63.
8. The failure / fault takes place, i.e., it is effective now. Since it is neither 'detected' nor 'controlled'[1], it is by definition a 'real hazard'.

   Please note: This corresponds to the system state ②, in figure 63.

9. The faulty system function is activated (e.g., setting of a route with missing exclusions). This corresponds to a 'hazardous state'.
10. The 'realised dangerous failure/fault' will lead – often combined with other factors – in the worst case to a 'non-acceptable incident'.

1) The expression 'not controlled' is used here to mean „there is no effective measure to prevent a potential hazard'.

6.3.3 Hazardous states

Dangerous faults or fault conditions can in connection with operational situations lead to non-acceptable incidents. According to Mü 8004 [19], this includes:

- untimely throwing of points,
- untimely clear proving of track or points,
- lack of coordination for points installations with the positioning and setting indication,
- untimely or too rapid signalling of a proceed aspect,
- untimely default position of a block resp. route logic,
- untimely cancellation of dependencies.

6.4 Measures against systematic faults

Since railway signalling systems by definition are commissioned 'fault-free', it is necessary to take measures in all phases of the life cycle (e.g., at the development stage, for proof of safety, at the design stage and also during commissioning and operation of the installations) against systematic faults. The efficacy of the measures must be demonstrated in the proof of safety document.

Since EN 50126, EN 50128, EN 50129 and EN 50159 explain measures against systematic faults, this report intentionally does not enter into any further detail. At this stage it will suffice to point out that the measures identified in the standards serve primarily to:

- avoid systematic faults
- reveal systematic faults
- 'neutralise' systematic faults

Please note: In some aspects the measures identified resp. specified in the above standards are applicable to relay-based safety systems only to a limited extent (occasionally only in essence). As a result, the section 'theoretical foundations' and Appendix C intentionally leave out any references to these.

6.5 Measures against random failures / faults

In accordance with the content of the section 'functional safety', signalling systems must control random failures / faults. They must also guarantee that safety integrity for the separate system functions is not affected in a non-permissible manner.

To implement the specifications, a stepped procedure is usually applied with the following objectives:

a. reduction of the probability of cases of failures / faults taking place
b. eliminating failures / faults (fault exclusion)

c. proof of absence of danger regarding failures / faults (exclusion of the consequences of a failure / fault)
d. restriction of the consequences of failures / faults

6.5.1 Measures to reduce the probability of failures / faults

The characteristics of the structural parts/components used have an effect on the volume of measures required to achieve the safety objectives in each case. Information on the failure behaviour of the components used and their failure rates therefore often plays a central role in the proof of safety document.

Please note: If failure rates are not known, in practice approximate values are often used that come from appropriate lists or are derived (by experts) from failure rates for similar components.

In order to reduce the probability of malfunctions occurring on the basis of failures, a combination of the following approaches has proven successful:

- use components with the lowest possible failure rate
- over-dimension structural parts (resp. lower the amount of stress)
- apply components with known safety characteristics (e.g., a preferential failure mode)
- use components with 'non-volatile characteristics'
- system design (e.g., use of redundancies)

Please note: If components with asymmetrical failure rates are used, care must be taken that the more frequent failures (= preferred failure mode) do not lead to hazards.

6.5.2 Exclusion of failures and faults (fault exclusion)

According to [18] *'design and circuitry measures can ... reduce the probability of hazardous operating conditions being created as a result of faults'* but *'the probability that an incident will take place does not theoretically become zero'*.

Please note: It should be noted in this connection that probabilities for incidents occurring are mean values, with which, according to [18], only *'the mean spacing (in temporal terms or actuation-related) between two incidents can be determined. However, this mean value for the spacing between two operationally hazardous states..., which by far exceed the application time for implemented installations, does not provide information on the actual time of occurrence'*. In other words: a fault that is theoretically expected to occur only in several million years, may in practice take place as early as tomorrow. Events from the recent past are proof of this.

The probability theory provides further important input. According to [18], the condition applies that *'as the mean distance between two operationally hazardous states increases, the probability of such a state occurring declines over a (lengthy) period of use. Based on experience and estimations, it is (therefore) agreed that as of a pre-determined probability regarding the occurrence of an operationally hazardous state, this cannot be assumed'*.

This means that measures against 'faults not to be assumed' can be excluded. According to the 'state of science and technology' this is only possible if:

a. the defined properties of a component are known *and* if

b. it can be proven that the characteristics concerned are either *'theoretically non-volatile'* or considered *'practically non-volatile'*.

Please note: Characteristics are considered *'practically non-volatile'* according to [8] if the *'probability of occurrence of the failure... is extremely small'*. As a rule, this can be suspected when the hazard probability concerned is $Q_{gf} << 10^{-13}$ per train journey under threat.

According to [20] the following failure exclusions can be distinguished:

- failure exclusion based on non-volatile, natural characteristics (e.g., gravitational force),
- failure exclusion based on characteristics defined as non-volatile (e.g., magnetism in cases where impact force can be excluded),
- failure exclusion based on structural principles (e.g., forced guidance of relay contacts),
- failure exclusion based on common agreements regarding the cause of faults (e.g., exclusion of effects relating to observed marginal conditions regarding acceleration, temperature, air humidity, electromagnetic effects, etc.).

The following is an example of a failure exclusion based on 'non-volatile characteristics':

In the case of signalling relay type C according to [1] it is excluded by means of design measures that NC contacts (break contact) and NO contacts (contact makers) close simultaneously. This exclusion is based on the forced guidance that is considered 'non-volatile' for these contacts, combined with the characteristics of the contact element, the contact supports and sufficient distance between contacts.

Please note: EN 50129 and Mü 8004 contain failure lists relating to assumed resp. excludable failures. According to Mü 8004 [19] part 94001, in the case of signalling relays, e.g., 'failure to energise' as well as 'failure to de-energise' must be assumed in the proof of safety for the relay armature. The same applies to 'failure to close' for a contact. However, 'failure to open' of a contact can be excluded if *'NC and NO contacts cannot be closed at the same time'*.

6.5.3 Exclusion of the consequences of faults and failures

As it is not possible in theory or in practice to exclude all the faults / failures that can be assumed, measures against the consequences of faults / failures must be defined.

'Safety' from failures that occur or already exist is provided according to [8] *'when signalling systems implement a safety-oriented response in the event of a malfunction and then remain in a safe condition (fail-safe characteristic)'.*

Please note: 'Safety' can also be present if the probability of dangerous failure / fault consequences is sufficiently small (limitation of the consequences of a failure).

The aspects generally to be taken into account within the scope of the exclusion of the consequences of faults / failures are briefly outlined in the following. However, we intentionally dispense with an in-depth consideration of this subject as this would exceed the scope of this report.

Proof of absence of danger in individual failures

According to Mü 8004 [19] part 50000 rule 2 'Individual failures must not lead to dangerous malfunctions'. In addition, individual failures must not impair the safety integrity of safety-relevant functions.

Absence of danger in individual failures or faults can be achieved according to [8] using the following approaches:

a. Fail-safe: *'By means of suitable components (e.g., a signalling relay) and appropriate circuit structures, a failure immediately leads to a safe state'*.

   Example: Use of a relay type N according to [1] in connection with measures M201 and M203 according to appendix B.

b. Quasi fail-safe: *Following failure detection, control measures are used to achieve the safe state*.

   The following are two examples on the subject 'interruption of power supply' (see appendix A, Fault F403):

   - use bistable relays for vital interlocking (measure M208),
   - measure M271 reveals an 'interruption in the power supply of track circuits' in response to route release will be blocked.

Please note: It is essential that the 'safe state' reached cannot be departed from, even if further faults / failures occur.

Use of redundancies

In relay-based safety systems, redundancies are applied mainly as a safety measure in connection with the use of type C relays according to [1] (see for instance appendix B, measures M233 - M238).

Please note: Since, in the case of electronic components, a failure / failure consequence analysis is often not possible, or only to a very limited extent, normally system redundancies or diverse system architectures are applied here. However, a precondition for this is proof of 'signalling independence' of the components / systems concerned and the use of a 'safe' comparator resp. evaluation circuit.

Signalling independence

If safety functions are achieved by a combination of components, their 'signalling independence' must be proven if a simultaneous failure / fault could lead to a hazardous state.

If 'signalling independence' can be proven, 'multiple systematic failures' can be excluded. This is an important condition for proving the 'absence of danger in individual failures'.

Please note: The term 'signalling independence' is defined in different ways in the specialised literature.

- According to [19] 'signalling independence' is given when a failure or a disturbance in a unit under observation does not affect another unit under observation or does so only in a permissible way.
- According to EN 50129, 'signalling independence' is the absence of mechanisms that affect the proper functioning of more than one unit under observation.

In relay-based safety systems, ‘signalling independence’ is based on the use of signalling relays according to [1] combined with circuitry measures. It should be noted here that the proof of safety document normally excludes the fault ‘loss of insulation in internal wiring’. If a loss of insulation cannot be excluded, multiple systematic failures must be assumed.

Detection of random individual failures / faults

If an individual failure / fault cannot be converted into the safe state immediately, it must be detected (and then made ineffective). Non-detected failures / faults are by definition ‘potentially dangerous’.

Mü 8004 [19] part 50000 rule 3 therefore requires that all failures must be detected. This can be done either by providing the respective indications and/or by inhibiting the function of parts of the safety system.

Please note: The notion ‘failure detection time’ is interpreted in different ways in the specialised literature. Depending on the ‘state of the art’, the ‘failure detection time’ covers the time until the failure / fault is found (detected) as well as the time that lapses until a safety-oriented system response becomes effective.

As a rule, the time until a failure / fault is detected is to be dimensioned so short that the qualitative safety target is observed. The failure detection time therefore has a major effect on the respective level of safety (resp. safety integrity).

Detection of multiple random failures / faults

According to [18] the *‘simultaneous occurrence of a second fault (independent from the first fault)... must be assumed if the high failure rates for the components make this assumption requisite’. Mü 8004 [19] part 50000 rule 4 requires in this context that ‘the period of time from the occurrence until the elimination of the failure, which is detected according to rule 3, must be so short that in the course of this period there is no need to assume that a second individual failure will also take place’*.

Please note: Part 43310, Mü 8004 [19] identifies the requirements for failure detection time. *‘Depending on the sum a of the failure rates for the units observed, their combined malfunctioning can become dangerous if the failure detection time (t_a) of the units observed in question does not exceed the value t_a = 1 / 1000 * a ’*.

If the first failure / fault cannot be detected within the identified fault detection period (and if no pertinent inspections take place), the safety analysis must take into account an additional failure / fault. This must not lead to a dangerous malfunction according to Mü 8004 [19] part 50000 rule 7.

Please note: according to [18] *‘failure detection must take place at the latest when the next... application of the faulty unit under observation takes place’*.

In relay-based signalling systems, random double failures are generally excluded by means of (systems) actuation-related failure detection. If assumed double failures cannot be excluded by means of circuitry measures, measures must be applied to limit the consequences of faults.

6.5.4 Limiting the consequences of faults

If the effects of a random failure / fault cannot be prevented, its potential consequences must be limited (e.g., by functional inspections).

For instance, Mü 8004 [19] part 50000 rule 5 requires *'If an individual failure occurring in isolation is not detected according to Rule 3, then determining the failure may be done by means of regular inspections.'*

In relay-based signalling systems, the following methods are usually used:

- overlapping functional inspections (e.g., by using contacts of the relay to be tested in functionally independent circuits, which can if necessary actuate the 'safe state'),
- partial functional inspections (e.g., special test circuits resp. test relays),
- manual functional inspections (e.g., inspection to detect contact bridging and the condition of core insulation).

6.5.5 Other measures

As a rule, measures identified to avoid systematic and random faults are subject to defined preconditions that must be observed during the operation of the installation and are mandatory. Many proof of safety documents identify so-called 'safety-oriented application rules' (SAR). In this section we give some typical focus points, but we intentionally avoid going into this subject at greater length.

Environmental conditions

Environmental conditions have a major effect on the failure rate of the components used and also on the assumed hazards. This concerns among other things:

- climatic conditions (e.g., temperature, air humidity, corrosive atmosphere),
- environmental influences (e.g., impacts, vibrations, contamination),
- electrical influences (e.g., stray currents as a result of resistive, inductive or capacitive effects, harmonics, asymmetrical traction return currents).

Please note: Appendix B identifies basic measures on the subject of 'environmental conditions' (see measures M310, M401 up to M407, M444 and M446).

Maintenance

Measures within the scope of maintenance also have a major effect on the failure rate of the components used and also on the assumed hazards. This concerns among other things:

- proper performance of the inspection (see appendix B, M301 up to M313),
- the use of approved tools, test devices and inspection procedures (M421 through M425),
- the required qualifications (M426 and M427),
- the use, transport and storage of components (M441 and M442).

Please note: The proof of safety documents usually assume malfunctions based on random human errors (e.g., the mistaken pressing of a relay). However, intentional faults (meaning intentional interventions in the functioning and/or the safety integrity of a safety system) are usually excluded.

6.6 Tried and proven measures in relay-based safety systems

For decades, measures against systematic and also random failures and faults have been used in all life cycle phases of relay-based safety systems. However, this generally concerns experience-based measures. Some examples are given below:

- qualitative risk estimate by experts,
- rule-based method to prevent systematic faults (in all LC phases),
- application of components with known failure characteristics (failure rate and preferential failure mode),
- the use of procedures and methods to avoid hazardous conditions (e.g., the use of redundancies, deterministic switching sequences, failure detection and failure treatment),
- identified maintenance strategies,
- protective measures against environmental influences.

Since the measures given above are usually based on expert knowledge and/or national regulating systems, safety systems in the different countries often have differing requirements relating to their functional safety.

Please note: Frequently used measures are listed according to themes in appendix B. The effectiveness of the individual measures is shown in appendix C.

At this point we wish to point out that the requirements resp. measures identified in EN 50126 and EN 50129 for relay-based safety systems are only applicable to a limited extent (possibly only in essence, as also expressed within the scope of the respective standard). This makes it more difficult for proof of safety documents to determine the interfaces between old systems and systems approved in accordance with the respective CENELEC standards.

Please note: Mü 8004 [19] part 10510 resp. 10520 shows solutions in this context that have been tried and proven in practice.

6.6.1 Methodology for inspecting a relay circuit with regard to failure behaviour

To this day there is no known measure that can fully eliminate resp. significantly reduce the effects of all assumed faults (see appendix A) in the context of signalling relays. As a general rule, a combination of measures is therefore always advocated. The choice of measures lies with the user – many (but not all) roads lead to success in this context.

In order to prevent resp. detect systematic faults within the scope of the development of relay circuits at the earliest possible stage, Mü 8004 [19] part 51000 proposes the following methodology to ‘test a relay circuit with regard to its failure behaviour’.

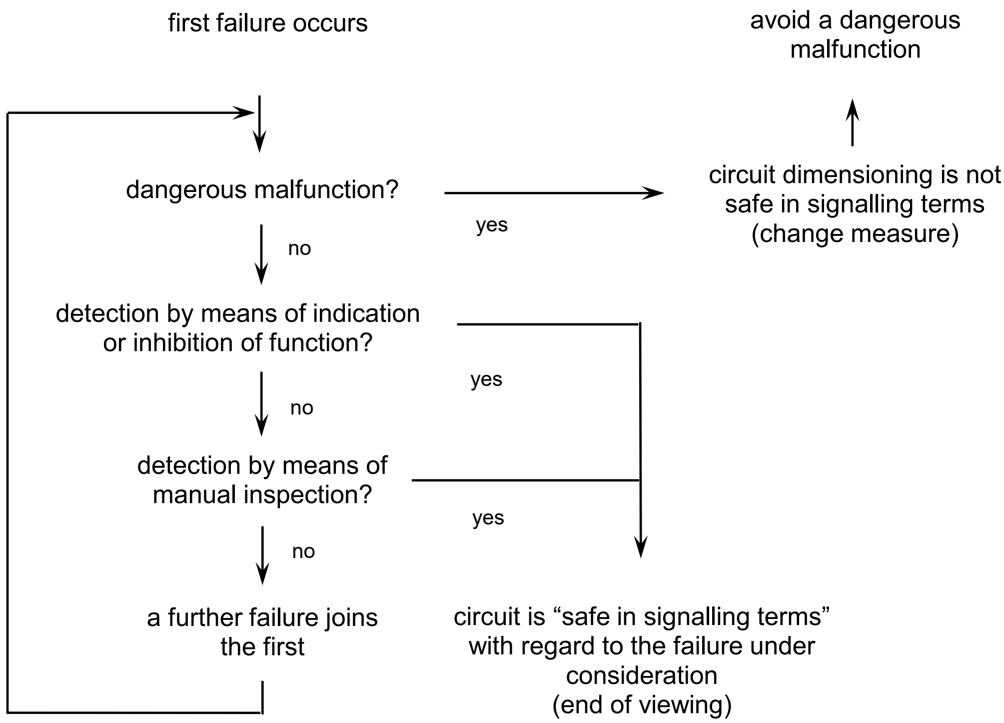


Figure 66: Inspection of relay circuit relative to failure behaviour according to [19], Part 51000

6.7 Quantitative analysis of relay circuits

The sections considered thus far have discussed the measures based on theoretical analyses and/or findings from reliability theory. The aim of this section is to take a more in-depth look at important measures based on qualitative analyses, using the method defined in [21].

6.7.1 Failure rates

Quantitative analyses are based theoretically on known failure rates. Since in practice, reliable failure rates are often not available, estimates by system experts are as a rule also accepted, provided this allows the objective of the analyses to be achieved.

Please note: If a proof of safety document is based on estimated failure rates, the plausibility of the data must be checked by independent experts.

In order to extend the data base, relay-related failure rates were collected and analysed within the scope of the project 'Use of Signalling Relays' in work package D.

As expected, the data concerned are based on studies relating to the reliability or the evaluation of field data over several years. The focus of the collected failure rates concerns relays type C according to [1]; for relays type N there are only sporadic items of information on failure rates available.

Since some of the data is sensitive in competitive terms, only the data that is publicly accessible will be published in this report (see appendix D). The following failure rates can serve as a basis for the following quantitative analyses.

Fault / incident	Symbol	Probability of fault / incident	
		Average fault rate	Unit
Relay system			
Armature does not drop when the relay is no longer excited (mechanical causes)	Q_{Rab}	0.2 * 10 Exp -8	per actuation
Armature does not stick when the relay is excited (mechanical causes)	Q_{Ran1}	1 * 10 Exp -8	per actuation
Interruption in coil winding	Q_{Ran2}	2.1 * 10 Exp -7	per 24 h
Short-circuit in coil winding	Q_{Ran3}	0.3 * 10 Exp -8	per 24 h
Relay contact			
Signalling relay - contact does not open	$Q_{Kö}$	0.2 * 10 Exp -10	per actuation
Signalling relay - contact does not close	Q_{KS}	0.2 * 10 Exp -8	per actuation
Wiring (jumper wire)			
Wire break	Q_{LU}	0.5 * 10 Exp -8	per 24 h
Intercore contact (short-circuit)	Q_{LK}	0.5 * 10 Exp -9	per 24 h
short to plus potential	Q_{LP}	0.5 * 10 Exp -9	per 24 h
short to minus potential	Q_{LM}	0.5 * 10 Exp -9	per 24 h

Figure 67: Failure rates (basis: Appendix D)

Please note: The failure rates referred to above were determined about 40 years ago within the scope of laboratory analyses of signalling relays type C according to [1]. However, current data from field observations demonstrate smaller failure rates in practice. A possible cause for this lies in a combination of technical optimisations relative to the relays concerned and optimised maintenance strategies. Based on the data situation, it is therefore justifiable within the scope of assessments to reduce the relay-specific failure rates given in figure 67 by factor 10 (i.e., the power of ten).

6.7.2 NO circuit versus NC circuit

The measures ‘release of safety-relevant functions by means of current flow’ (see M201 and M203), ‘locking of safety-relevant functions through absence of current’ (M202) and ‘NC circuits in safety-relevant monitoring functions’ (M204) have been tried and proven in practice. These are therefore also referred to as ‘elementary measures’.

The theoretical background to these measures will therefore be shown in a quantitative analysis based on data from figure 67 resp. Appendix D. To this end we apply the methodology used in [21].

Please note: For expenditure-related reasons the failure rates for fuses and soldering / clamp points are not taken into account in the analysis. However, this has no effect on the validity of the findings obtained.

NO circuit - Calculation of failure probability relating to functional failure (Q_W A)

In figure 68 relay A *'does not'* energise when the following conditions occur:

- one of the three lines interrupts (Q_{LU}) or
- the relay does not energise (owing to mechanical constraint (Q_{Ran1}), coil with interruption (Q_{Ran2}) or short-circuit (Q_{Ran3})) or
- interference voltage (minus) on L1 or L2 (Q_{LM}) or
- lines L3 and L1 or L2 touching (Q_{LK}) or
- contact K1 does not close (Q_{KS}).

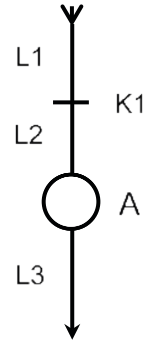


Figure 68: NO circuit

From a reliability point of view this corresponds to the following interpretation:

Q_W A (t) ≈ 3 * Q_{LU} (t) + Q_{Ran2} (t) + Q_{Ran3} (t) + 2 * Q_{LM} (t) + 2 * Q_{Lk} (t)

Q_W A (b) ≈ Q_{Ran1} (b) + Q_{KS} (b)

Using the values from figure 67, we obtain the following partial results for a timespan of 24h resp. 100 actuations: Q_W A (t) ≈ 2.3 Exp -7 and Q_W A (b) ≈ 1.2 Exp -6.

If we assume 100 actuations per 24h, we therefore obtain Q_W A (t) ≈ 1.4 Exp -6.

NO circuit - calculation of failure probability relating to untimely action (Q_U A)

In figure 68 relay A energises *'in an untimely manner'* when one of the following conditions occurs:

- lines L1 and L2 touching (Q_{LK}) or
- contact K1 does not open ($Q_{KÖ}$) or
- interference voltage (plus) on L2 (Q_{LP}) or
- the relay does not de-energise (owing to mechanical constraint on dropping, Q_{Rab}).

From a reliability point of view, this corresponds to the following interpretation:

Q_U A (t) ≈ Q_{Lk} (t) + Q_{LP} and Q_U A (b) ≈ $Q_{Kö}$ (b) + Q_{Rab} (b)

Using the values from figure 67, we obtain the following partial results for a timespan of 24h resp. 100 actuations: Q_U A (t) ≈ 1 Exp -9 and Q_U A (b) ≈ 2 Exp -7.

If we assume 100 actuations per 24h, we therefore obtain Q_U A (t) ≈ 2 Exp -7.

NC circuit - calculation of failure probability relating to functional failure (Q_W B)

In figure 69 relay B does not *'de-energise'* when one of the following conditions occurs:

- the relay does not de-energise (owing to mechanical constraint, Q_{Rab}) or
- interference voltage (plus) on L2 (Q_{LP}) or
- contact K1 does not open ($Q_{KÖ}$) or
- lines L1 and L2 touching (Q_{LK}).

From a reliability point of view this corresponds to the following interpretation:

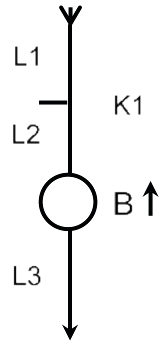


Figure 69: NC circuit

Q_W B (t) ≈ Q_{LP} (t) + Q_{LK} (t) und Q_W B (b) ≈ Q_{Rab} (b) + $Q_{KÖ}$ (b)

Using the values from figure 67, we obtain the following partial results for a timespan of 24h resp. 100 actuations: Q_W B (t) ≈ 1 Exp -9 and Q_W B (b) ≈ 2 Exp -7.

If we assume 100 actuations per 24h, we therefore obtain Q_W B (t) ≈ 2 Exp -7.

NC circuit - Calculation of failure probability relating to untimely action (Q_U B)

In figure 69 relay B drops when one of the following conditions occurs:

- one of the three lines interrupts (Q_{LU}) or
- contact K1 does not close (Q_{KS}) or
- the relay does not energise (owing to mechanical constraint (Q_{Ran1}), coil with interruption (Q_{Ran2}) or short-circuit (Q_{Ran3})) or
- lines L1 and L3 or L1 and L2 touching (Q_{LK}) or
- interference voltage (minus) on L1 or L2 (Q_{LM}).

From a reliability point of view, this corresponds to the following interpretation:

Q_U B (t) ≈ 3 * Q_{LU} (t) + Q_{Ran2} (t) + Q_{Ran3} (t) + 2 * Q_{LM} (t) + 2 * Q_{Lk} (t) and

Q_U B (b) ≈ Q_{Ran1} (b) + Q_{KS} (b)

Using the values from figure 67, we obtain the following partial results for a timespan of 24h resp. 100 actuations: Q_U B (t) ≈ 2.3 Exp -7 and Q_U B (b) ≈ 1.2 Exp -6.

If we assume 100 actuations per 24h, we therefore obtain Q_U B (t) ≈ 1.4 Exp -6.

Evaluation of Q_W and Q_U

The following findings can be derived from a comparison of Q_w and Q_U:

a. From Q_W A > Q_U A and Q_W B < Q_U B we derive that the failure probability rate is distributed asymmetrically. This should be taken into account in the circuit dimensioning.

b. From Q_W A > Q_U A we derive that for 'release of safety-relevant factors' the NO circuit is the preferred application. This corresponds to the theoretical basis for measures M201 and M203.

c. From Q_W B < Q_U B we derive that for 'locking of safety-relevant functions' the NC circuit is the preferred application. The greater probability relating to 'untimely locking' is accepted due to the primary safety target. This corresponds to the theoretical basis for measures M202 and M204.

d. From Q_U A < Q_U B we derive that when using the NC circuit, supplementary measures are required (mainly to achieve the safety level given by Q_U A). This corresponds to the theoretical basis for measures M205.

Please note: If no signalling relays according to [1] are used, the above statements are obsolete.

Estimation of the influence of relays type N

An important characteristic of relays type N according to [1] is that (for constructional reasons combined with the use of 'non-weldable' contacts), the probability of 'contacts that fail to open' ($Q_{Kö}$) and 'relays that fail to drop' (Q_{Rab}) is negligible. The proof of safety document therefore normally gives both these values as '0'.

Taking into account the formulas derived in the preceding sections and the values given in figure 67, we therefore obtain the following results for a timespan of 24h resp. 100 actuations:

NO circuit	type C relay	type N relay
Functional failure (Q_W A)	1.4 Exp -6	1.4 Exp -6
Untimely action (Q_U A)	2.0 Exp -7	1.0 Exp -9
NC circuit		
Functional failure (Q_W B)	2.0 Exp -7	1.0 Exp -9
Untimely action (Q_U B)	1.4 Exp -6	1.4 Exp -6

Figure 70: Effect of relays type C and N with regard to Q_W and Q_U

From the values in figure 70 we derive that the use of relays type N in NO circuits reduces the probability relating to 'untimely action' (Q_U A), whereas the probability relating to functional failure (Q_W A) remains virtually unchanged. In NC circuits, on the other hand, the probability relating to functional failure (Q_W B) is reduced, but there is no optimisation relating to 'untimely action' (Q_U B).

From this we derive that the use of relay type N primarily leads to an increase in switching safety.

6.7.3 Arrangement of contacts with differing valencies

If a circuit contains several contacts with different safety valencies, the 'high-valency contacts' (here meaning 'high safety requirements') will traditionally be installed immediately in front of the coil. We explain the theoretical background for this in figure 71.

In order to make statements regarding the effectiveness of contacts K1 and K2, it is necessary to examine their effect on the probability relating to 'untimely action' (Q_U C).

Please note: As this concerns a NO circuit, we dispense with quantitative analysis relating to Q_W C (the values for Q_W C (K1) and Q_W C (K2) are identical).

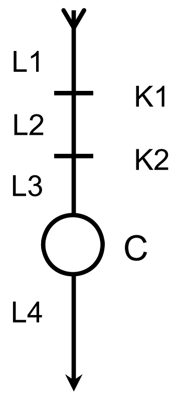


Figure 71:
Sequence of contacts

Influence of K1

Contact K1 is no longer effective with regard to 'untimely actuation' (Q_U C) of the circuit when one of the following conditions is met:

- relay C does not de-energise (owing to mechanical constraint on dropping, Q_{Rab}) or
- contact K1 does not open ($Q_{KÖ}$) or
- interference voltage (plus) on L2 or L3 (Q_{LP}) or
- lines L1 + L2 or L1 + L3 touching (Q_{LK}).

The probability of 'lack of functionality' of contact K1 is therefore
Q_U (K1) ≈ Q_{Rab} + $Q_{KÖ}$ + **2 Q_{LP}** + 2 * Q_{LK}

Influence of K2

Contact K2 is no longer effective with regard to 'untimely actuation' (Q_U C) of the circuit when one of the following conditions is met:

- relay C does not de-energise (owing to mechanical constraint on dropping, Q_{Rab}) or
- contact K2 does not open ($Q_{KÖ}$) or
- interference voltage (plus) on L3 (Q_{LP}) or
- lines L1 + L3 or L2 + L3 touching (Q_{LK}).

The probability of 'lack of functionality' of contact K2 is therefore
Q_U (K2) ≈ Q_{Rab} + $Q_{KÖ}$ + **Q_{LP}** + 2 * Q_{LK}

Evaluation Q_U

If we compare the values of Q_U C (K1) and Q_U C (K2) the result is that the probability for 'lack of functionality' of contact K2 relating to 'untimely actuation' of the circuit is smallest. High-quality contacts are therefore normally arranged immediately above the relay coil.

Please note: In our example, the differential caused by the effect of the plus short is minimal. However, in circuits with many contacts, the effect is no longer negligible.

6.7.4 Contact duplication in the same circuit

If the safety targets cannot be achieved using standard measures, the use of redundant contacts in the same circuit can be considered. We explain the theoretical background for this in figure 71 and figure 72.

CASE 1 - SYMMETRICAL CONTACT ARRANGEMENT

Calculation of failure probability relating to functional failure (Q_W D)

In figure 72 relay D does *not* 'energise' when one of the following conditions occurs:

- one of the four lines interrupts (Q_{LU}) or
- the relay does not energise (owing to mechanical constraint (Q_{Ran1}), coil with interruption (Q_{Ran2}) or short-circuit (Q_{Ran3}) or
- interference voltage (minus) on L1 or L2 (Q_{LM}) or
- lines L3 and L1 or L2 touching (Q_{LK}) or
- contact K1 or K2 does not close (Q_{KS}).

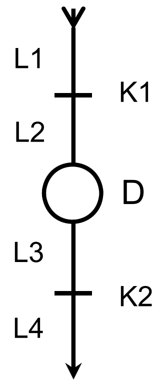


Figure 72: Redundant contacts

From a reliability point of view this corresponds to the following interpretation:

Q_W D (X) ≈ 4 * Q_{LU} (t) + Q_{Ran1} (b) + Q_{Ran2} (t) + Q_{Ran3} (t) + 2 * Q_{KS} (b) + 2 * Q_{LM} (t) + 4 * Q_{Lk} (t)

Using the values from figure 67 for a timespan of 24h resp. 100 actuations per 24h, we obtain Q_W D (t) ≈ 1.6 Exp -6.

Calculation of failure probability relating to untimely action (Q_U D)

When calculating Q_U D, care must be taken to ensure that K1 and K2 represent a parallel system from a reliability point of view. The contribution of contacts K1 and K2 to Q_U D must therefore be calculated separately and subsequently multiplied. This corresponds to the following interpretation:

Q_U D (X)= Q_{Rab} + (Q_U D (X_{K1}) * Q_U D (X_{K2})) ≈ Q_{Rab} + (Q_{LK} (X) + $Q_{LP/M}$ (X) + $Q_{KÖ}$(X)$)^2$

Using the values from figure 67 for a timespan of 24h resp. 100 actuations per 24h, we obtain Q_U D (t) ≈ 2 Exp -7 + (9 Exp -18) ≈ 2 Exp -7.

CASE 2 - ASYMMETRICAL CONTACT ARRANGEMENT

Calculation of failure probability relating to functional failure (Q_W)

For the circuit shown in figure 71, this produces Q_W (C) for

Q_W (C) ≈ 4 * Q_{LU} (x) + Q_{Ran1} (x) + Q_{Ran2} (x) + Q_{Ran3} (x) + 2 * Q_{KS} (x) + 3 * $Q_{LP/M}$ (x) + 3 * Q_{Lk} (x)

Using the values from figure 67 for a timespan of 24h resp. 100 actuations per 24h, we obtain Q_W C (t) ≈ 1.6 Exp -6.

Calculation of failure probability relating to untimely action (Q_U)

Factoring in the "And" connection between contacts K1 and K2, for the circuit shown in figure 71 this produces Q_U (C) for

Q_U (C) ≈ Q_{Rab} + Q_{LP} + Q_{LK} + (($Q_{KÖ1}$) * ($Q_{KÖ2}$)) ≈ Q_{Rab} + Q_{LP} + Q_{LK} + $Q_{KÖ}{}^2$

Using the values from figure 67 for a timespan of 24h resp. 100 actuations per 24h, we obtain Q_U C (t) ≈ 2 Exp -7 + (4 Exp -18) ≈ 2 Exp -7.

Evaluation of Q_W and Q_U

The following findings can be derived from a comparison of Q_w and Q_U :

a. From Q_W A < Q_W C and Q_W A < Q_W D we can derive that contact duplication in the same circuit is not an effective measure with regard to functional failure.

b. From Q_U A = Q_U C = Q_U D it can be derived that redundant contacts in the same circuit are not an effective measure with regard to untimely actuation.

   Please note: Q_U is primarily influenced by the probability of the relay's failure to de-energise (Q_{Rab}). Where the value of Q_{Rab} is very low, it is possible for Q_U A > Q_U C or Q_U D. In this case, redundant contacts in the same circuit would be an effective measure against untimely actuation, albeit at the cost of reduced availability.

c. From Q_W C = Q_W D it can be derived that the arrangement of redundant contacts in the same circuit is not an effective measure with regard to functional failure.

d. From the contribution of Q_{LP} + Q_{LK} + $Q_{KÖ}$ to Q_U C resp. Q_U D it can be derived that an asymmetrical arrangement of redundant contacts in the same circuit is not effective.

Please note: If no signalling relays according to [1] are used, the above statements are obsolete.

Estimation of the influence of relays type N in the case of contact duplication

As mentioned previously, the probability of relay type N according to [1] regarding 'contacts fail to open' ($Q_{Kö}$) and 'relay fails to drop' (Q_{Rab}) is negligible. The proof of safety document therefore normally gives both these values as '0'.

Taking into account the formulas derived in the preceding section and the values given in figure 67, we therefore obtain the following results for a timespan of 24h resp. 100 actuations for a NO circuit:

Symmetrical arrangement of contacts (Fig. 72)	Type C relay	Type N relay
Functional failure (Q_W D)	1.6 Exp -6	1.6 Exp -6
Untimely action (Q_U D)	2.0 Exp -7	1.0 Exp -18
Asymmetrical arrangement of contacts (Fig. 71)		
Functional failure (Q_W C)	1.6 Exp -6	1.6 Exp -6
Untimely action (Q_U C)	2.0 Exp -7	1.0 Exp -9

Figure 73: Influence of relay type relating to Q_W and Q_U with contact duplication

From the values in figure 73 we derive that in the case of contact duplication, the use of relays type N in active circuits reduces the probability relating to 'untimely action' (Q_U C) resp. (Q_U D), whereas the probability relating to functional failure (Q_W C) resp. (Q_W D) remains virtually unchanged. From this we derive that the use of relay type N primarily leads to an increase in switching safety.

6.7.5 Duplication of contacts in different circuits

If the safety targets relating to untimely action (Q_U) cannot be achieved with standard measures, the entire circuit must be designed to be redundant. The following section therefore explains the theoretical background by means of the following circuit.

Please note: For reasons of cost and complexity, a numerical calculation is dispensed with.

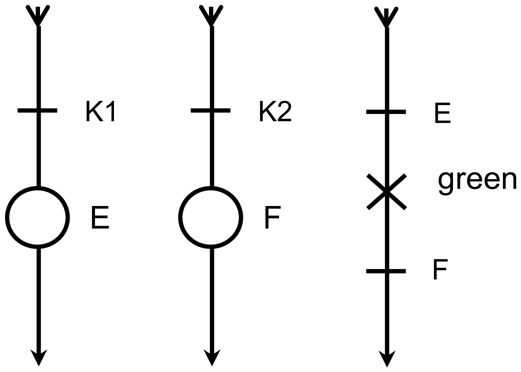


Figure 74: Duplication of contacts in different circuits as per [21]

Estimation of failure probability relating to functional failure (Q_W green)

As the green lamp only lights up when the contacts in both relays (here E and F) are closed, the values for Q_W (E) and Q_W (F) must be added up. This corresponds to a duplication of the probability relating to functional failure, i.e., availability deteriorates significantly.

Estimation of failure probability relating to untimely action (Q_U green)

When calculating Q_U (green), care must be taken to ensure that relays E and F represent a parallel system from a reliability point of view. The contributions of contacts E and F to Q_U (green) must therefore be multiplied. This leads to a significant reduction of Q_U (green), which is however achieved with an associated deterioration of availability.

6.7.6 Change of polarity of circuits

As a result of the excessive circuitry requirement, a change of polarity of circuits (i.e., a change in the direction of the current) is only rarely used. For resourcing reasons, a numerical calculation is therefore dispensed within the scope of this report.

In [21] a quantitative analysis shows that the value for Q_U hardly changes as a result of a change of polarity. The causes for this are primarily the additional requirement of conductors and the random similarity in failure rates relating to stray voltage effects (Q_{LM}) and intercore contact (Q_{Lk}).

The consequence of this is that the measure ‘change of polarity’ serves primarily to put into evidence stray voltages (in this case by means of the ‘triggering of fuses’).

Please note: If the failure rate relating to stray voltage effects (Q_{LM}) is greater than the failure rate relating to intercore contact (Q_{Lk}), reliability can theoretically be increased.

6.7.7 Use of interlocked relays

As a result of their structural design, the following circuitry measures must be observed when interlocked relays are used:

- When using a interlocked relay, care must be taken in the circuit to ensure that the right contacts are used both for 'locking a function' and 'releasing a function' (M210).
- In the case of interlocked relays, the actual locking action must be tested (M211).

The following section explains the theoretical background for both measures by means of a circuit with a symmetrical interlocked relay. The aim is to demonstrate a high level of safety relative to locking failure (expressed here as Q_U (Z)) when the measures M210 and M211 are applied.

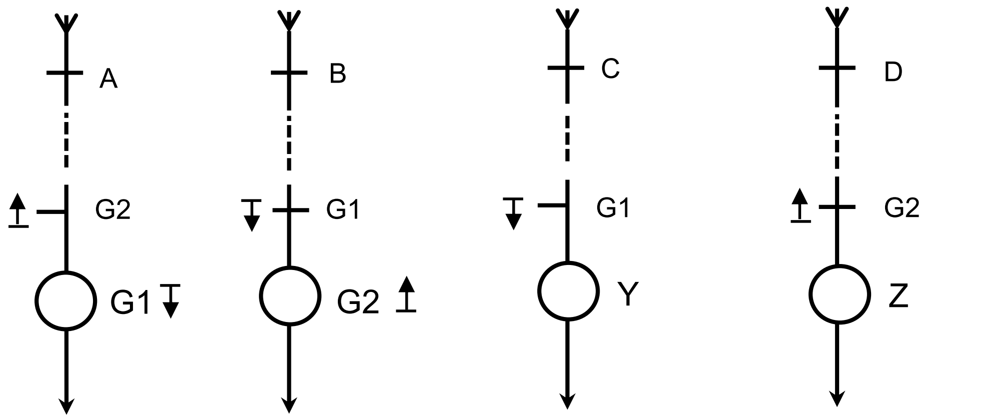


Figure 75: Use of interlocked relays as per [21]

In figure 75 relay Y is to be locked using contact G1. However, as the locking action is only attained when sub-system G1 of the interlocked relay energises, Q_U (Y) at this time still corresponds to the values of comparable circuits with 'relays with no-current default position', the use of an interlocked relay would thus make no sense (yet).

Reliability can be increased significantly if the initiation of the locking action is monitored. As in the case of interlocked relays, the design cannot exclude the situation in which both sub-systems stick or remain energised, it is tested in the Z circuit whether sub-system G2 of the interlocked relay has dropped (monitoring of locking effect).

The failure of the locking effect in the actuator to take place in the given circumstances is only possible if sub-system G1 does not energise and at the same time contact G2 is bridged in circuit Z. This results in Q_U (Z) ≈ Q_W (G1) * [Q_{LP} (X) + 2 * Q_{Lk} (X)]. As Q_W (G1) corresponds in principle to Q_W A (t), taking into account the values from figure 67 for a timespan of 24h resp. 100 actuations per 24h, we obtain for Q_U (Z) ≈ 2.1 Exp -15.

It should be noted that after the actuation of the actuator (i.e., relay Z energises) sub-system G2 can cancel out the locking effect again by 'untimely' energising. The probability of this happening is in principle Q_W for 'relays with no-current basic position' (see figure 68, Q_W A (t) ≈ 1. 4 Exp -6).

Evaluation

By using the monitoring contact of an interlocked relay in the actuator, the probability of a functional locking failure (expressed here as Q_U (Z)) can be reduced relative to functionally comparable circuits on the basis of the NO circuit and the NC circuit (by several powers of ten), which is what was to be proven.

In the 2nd setting phase, Q_U (Z) corresponds to functionally comparable circuits based on the NC circuit. However, Q_U (Z) is smaller than functionally comparable circuits based on the NO circuit.

We wish to add here that in a direct comparison to functionally comparable circuits based on the NO circuit and the NC circuit, the probability regarding the initiation of ‘untimely locking’ (expressed here as Q_W (Z)) increases.

7. TESTING RELAY CIRCUITS

This section provides information on the testing of relay circuits. However, we purposely dispense with an extensive consideration of this subject as this would exceed the scope of this report. Our further statements therefore focus on the inspection of new or changed relay circuits prior to commissioning.

Please note: In Section 6.6 we already explained some proven measures in the design phase.

7.1 Planning inspections

The depth and focus points of an inspection are usually oriented according to:

- the design and functional properties of the safety system
- the functionality of the relay circuit to be implemented
- the complexity of the measure to be applied
- the given safety requirements
- the availability requirements and operational aspects

In the planning stage, the project status must be taken into account in each case. This requires close agreements between the units involved. In addition, attention must be given to any provisional systems present (e.g., temporary circuits).

If a safety system can be operated both locally (e.g., via a push-button panel) and centrally (e.g., from an operating centre), it must be ascertained which operating system is to be used for the inspection.

Please note: Central display and operating options do not necessarily correspond to those of local panels. In the case of centralised operation, it must also be taken into account that temporal behaviour will differ.

If several inspectors are used (e.g., in large projects), responsibilities must be identified in addition to the respective areas of authority. It is further essential to coordinate individual (sometimes parallel) inspections.

Please note: In the event that inspectors with different language qualifications are used, binding language regulations are to be agreed to avoid misunderstandings.

7.2 Requirements to be met by the persons involved

The persons involved in inspections must have the required specialised know-how for the purpose (see appendix B, measure M426). This concerns among other things:

- The structure, function and documentation for the relay circuit to be implemented as well as the safety system concerned,
- sufficient expertise relating to the circuit principles to be applied and
- the testing methodology to be applied, the tests themselves and the correct utilisation of the tools used, as well as
- the documentation of the inspection results.

As a rule, it must also be assured that the persons performing the tests were not involved in the development of the relay circuit (‘four-eyes’ principle). This also includes the requirements regarding an inspector’s experience.

Please note: the 'four-eyes' principle is also to be applied to any changes made during testing.

7.3 Requirements relating to documentation

The plans used for inspection must represent the current (or planned) state of the installation.

If commissioning takes place in several phases, care must be taken to ensure that the circuit measures planned in separate phases are not confused.

If redundant plans are used (e.g., assembly charts), it must be ensured that each plan contains identical data.

The results of the tests must be documented. As a rule, special forms are utilised for this purpose, reducing expenditure.

It is essential to ensure the uniform use of specialised terms, abbreviations, symbols, colours etc..

Please note: As a rule, the documentation will reveal who tested what and when.

7.4 Focus points for inspection

The following compilation shows a selection of focus points for inspection that are often used in connection with relay circuits. This list is not exhaustive.

7.4.1 Functional inspections

- Tests to establish the correspondence of the element status in the internal and external installations
- Element-specific functional tests (incl. auxiliary actions)
- Testing of signal dependency (incl. fault response to assumed cases of failure)
- Testing of signal logic (incl. sequences and assumed cases of failure)
- Inspecting route exclusion and other exclusions
- Inspecting the block or interlocking dependencies
- Inspecting the level crossing safety installations (e.g., autonomous installations)
- Inspecting the system response of the interlocking installation to an interruption in the power supply of track circuits

Please note: In geographical circuit interlocking systems, the group-internal wiring is often considered 'non-volatile' in the proof of safety document and is therefore generally not inspected in situ. However, this does not apply to the program plugs for relay groups (if present).

7.4.2 Other inspections

- Inspection of core resp. cable insulation in the external installation
- Inspection of the insulation monitoring system (if present, M406)
- Visual inspection relating to the effectiveness of relay contacts (M301, focus: soldering bridges, wire remnants, correct contact connection, etc.)
- Visual inspection of the state of core insulation (M301, focus: brittle wires, damaged insulation, core fixation, distances to 'hot components', etc.)
- Inspection to find 'cold soldered spots' (so-called 'plucking test')

- Power supply: inspection of minimum supply voltage (e.g., with large spatial distances between power supply rooms and the relay rooms and/or in geographical circuit interlocking systems in the presence of long cables)
- Power supply: testing of the monitoring equipment (M271)
- Testing of the relay types or relay groups used
- Testing of the type of fuse used (M253 and M254)
- Testing of correct implementation of repeater relay in free circuit
- Testing of correct relay assembly (M309, particularly in provisional cases)

7.5 Use of tools

Within the scope of inspection, only approved tools may be used (M421). In addition, it must be ensured that properties that determine the safety of relays are not jeopardised (e.g., forced guidance of relay contacts), for instance by non-permissible mechanical strain.

When using insulation thimbles or contact strips, care must be taken that silicone-free tools are used (M310). It is essential to remove the tools used for inspection on completion of the tests. In terms of the above, it is therefore useful to mark the tools as clearly as possible (M422).

If, within the scope of the inspection, tools are used to simulate elements of the external installation and/or internal installation (e.g., ‘operation substitution plug’ it must be ensured that these are all fully removed from the installation when the inspection is over.

Please note: As a rule, tools for simulating the external installation are only provided in return for a receipt (i.e., signature).

If within the scope of an inspection, measuring instruments or special test devices are used, it must be ensured that these (where necessary) are verified or calibrated (M423).

If parts of the safety system concerned are already in operation (i.e., in safe mode), care must be taken that the inspection is performed with minimum repercussions (if possible). It is essential in this context that the procedures identified for this (M425) are observed together with the use of suitable tools (M424).

8. MAINTENANCE MEASURES

In addition to the 'essential measures' already described in section 3.5, further measures that have a major effect on the availability of the safety system must be observed within the scope of maintenance activities.

8.1 Observing environmental conditions

The environmental conditions recommended by the manufacturer or required by 'safety-oriented application rules' (SAR) must be observed when operating the signalling system.

8.1.1 Permitted temperature range

Relays must only be used in the temperature range identified by the manufacturer (M443).

If the temperature is below the permitted range, there is a danger that the lubrication of moving relay components will fail. A possible consequence is sluggish relays. In the worst case scenario, a de-energising resp. energising failure can result, which may represent a potential hazard for NC circuits.

If the permitted temperature range is exceeded, this can lead to premature ageing of relay components (e.g., the insulation of the relay coil) and also of the core insulation. In addition, the probability that fuses trigger in an 'untimely fashion' increases.

If the permitted temperature range is exceeded by far, it can no longer be excluded that relay components made from synthetic material (e.g., the forced guidance of relay contacts) will become deformed under the pressure of the contact springs. In the worst-case scenario, the forced guidance of the contacts (potential hazard, loss of dependencies) will fail.

8.1.2 Dust formation

Based on statistics (and also the experience of experts), it can be assumed that around 50% of all disruptions in relay interlocking systems are caused by dust particles. This concerns particularly interlocking constructions in which relays are used that are designed to achieve 'safe opening'.

Please note: If relays are retro-fitted with 'double contacts', account should be taken of the fact that the contact pressure sinks. This leads, among other things, to changed contact bounce times and, in addition, in some cases, to a deterioration in the automatic cleaning of the contacts.

One of the most important measures to take is therefore to avoid dust development and to use encased relays resp. relay groups (M446).

If chemical additives are used for cleaning of the equipment room (e.g., floor wax), care must be taken that cleaning agents containing silicone are avoided (M310, for further details see section 3.5.15).

8.1.3 Air humidity

If, for instance, an air-conditioning system is used to prevent dust development, take into account that the air humidity (over lengthy periods) will have an effect on the reliability of the safety system.

If the air humidity is too low, there is a danger of the core insulation ageing prematurely and, in addition, there may be increased dust development. According to [32], the following factors are responsible for this:

- *'In dry air, more dust is generated;*
- *damp dust particles clump together and therefore remain suspended for a shorter period of time;*
- *because of their larger grain size, on average, and the lubricating effect of the moisture, damp particles can be rubbed off the contact more easily'*.

If the air humidity is too high (according to [32] this is more than 75%), there is a danger of current leaks and / or short-circuits being caused by condensation (chance of pot. hazard). [32] therefore recommends maintaining air humidity at 60%.

8.1.4 Vibrations

In the event of excessive vibrations, there is a danger of 'untimely opening' of contacts (worst case: potential hazard). Civil construction related measures must therefore be optimised in this context.

Please note: Cases are known in which up to 800 contact disruptions in 24h were detected from adjacent construction sites.

8.2 Specific maintenance for relays

The measures recommended by the manufacturer or required by 'safety-oriented application rules' (SAR) must be observed when operating the signalling system.

8.2.1 Cleaning contacts

Contacts resp. contact elements may be cleaned if this has not been expressly prohibited by the manufacturer (M305). To do so, the methods, means and tools recommended by the manufacturer must be used (M304). Debris (shavings, particles) must be removed.

When cleaning contacts, care must be taken to prevent mechanical damage to the relay components (e.g., the forced guidance of relay contacts).

Please note: The use of contact spray is normally not permitted due to the danger of conducting debris resp. premature ageing of the insulation.

8.2.2 Use of lubricants

Only approved lubricants may be used (oils, greases, etc.), (M306). Lubricants may only be used in accordance with the specifications (M307).

Please note: In the case of some types of relays, when deciding 'whether or not to lubricate', the material used for the component concerned must also be taken into account. With interlocked relays type L72 by SEL (now Thales), for instance, latching mechanism made of steel must be oiled, while in the case of latching mechanism made from sintered bronze, lubrication is not permitted.

8.2.3 Testing relay properties

As a rule, relays are given visual checks within the scope of cyclical maintenance (M301). The focus in this connection lies on the condition of the relay contacts, the contact elements and the insulation (wires, coils, debris, etc.).

Please note: Mechanical properties (e.g., contact spacing, armature clearance, contact alignment, etc.) are normally inspected within the scope of relay refurbishing (M303).

If the manufacturer specifies cyclical testing of electrical properties (M302), the pertinent approved and calibrated test equipment must be used (M425). The test procedures identified for this purpose must be observed (M425).

Please note: As this often concerns safety-relevant inspections, these inspectors are required to meet special requirements in terms of their qualifications (M426). Licenses are as a rule required as proof of the necessary qualifications.

8.3 Refurbishment (overhaul) of relays

A proven measure is to extend relay utilisation time by refurbishment (overhaul). As a rule, the work in this connection is performed in a workshop equipped for this purpose.

Please note: As this concerns safety-relevant work resp. inspections in this case, the persons involved are required to meet special requirements in terms of their qualifications (M426). Licenses are as a rule required as proof of the necessary qualifications.

If approved replacement parts, working methods and inspections are used within the scope of refurbishment, it can be assumed that a refurbished (overhauled) relay meets the same safety requirements as a new relay.

8.4 Use of diagnostic tools

If for fault analysis resp. within the scope of maintenance, diagnostic tools are used, care must be taken that their use does not have repercussions on the functionality or safety integrity of the interlocking installations.

Please note: As a rule, express proof of 'freedom from repercussions' is required.

In order to avoid disruptions when using diagnostic tools, account must also be taken of the fact that some circuits are operated earth-free (M405) and the earth-free state may have to be monitored (M406). As a rule, tools with potential separation are therefore used (M424).

8.5 Exchanging relays

In connection with the exchange of relays resp. relay groups, care must be taken to ensure that the correct relays resp. relay groups are re-assembled. An important precondition here is that the data on the type label are correct (and legible).

Any later changes to the non-error identification (insofar as this exists) must be avoided wherever possible.

When replacing the relays resp. relay groups, they must be checked for robust seating; lock into place where necessary (M309 and M441).

For bistable relays (e.g. interlocked relays), it is to be ensured that the replacement relays are in the correct position when mounted.

8.6 Testing interlocking functionality

In many types of interlocking, not all the assumed faults can be detected within the scope of normal testing of functionality. As a result, within the scope of cyclical maintenance, there is also often a safety-relevant set of tests of interlocking functionality (M427).

A typical example for this is the testing of emergency actions, e.g., the function ‘set signal to stop’ (signal stop button).

Please note: The function set ‘signal to stop’ is no longer available if the pertinent fuse has been triggered. As the triggering of a fuse is usually not detected, fault detection often takes place within the scope of cyclical maintenance.

As an alternative, it is possible to feed the relevant ‘set signal to stop’ buttons via the same fuse as that feeding the signal switching relays.

9. USE OF OTHER COMPONENTS

Electrical components often utilised in connection with the use of signalling relays can affect the functionality of the relay circuit. This section therefore contains relevant information.

9.1 Use of diodes

If diodes are used in relay circuits, their failure behaviour must be taken into account in the proof of safety document for the relay circuit. As a rule, this relates to interruptions and short-circuits of the diode, sometimes also to changes in the working characteristic.

As a rule, diodes are used in the following applications:

- to rectify AC to DC voltage,
- to protect against return feeds in redundant DC power supply modules,
- for (limited) drop delaying,
- to protect the contacts against voltage peaks (as a result of automatic induction when switching off the coil) and/or
- to ensure pre-magnetisation of directional relays in circuits with rapid polarity changes.

If arc suppressor diodes are connected parallel to the relay coil, the following points are to be borne in mind:

- The diode must be connected anti-parallel to the direction of current in the coil.
- Since it is often not possible to detect an interruption of the diode, it cannot be assumed that the protecting effect of the contacts is always present.
- As a result of the armature dropping more slowly, the automatic cleaning effect is reduced. This is particularly important in the case of relays with a contact pressure < 0.2 N (resp. < 20 g).
- In circuits that run via earth cables, arc suppressor diodes can produce malfunctions due to equidirectional interference voltages (M257). This is particularly relevant in connection with M204 (NC circuits in safety-critical monitoring functions).

Diodes must not be used in safety-critical relay circuits as a replacement for relay contacts (M273).

Please note: If the use of diodes as a replacement for relay contacts cannot be avoided resp. if diodes are already present in existing relay circuits, the probability of functional failure can be reduced by switching two identical diodes in series. An alternative is the use of over-dimensioned diodes.

9.2 Use of resistors

Resistors are used in many relay circuits. Care must be taken to use the proper design (resp. type) in addition to the required resistance value.

Please note: In the proof of safety document, proof of freedom from repercussions is often also based on the use of resistors with a defined failure behaviour (so-called ‘safety designs’, e.g., carbon layer resistors). If in this case ordinary resistors are used by mistake, the relay circuit may function, but safety integrity for the relay circuit is no longer assured.

Since high temperatures accelerate the ageing of the core insulation, care must be taken to ensure that the resistor for the application concerned is correctly dimensioned.

If an intensive warming of resistors cannot be avoided, care must be taken to ensure that the core arrangement is optimised in this respect.

9.3 Use of capacitors

Capacitors are preferentially used for energising / de-energising deceleration. They therefore have a major effect on the availability of the safety system.

When using capacitors, it should be noted that their capacitance lessens over time (at different rates depending on the type). Within the scope of overhaul activities, capacitors are usually exchanged as a precaution.

Please note: For capacitor formatting, reserve relays resp. relay groups are often used cyclically.

9.4 Wiring

Circuits are to be dimensioned such that they comply with the required values and functions. Only authorised core cross-sections are to be used in circuit designs.

If several wires are connected to clamps, it must be ensured that the wires all have the same core cross-section. The rules governing the maximum number of wires connected to a single clamp are to be observed.

It is to be ensured that the distances required for cable/wire routings are as short as possible and that cable/wire loops are avoided.

Since proof of safety documents generally assume the absence of short circuits from the wiring of the internal systems of signal boxes (i.e. the wiring insulation is assumed to be a ‘non-volatile characteristic’ of the system), the cabling condition is to be checked cyclically (M301).

Please note: the ambient conditions, colouring agent and insulation material all have a major impact on when the cable insulation turns brittle and/or when parts thereof begin to “peel off” (e.g. to the touch). In addition, please note that on PVC-based cable insulation the plasticisers used in the insulation may start to leak (sticky, conductive residues following the cable, possibly dripping).

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APPENDIX A ‘ASSUMED FAILURES / INCIDENTS AND RESULTING HAZARDS’

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
Contact faults (failure 100-199)						
F100	**make contacts (NO contact)**					
F101	make contact does not open when the relay is no longer energised	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	x	x	
F102	make contact does not open when the relay is no longer energised (e.g. due to welded contacts)	contacts do not follow the de-energised position (down-proving)		x	x	
F103	make contact does not open when the relay is no longer energised (e.g., in the case of a failure of the protective measures against welding of contacts).	contacts do not follow de-energised position (down-proving)	wrong side failure, loss of dependencies	x	see a) + b)	a) only when relay is used as type N relay b) no measures for ‘non-safe’ applications
F104	make contact is consistently closed (permanently)	make contact consistently closed (permanently)	wrong side failure, loss of dependencies	x	x	
F105	make contact does not open due to adhesion / hooked contacts (material migration)	make contact consistently closed (permanently)	wrong side failure (see note)	x	x	see F101, F102 and F103, especially in “NO circuits”
F106	make contact does not open due to adhesion / hooked contacts (material migration)	possible overlapping of contacts (both make and break established contacts)	wrong side failure	x	x	
F107	make contact does not close when the relay is energised	malfunction in case a normally open circuit is used	none (see note)			condition: use of NO circuits and realised measures against F201 and F212
F120	**break contacts (NC contacts)**					
F121	break contact does not open when the relay is energised	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	x	x	
F122	break contact does not close when the relay is no longer energised	malfunction in case a normally open circuit is applied	none (see note)			condition: measures applied against F201 and F212
F123	break contact is consistently closed (permanently)	break contact consistently closed (permanently)	wrong side failure, loss of dependencies	x	x	

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F124	break contact does not open when the relay is energised (e.g. welded contacts)	contacts do not follow the energising condition of the relay	wrong side failure, loss of dependencies	x	x	
F125	break contact does not open due to adhesion / hooked contacts (material migration)	break contact consistently closed (permanently)	wrong side failure, loss of dependencies	x	x	
F126	break contact does not open due to adhesion / hooked contacts (material migration)	possible overlapping of contacts (both make and break established contacts)	wrong side failure, loss of dependencies	x	x	
F140	**wear to contacts / contact system**					
F141	wear to contacts or contact members	malfunctions as a result of changed mechanical / electrical properties during the operating period	none (malfunction)			see [1] section 3.6.3
F142	wear to contacts or contact members unsuitable material	malfunctions as a result of changed mechanical / electrical properties during the operating period	none (malfunction)			use of suitable contact materials and designs / types of contact tips
F143	wear to contacts or contact members	malfunctions due to insufficient self- cleaning	none (malfunction)			
F144	wear to contacts or armature	malfunctions as a result of changed mechanical / electrical properties during the operating period	none (malfunction)			
F150	**contact pressure**					
F151	low contact pressure of break contacts	malfunctions due to break contacts do not close properly	none (malfunction), see note			According to [1] the return spring may not be used for safety reasons
F152	low contact pressure of break contacts	malfunctions due to contact bounce	none (malfunction), see note			
F153	loss of contact pressure during the operating period	malfunctions due to contact bounce	none (malfunction)			
F154	loss of contact pressure during the operating period	malfunctions due to contacts opening as a result of vibrations / impacts	none (malfunction), see note			[1] identifies limiting values regarding impacts
F155	low contact pressure of make contacts	malfunctions	none, see note			condition: measures applied against F201 and F212
F156	low contact pressure of make contacts	malfunctions due to contacts do not closed within bounce time	none, see note			

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F160	**hot contacts / contact elements**					
F161	hot contact / contact elements	wear or fracture in forced guidance	possible wrong side failure, (triggers F101, F121, F201 and F212)	x	x	measures against F162 based on the measures against F161
F162	hot contact / contact elements due to incorrect circuit dimensioning	wear or fracture in forced guidance	possible wrong side failure, (triggers F101, F121, F201 and F212)	x	x	
F170	**broken / loose contacts**					
F171	broken or loose contact due to wear	make and break contacts can be closed at the same time	possible wrong side failure (with consideration of the measures against F212)	x	x	[1], section 3.6.4 defines requirements for minimum lifespan
F172	broken or loose contact member due to wear	make and break contacts can be closed at the same time	possible wrong side failure (with consideration of the measures against F212)	x	x	[1], section 3.6.4 defines requirements for minimum lifespan
F180	**electric arc**					
F181	electric arc between contacts	non-permissible heat transmission to synthetic components (e.g., for insulation or forced guidance)	possible wrong side failure	x	x	observe maximum permitted contact stresses; use no-load switching if possible
F190	**choice of contact**					
F191	using false contacts of interlocked relay in circuits	possible faults (e.g., de-energised / energised failure) are not detected	wrong side failure, loss of dependencies	x	x	see also with regard to consequences failure group 250
Faults in the relay system (failure 200-299)						
F200	**forcibly guided contacts**					
F201	contact member does not follow armature position	other contacts of the same type (make or break) are not in the same position	wrong side failure, loss of dependencies	x	x	exception: pre-leading & last break contacts (bent contacts)
F210	**wear to contacts / armature**					
F211	wear to armarture and contacts / contact elements	changed mechanical / electrical properties during the operating period	possible wrong side failure	x	x	
F212	wear or breakage of forced guidance of contacts	loss of forced guidance of contacts	wrong side failure, loss of dependencies	x	x	
F213	changed distance between contacts due to wear	loss of electrical insulation	possible wrong side failure	x	x	

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F214	bent contact member do not follow the armature position (applies only to these contacts)	see F201 and F212	none (see note)			condition: measures applied against F201 and F212
F215	fracture of forced guidance system or other contact guidance components	possible dissociation of the contact springs/blades	possible wrong side failure (with consideration to the measures against F201 and F212)	x	x	
F216	deformation of synthetic components (e.g. contact guide)	possible dissociation of the contact springs/blades	possible wrong side failure (with consideration to the measures against F201 and F212)	x	x	
F220	**distance between armature / contacts and other components**					
F221	insufficient space between armature, contact system, contacts and other relay components	mechanical interference	possible wrong side failure	x	x	
F230	**failure to drop**					
F231	armature does not drop when the relay is no longer energised (mechanical causes)	make contacts do not open	wrong side failure, loss of dependencies (observing measures against F101)	x		
F232	armature does not drop when the relay is no longer energised (armature sticks)	make contacts do not open	wrong side failure	(x)	(x)	
F233	armature does not drop when the relay is no longer energised	if no measures taken: see F201	none (see note)			condition: measures implemented against F201
F234	armature does not drop within the usual timespan when the relay is no longer energised (due to ponderousnes)	malfunction if the NO circuit is applied	none (see note)			
F235	armature does not drop for mechanical reasons (e.g., relay installed in wrong position)	make contacts remain closed	wrong side failure, loss of dependencies	x	x	possible cause: incorrect relay position (e.g., mounted at an angle of 90° or 180°)

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F240	**failure to pick up**					
F241	armature does not pick up when the relay is energised	malfunction if the NO circuit is applied	none (see note)			condition: measures implemented against F201 and F212
F242	armature does not pick up within the usual timespan when the relay is energised (due to ponderousness)	malfunction if the NO circuit is applied	none (see note)			
F243	incorrect spring force (of the return spring)	low contact pressure or the relay does not pic up when energised	none (see note)			
F250	**bi-stable relay**					
F251	relay does not attain the opposite end position (relay remains in the intermediate or central position)	malfunction if the NO circuit is applied	none (see note)			condition: measures implemented against F201 and F212
F252	incorrect position proving for bistable relays	possible failure are may be not detected	possible wrong side failure	(x)	x	possibly also to be observed in the case of type N relays
F253	ponderousness of the supporting mechanism with interlocked relay	malfunction	none			
F260	**various**					
F261	wear, contact burn, pollution, over-voltage	loss of electrical insulation	possible wrong side failure	x	x	
F262	insufficient length of contact spring / blade (e.g., too short)	dissociation / exit of the contact spring / blade	possible wrong side failure (with consideration of the measures against F101 and F201)	x	x	
Insulation faults (failure 300 - 399)						
F301	plus influence	possibly untimely energising of the relay	wrong side failure, loss of dependencies	x	x	
F302	minus influence	malfunction as a result of short-circuits worst case: untimely energising of the relay	possible wrong side failure, possible loss of dependencies	x	x	see also F301
F303	brittle core insulation	possible plus or minus influence	possible wrong side failure, possible loss of dependencies	x	x	violet and red insulation is usually the first affected
F304	material migration (e.g., ‘irisation’ of multiple contact plug)	insulation failure	possible wrong side failure,	x	x	chemo-physical reaction between bakelite and silver
F305	short-circuit in coil windings	malfunction	none (see note)			possible wrong side failure in case of ‘locking via current flow’
F306	cold soldering spot on the coil (repeated drop-outs)	sporadic malfunction	none (see note)			

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
Faults in the power supply (failure 400 - 499)						
F400	**current / voltage below threshold value**					
F401	current or voltage below threshold value (at the coil)	malfunction if the NO circuit is applied	none (see note)			condition: measures implemented against F201 (see also M206), possibly further measures in redundant system architectures
F402	current / voltage below threshold value (at the coil)	malfunction if the NC circuit is applied	none (see note)			conditions: correct circuit dimensioning
F403	short feed interruption	possible route release as a result of a drop and re-energising of track circuit relay	possible wrong side failure for Track Circuits	x	x	option: use of interlocking function ‘track network monitoring’
F410	**current / voltage above threshold value**					
F411	current / voltage above threshold value	possible loss of electric insulation	possible wrong side failure	x	x	
F412	over-voltage (e.g., lightning), destruction of parts of the insulation	non-permissibly high contact voltage (e.g., on the relay housing)	safe working conditions not guaranteed	(x)	(x)	
F420	**various**					
F421	inductive / capacitative stray voltages	worst case: untimely energising of the relay	possible wrong side failure	x	x	
F422	transient voltages / currents	malfunctions resulting from changed electrical properties	none if the NO circuit is applied			
F423	transient voltages / currents	failure to drop owing to transient voltages / currents	possible wrong side failure in case a NC circuit is applied (see note)	(x)	(x)	example for C class relay: actuation level crossing
Faults / maintenance incidents (failure 500 - 599)						
F500	**use of a wrong type of relay**					
F501	use of a wrong relay type	wrong type of contact (make, break or change over contacts)	wrong side failure, loss of dependencies	x	x	
F502	use of a wrong relay type	changed electrical properties of the coil	possible wrong side failure	x	x	
F503	use of a relay with incorrect electrical components (e.g., diodes)	changed electrical properties of the coil	possible wrong side failure	x	x	

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F510	**maintenance (excluding overhaul / repair)**					
F511	cleaning of contacts / contact elements if this is expressly prohibited by the manufacturer	see F212	possible wrong side failure	x	x	
F512	incorrect cleaning of contacts / contact elements (e.g., using too much force or unsuitable tools)	see F212	possible wrong side failure	x	x	
F513	use of unknown cleaning products (e.g., contact spray)	physical / chemical damage (oxidation, etc.)	possible wrong side failure	x	x	
F514	use of contact spray that has not been approved	jeopardizes electrical insulation (see also F261)	possible wrong side failure	x	x	
F515	use of an unknown type of oil (see note)	possible malfunction due to loss of viscosity (see also F231 and F242)	none			to be taken into account for interlocked relays, amongst others
F516	use of oil if this is expressly prohibited (see note)	possible malfunction (see also F231 and F242)	none			only to be taken into account for interlocked relays
F520	**relay housing / cover**					
F521	removal of relay housing	possible malfunction, triggers F651 (see also F107 and F122)	none			
F522	incorrect mounting of relay housing	triggers F221	possible wrong side failure	x	x	
F523	incorrect marking of relay	triggers F501, F502 and F503	none (if the measure against F501 is observed)			
F524	incorrect marking of relay housing	triggers F501, F502 and F503	none (if measure against F501 is observed)			
F530	**relay resp. contact fixing (anchoring)**					
F531	no securing of the relay in the relay holder (e.g. not tightened screws)	malfunction (see note)	none (see note)			possible wrong side failure in case of 'locking via current flow'
F532	attachment of relay placement / position (e.g., wedging)	contact / contact member does not follow the energising condition of the relay; triggers F104 and F123	wrong side failure, loss of dependencies	x	x	
F533	attachment of relay placement / position with 'crocodile clamps'	short-circuits as a result of material separation at the galvanised parts of the coil core	possible wrong side failure	x	x	nicks in nickel galvanisations tend to flake off

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F534	attachment of contacts / contact members	contact / contact member does not follow the energising condition of the relay; triggers F101, F107, F121 and F122	wrong side failure, loss of dependencies	x	x	
F535	insulation of contacts (e.g., using an insulating tube)	contact / contact member does not follow the energising condition of the relay, could trigger F641	possible wrong side failure, loss of dependencies (see note)	x	x	correctly insulating contacts usually protects against potential hazards (which are detected as “malfunctions”)
F540	**transport damage**					
F541	transport damage	changed mechanical / electrical properties	possible wrong side failure,	x	x	
F550	**overhaul / repair**					
F551	non-qualified / unskilled repair work	changed mechanical / electrical properties	possible wrong side failure,	x	x	
F552	incorrect adjustment of contacts / contact members	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	x	x	
F553	incorrect mounting (e.g., bolt securing system is missing)	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	x	x	
F554	use of incorrect or unsuitable test equipment	changed mechanical / electrical properties are not detected	possible wrong side failure	x	x	
F555	incorrect / unsuitable test of relay properties (e.g., testing K factor)	changed mechanical / electrical properties are not detected	possible wrong side failure,	x	x	
Environment-related faults / incidents (failure 600 - 699)						
F600	**vibrations and shocks**					
F601	(non-permissibly strong) vibrations and shocks	closed contacts open or open contacts close	possible wrong side failure	x	x	
F610	**temperature**					
F611	temperature range non-permissible	failures as a result of changed electrical or mechanical properties	none if the NO circuit is applied			

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F620	**air humidity**					
F621	low air humidity together with high temperature	triggers F303	possible wrong side failure, possible loss of dependencies	x	x	
F622	(excessively) high air humidity	loss of electrical insulation / insulation strength	none (if limit values according to [1] are observed)			reduced air gaps and creepage paths
F623	oxidation of the contact spring (e.g., as a result of high air humidity and/or temperature fluctuations)	malfunctions due to changed mechanical or electrical properties	none if the NO circuit is applied			
F630	**effect of water**					
F631	influence of water	loss of electrical insulation	possible wrong side failure, possible loss of dependencies	x	x	
F632	pollution / residue following the effects of water (e.g., after flooding)	loss of electrical insulation due to electrically conducting residue	possible wrong side failure, possible loss of dependencies	x	x	
F640	**influence of silicone**					
F641	material containing silicone in combination with - high ozone concentration - reduced contact cleaning and - no-load switching (no contact burn up)	(slow) formation of SiO_2 mono crystals (diodes) on the contacts	possible wrong side failure, (triggers F161, F201, and F212)	x	x	
F642	cleaning substances containing silicone in combination with - high ozone concentration - reduced contact cleaning and - no-load switching (no contact burn up)	(slow) formation of SiO_2 mono crystals (diodes) on the contacts	possible wrong side failure, (triggers F161, F201, and F212)	x	x	
F650	**pollution / dust**					
F651	high dust concentration	malfunction (see note)	none (see note)			condition: measures implemented against F201 and F212. Chance of potential hazard in case of 'locking via current flow'.
F652	influence of aerosols	loss of electrical insulation	possible wrong side failure, loss of dependencies	x	x	

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F660	**over-voltage (e.g., lightning)**					
F661	over-voltage (higher than the protection measures taken)	short-circuits between contacts, insulation malfunctions, etc.	possible wrong side failure	x	x	
F670	**insects**					
F671	influence of insects (spiders, cockroaches, etc.)	loss of electrical insulation / insulation strength (see note)	possible wrong side failure, loss of dependencies	x	x	e.g. reduced air gaps and creepage paths as a result of electrically conducting residue
F672	core / cable insulation damaged by rodents	possible plus or minus influence	possible wrong side failure, possible loss of dependencies	x	x	
F680	**various**					
F681	influence of tin (‘tin threads’)	possible short-circuits	possible wrong side failure	x	x	
Malfunctions / incidents when using other components (failure 700 - 799)						
F700	**general**					
F701	malfunction of a delay unit (all types)	malfunctions due to changed electrical properties	none			
F710	**resistors and varistors**					
F711	use of a wrong resistor	worst case: relay is energised at the wrong time	possible wrong side failure, possible loss of dependencies	x	x	
F712	failure of a varistor (e.g., for limiting voltage)	triggers F261	possible wrong side failure,	x	x	
F720	**capacitors**					
F721	failure of a capacitor	malfunctions due to changed electrical properties	none			
F730	**diodes**					
F731	failure of a diode (rectification)	malfunctions due to changed electrical properties	none			
F732	failure of a arc suppressor diode	malfunctions due to changed mechanical and/or electrical properties	none			

Fault No.	failure / incident	possible consequence	resulting potential hazard	to be taken into account for relay type		comments / observations
				N	C	
F733	failure of a diode as a functioning component in relay circuits (blocking diode)	malfunctions due to changed electrical properties	possible wrong side failure,	x	x	
F734	failure of a Z diode (e.g., for limiting voltage)	triggers F261	possible wrong side failure,	x	x	
F740	**fuses**					
F741	incorrect dimensioning of fuses for special applications	no evidence of defects / failures	wrong side failure, loss of dependencies	x	x	
F750	**transformers**					
F751	short-circuit in transformer (transformer coil)	worst case: untimely energising of relay	possible wrong side failure, possible loss of dependencies	(x)	(x)	only to be observed if transformers are used for lamp or switch-position monitoring
F752	incorrect dimensioning of transformer core	no evidence of a lamp failure for flashing lights	no immediate hazard	(x)	(x)	

APPENDIX B 'TRIED AND PROVEN MEASURES'

Measure No.	proven measures	availability			safety			comments / observations
		focused measure						
		R	A	M	S	type N relay	type C relay	
Relay related measures according to [1] (measure 100 - 199)								
M101	forcibility guided (mechanically linked) contacts				x	x	x	see [1], section 3.1.1
M102	forcibility guided (mechanically linked) operation during the entire operating period	x	x		x	x	x	see [1], section 3.1.2
M103	direct (integral) link between armature and contact members				x	x	x	see [1], section 3.1.4
M104	use of non weldable make contacts points				x	x	(x)	measure required for type N relays according to [1], section 3.2.1.1; also theoretically possible for type C relays
M105	use of special constructional conditions preventing risks of welding				x	x	see note	measure required for type N relays according to [1], section 3.2.1.1; required for type C relays only if the relay is used as a type N relay
M106	the armature shall drop under its own weight, possibly with support from a return spring				x	x		measure required for type N relays according to [1], section 3.2.1.2
M107	use of a return spring (to increase contact force)	x	x					see [1], section 3.2.1.3
M108	use of protection against mistaken exchange for individually pluggable relays and/or relay groups	x	x	x	x	(x)	(x)	the requirement in [1], section 3.3.1 only applies to individually pluggable relays and relay groups
M109	sufficient distance between movable parts of the relay and other components (e.g., a removable cover)				x	x	x	see [1], section 3.3.2
M110	protection against vibrations and shocks	x	x		x	x	x	see [1], section 3.3.3; part of type testing
M111	operates sufficient within the temperature range specified by the manufacturer	x	x					see [1], section 3.3.4; part of type testing
M112	air gap between coil and armature and/or armature stop	x	x		x	x	(x)	see [1], section 3.4 for type C relay, taking into account M207 with relevance to aspects of reliability and availability
M113	use of anti-remanent material (e.g. partition plate)	x	x		x	x	(x)	for type C relay, taking into account M207 with relevance to aspects of reliability and availability
M114	drop factor for energising and de-energising current (K factor)	x	x		x	x	x	see [1], section 3.4.1

Measure No.	proven measures	availability			safety			comments / observations
		focused measure						
		R	A	M	S	type N relay	type C relay	
M115	energising and de-energising current - max. deviations during entire operating period	x	x		x	x	x	see [1], section 3.4.2
M116	sufficient dielectric strength				x	x	x	see [1], section 3.5; part of type testing
M117	alternative contact types and materials	x	x	x	x	x	x	see [1], section 3.6.1; relates to use of series contacts for instance, also to be observed is the safety relevance of hot contacts
M118	make and break contacts may not be closed at the same time (not even in the case of 1.5x nominal current)				x	x	x	see [1], section 3.6.2
M119	correct dimensioning of contacts	x	x	x	x	x	x	see [1], section 3.6.3
M120	guaranteed minimum service life (2x 10^6 switching cycles)	x	x	x	x	x	x	see [1], section 3.6.4
M121	sufficient distance between contacts (for the entire operating period)				x	x	x	see [1], section 3.6.5
M122	sufficient contact force (for the entire operating period)	x	x	x				see [1] ,section 3.6.6
M123	sufficient self cleaning capacity of contacts	x	x	x				see [1], section 3.6.7
M124	sufficient threshold values for contact bounce time	x	x					see [1], section 3.6.8
Circuit dimensioning (measure 200-299)								
M200	**circuit logic**							
M201	release of safety-relevant functions by means of current flow				x	x	x	theoretical foundation for M203
M202	locking of safety-relevant functions by lack of current				x	x	x	
M203	use of NO circuits to release a safety-relevant function				x	x	x	converts M201
M204	use of NC circuits in safety-relevant monitoring functions				x	x	x	e.g., monitoring of points end position
M205	use of NC circuits in safety-relevant release functions only in combination with supplementary measures				x	x	x	this measure is dependent on the system / circuit dimensioning and the safety function

Measure No.	proven measures	availability		focused measure	safety			comments / observations
		R	A	M	S	type N relay	type C relay	
M206	up-proving of the relay position for relays that lock safety-relevant functions ‘by means of current flow’				x	x	x	
M207	drop test for a normal relay (applies in principle also to relays with memory effect, e.g., interlocked and latched relays)				x		x	see [1], section 3.2.2, only required for type C relays
M208	use of relays with memory effect (e.g., interlocked and latched relay) to lock safety-relevant functions				x	(x)	(x)	enables ‘locking by means of permanent current’ to be dispensed with
M209	use of more stable condition of relays with memory function for safety-relevant functions				x	(x)	(x)	applies only to bistable relays with asymmetrical characteristics / failure rate (e.g., for energised relays)
M210	when using an interlocked relay, care must be taken in the circuit to ensure that the right contacts are applied both for ‘locking a function’ and ‘releasing a function’				x	(x)	(x)	for detailed requirements, see sections 3.5.10 and 6.7.7.
M211	in the case of interlocked relays, the actual locking effect must be tested				x	(x)	(x)	for detailed requirements, see sections 3.5.10 and 6.7.7.
M212	use deterministic circuit logic			x	x	x	x	avoid logic that functions in parallel, see also M251
M213	mandatory sequence: release only after locking				x	x	x	reveals possible ‘wrong side failure’
M230	**arrangement of contacts**							
M231	arrange contacts between feed source and relay core				x	x	x	
M232	arrangement of contacts between relay coil and negative terminal/minus				x	(x)	(x)	M232 is only permissible if M212 and M251 are observed
M233	redundant contacts of the same relay in one relay circuit (one contact between feed source and relay coil, one contact between coil and negative terminal/minus)				x	(x)	x	the use of M233 depends partly on the system structure of the application concerned. M233 is rarely used for type N relays
M234	redundant contacts of the same relay in different circuits (both circuits implement M201)				x	(x)	x	the use of M234 depends partly on the system structure of the application concerned. M234 is rarely used for type N relays.

Measure No.	proven measures	availability			safety			comments / observations
		focused measure						
		R	A	M	S	type N relay	type C relay	
M235	redundant contacts of the same relay in different circuits (only one of the circuits applies M201)				x	(x)	x	see note regarding M234
M236	redundant contacts of the same relay in different circuits (neither circuit applies M201)				x	(x)	x	see note regarding M234, example for type C relay: “stop aspect” signals
M237	redundant contacts of different relays in the same circuit (the circuit concerned applies M201)				x	x	x	M237 is often used in redundant system structures
M238	double redundant contacts of different relays in the same circuit (each relay has one contact between feed source and coil and one contact between coil and negative terminal/minus				x	(x)	(x)	see also note regarding M234 and M237
M239	avoid leading and trailing contacts (bent contacts) if possible		x	x				
M250	**effect of plus & minus influence**							
M251	avoid zig-zag circuit resp. parallel circuits	x	x	x	x	x	x	reduces the risk of untimely minus connections
M252	structure connections to minus as ring feeders	x	x		x	x	x	
M253	minus as a safety function (protection function)				x	x	x	depends on system / circuit dimensioning
M254	correct dimensioning of fuses that achieve functions in terms of functional safety of a circuit				x	x	x	no relation to protection of persons, devices or against fire
M255	directional change of feed voltage to detect plus or minus influence				x	x	x	
M256	use of polarity change loops via the earth cable				x	(x)	x	the measure can theoretically also be used for circuits with type N relays.
M257	avoidance of spark extinction / flyback diodes in circuit components that run via earth cables				x	(x)	x	
M270	**various**							
M271	monitoring of power supply incl. safety-oriented fault response	x	x		x	(x)	(x)	usual measures relating to track circuits: - prevention of route release - switching off of power supply in the event of over-voltage
M272	the circuit is to be designed such that electrical loads (if any) are switched only via suitable contacts	x	x	x				

Measure No.	proven measures	availability			safety			comments / observations
		focused measure						
		R	A	M	S	type N relay	type C relay	
M273	do not use diodes in safety-relevant circuits to replace relay contacts				x			if diodes have to be used, they must be switched in series and/or dimensioned larger than necessary
M274	signal transformer: correct dimensioning of the iron core	x	x	x				
M275	signal transformer: winding-short-safe design				x			in the case of installations with current monitor
M276	use correctly dimensioned resistor ('fail-safe design'), if this is required by the proof of safety document				x			
Maintenance (measure 300-399)								
M301	visual inspection of the condition of the relays and the core/cable insulation	x	x	x	x	x	x	
M302	inspection of electrical properties (e.g., K factor)	x	x	x	x	x	x	observe manufacturer's specifications
M303	inspection of mechanical properties (e.g., distance between contacts)	x	x	x	x	x	x	
M304	correct contact cleaning (in accordance with manufacturer's requirements)	x	x	x				
M305	no cleaning of contacts/contact elements if explicitly prohibited by the manufacturer				x	(x)	(x)	measure depends on the type of signal relay used
M306	use of permitted lubricants (oils/greases)	x	x	x				
M307	use of lubricants (oils/greases) according to specification only	x	x	x				some interlocked relays have locking mechanisms that may not be oiled
M308	correct contact adjustment	x	x	x	x	x	x	observe manufacturer's specifications
M309	correct mounting of relay	x	x	x	x	x	x	
M310	avoid using material containing silicone	x	x	x	x	x	x	
M311	temperature measurement of contacts	x	x		x	(x)	(x)	optional measure
M312	temperature measurement of cores / cables	x	x		x	(x)	(x)	optional measure
M313	regular testing of dependencies (route locking, signal dependencies, etc.)				x	(x)	(x)	volume and intervals are dependent on interlocking

Measure No.	proven measures	availability			safety			comments / observations
		focused measure						
		R	A	M	S	type N relay	type C relay	
Various measures (measure 400-499)								
M400	**insulation**							
M401	protection against (excessive) inductive / capacitative interference voltages	x	x	x	x	x	x	
M402	limitation of operating distance (lower interference voltages)	x	x	x	x	x	x	
M403	consequent realisation of the (agreed) earth-concept	x	x	x				
M404	use of voltage limiting devices	x	x	x	x	(x)	(x)	use of this measure depends on the system / circuit dimensioning
M405	use of earth-free circuits	x	x	x	x	(x)	(x)	
M406	use of earth detectors in circuits and/or power supply			x	x	(x)	(x)	
M407	symmetrical circuits (e.g. separate return line)				x	x	x	
M408	change stop if the condition of the core insulation so requires				x	(x)	(x)	last resort
M420	**test/check**							
M421	use of approved tools			x	x	(x)	(x)	
M422	use of recognisable tools			x	x	(x)	(x)	e.g., optically visible tools, groups that no longer close, etc.
M423	test equipment must be verified / calibrated			x	x	(x)	(x)	
M424	test equipment must (if necessary) test potential-free		x	x	x			
M425	test procedures must be defined and observed		x	x	x	(x)	(x)	
M426	corresponding qualification		x	x	x			
M427	periodic testing of elements (e.g., relays) and/or circuit components that cannot perform automatic tests on themselves for technical circuitry reasons				x	x	x	e.g., in the case of missing up/down proving

Measure No.	proven measures	availability			safety			comments / observations
		focused measure						
		R	A	M	S	type N relay	type C relay	
M440	**various**							
M441	mount and operate relays only in permitted positions	x	x		x	x	x	
M442	protect relays and relay groups during transport (and storage)	x	x	x	x	x	x	use of approved transport packaging
M443	ensure that required climatic operating conditions are provided	x	x	x	x	x	x	e.g., air humidity, temperature, dust concentration
M444	If used: cyclic test of circuit breaker (CB) as well as motor circuit breaker (MCB).	x	x	x				usually CB and MCB can`t be "switch-on" after 10..12 years due to resinified synthetic oil
M445	observing the manufacturer's requirements for cable planning (e.g., own cables for points, signals, axle-counters, etc.)				x			depending on the respective interlocking design
M446	relays must be installed either in groups or be covered	x	x		x	x	x	
M447	cable connection between internal installation and external installation: either construction of a circuit secured against core shorting, or regular monitoring of cables to ensure freedom from core shorting.				x	x	x	

APPENDIX C 'EFFICIENCY OF MEASURES'

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
Contact faults (failure 100-199)					
F100	**make contacts (NO contact)**				
F101	make contact does not open when the relay is no longer energised	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	M101, M102, M118, M207	M103, M105, M106, M108, M119, M120, M271, M301, M303, M308, M309, M311, M442, M446, type N relay: M104
F102	make contact does not open when the relay is no longer energised (e.g., due to welded contacts).	contacts do not follow de-energised position (down-proving)	wrong side failure, loss of dependencies	Type N relay: M104 and M106 Type C relay: M207	M101, M102, M103, M118, M120, M271, M301, M303, M311, type C relay: M104
F103	make contact does not open when the relay is no longer energised (e.g., in the case of a failure of the protective measures against welding of contacts).	contacts do not follow de-energised position (down-proving)	wrong side failure, loss of dependencies	Type N relay: M105 and M106 Type C relay: M207	M271, M301, M303, M311, type C relay: M105
F104	make contact is consistently closed (permanently)	make contact consistently closed (permanently)	wrong side failure, loss of dependencies	M101, M102, M109, M207, M213, M233, M234, M237, M446	M103, M108, M210, M211, M212, M235, M238, M301, M303, M308, M309, M310, M311, M313, M442
F105	make contact does not open due to adhesion / hooked contacts (material migration)	make contact consistently closed (permanently)	wrong side failure,	M101, M102, M117, M119, M121, M123, M207, M213, M233, M234, M237	M103, M122, M210, M211, M212, M235, M238, M301, M303, M313
F106	make contact does not open due to adhesion / hooked contacts (material migration)	possible overlapping of contacts (both make and break established contacts)	wrong side failure	M101, M102, M117, M119, M121, M123, M207, M213, M233, M234, M237	M103, M122, M210, M211, M212, M235, M238, M301, M303
F107	make contact does not close when the relay is energised	malfunction in case a normally open circuit is used	none (if measures implemented against F201 and F212)	M201, M202, M203, M204, M213, M237, M446	M114, M206, M210, M211, M212, M235, M238, M301, M302, M313, M442
F120	**break contacts (NC contacts)**				
F121	break contact does not open when the relay is energised	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	M101, M102, M118, M201, M202, M203, M204, M206, M213, M233, M234, M237	M103, M105, M108, M119, M210, M211, M212, M235, M238, M271, M301, M303, M308, M309, M311, M442, M446

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F122	break contact does not close when the relay is no longer energised	malfunction in case a normally open circuit is applied	none (if measures implemented against F201 and F212)	M201, M202, M203	M207, M212, M301, M313, M442, M446
F123	break contact is consistently closed (permanently)	break contact consistently closed (permanently)	wrong side failure, loss of dependencies	M101, M102, M109, M213, M233, M234, M237, M446	M103, M108, M210, M211, M212, M235, M238, M301, M303, M308, M309, M311, M313, M442
F124	break contact does not open when the relay is energised (e.g., welded contacts)	contacts do not follow the energising condition of the relay	wrong side failure, loss of dependencies	M101, M102, M206	M103, M105, M118, M120, M271, M301, M303, M311
F125	break contact does not open due to adhesion / hooked contacts (material migration)	break contact consistently closed (permanently)	wrong side failure, loss of dependencies	M101, M102, M117, M119, M121, M123, M206, M213	M103, M122, M210, M211, M212, M233, M234, M235, M237, M238, M301, M303
F126	break contact does not open due to adhesion / hooked contacts (material migration)	possible overlapping of contacts (both make and break established contacts)	wrong side failure, loss of dependencies	M101, M102, M117, M119, M121, M123, M206, M213	M103, M122, M210, M211, M212, M233, M234, M235, M237, M238, M301, M303
F140	**wear to contacts / contact system**				
F141	wear to contacts or contact members	malfunctions as a result of changed mechanical or electrical properties during operating time	none (malfunction)	M117, M119, M120, M121, M122, M272	M116, M124, M301, M303, M304, M305, M441, M443
F142	wear to contacts or contact members due to unsuitable material	malfunctions as a result of changed mechanical or electrical properties during operating time	none (malfunction)	M117	
F143	wear to contacts or contact members	malfunctions due to insufficient self- cleaning	none (malfunction)	M122, M123, M441, M443, M446	
F144	wear to contacts or contact system	malfunctions as a result of changed mechanical or electrical properties during operating time	none (malfunction)	M124	M122, M443
F150	**contact pressure**				
F151	low contact pressure of break contacts	malfunctions due to break contacts do not close properly	none (malfunction)	M107, M117, M120, M122, M124, M308, M309	M110, M303
F152	low contact pressure of break contacts	malfunctions due to contact bounce	none (mailfunction)	M107, M117, M120, M122, M124, M308, M309	M110, M303

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F153	loss of contact pressure during operating period	malfunctions due to contact bounce	none (malfunction)	M117, M120, M122, M124	M107, M303
F154	loss of contact pressure during operating period	malfunctions as a result of contacts opening due to vibrations / impacts	none (malfunction)	M110, M117, M120, M122, M124	M107, M303
F155	low contact pressure of make contacts	malfunctions	none (if measures applied against F201 and F212)	M107, M117, M120, M122, M124, M308, M309	M110, M303
F156	low contact pressure of make contacts (closing contacts)	malfunctions due to contacts do not closed within bounce time	none (if measures applied against F201 and F212)	M107, M117, M120, M122, M124, M308, M309	M110, M303
F160	**hot contacts / contact elements**				
F161	hot contacts / contact elements	wear or fracture in forced guidance	possible wrong side failure, (triggers F101, F121, F201 and F212)	M119, M310	M105, M111, M117, M271, M301, M311
F162	hot contacts / contact elements due to incorrect circuit dimensioning	wear or fracture in forced guidance	possible wrong side failure (triggers F101, F121, F201 and F212)	M271	M105, M301, M311
F170	**broken / loose contacts**				
F171	broken or loose contact due to wear	make and break contacts can be closed at the same time	possible wrong side failure	M119, M120, M442, M446	M101, M102, M301
F172	broken or loose contact member due to wear	make and break contacts can be closed at the same time	possible wrong side failure	M119, M120, M442, M446	M101, M102, M301
F180	**electric arc**				
F181	Electric arc between contacts	non-permissible heat transmission to synthetic components	possible wrong side failure	M119, M272	
F190	**choice of contact**				
F191	using false contacts of interlocked relay in circuits	possible faults (e.g., de-energised / energised failure) are not detected	wrong side failure, loss of dependencies	M209, M210, M211, M213	M108
Faults in the relay system (failure 200-299)					
F200	**forcibly guided contacts**				
F201	contact member does not follow armature position	other contacts of the same type (make or break) are not in the same position	wrong side failure, loss of dependencies	M101, M102, M103	

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F210	**wear to contacts / armature**				
F211	wear to armature and contacts / contact elements	changed mechanical / electrical properties during operating time	possible wrong side failure	M114, M115, M119, M120, M121	M122, M271, M301, M302, M303, M308
F212	wear or breakage of forced guidance of contacts	loss of forced guidance of contacts	wrong side failure, loss of dependencies	M102, M120	M103, M301, M303, M308
F213	changed distance between contacts due to wear	loss of electrical insulation	possible wrong side failure	M120, M121	M301, M303, M308
F214	bent contact member do not follow the armature position	see F201 and F212	none (if measures implemented against F201 and F212)		M239
F215	fracture of forced guidance or other contact guidance components	possible dissociation of the contact springs/blades	possible wrong side failure	M102, M118, M120, M309, M443	M103, M109, M301, M303, M304, M310, M442
F216	deformation of synthetic components (e.g. contact guide)	possible dissociation of the contact springs/blades	possible wrong side failure	M101, M102, M109, M111, M118, M119, M120, M301, M309, M443	M103, M303, M304, M310, M311, M442
F220	**distance between contact system and other components**				
F221	insufficient space between armature, contact system, contacts and other relay components	mechanical interference	possible wrong side failure	M109	M441, M442, M446
F230	**failure to drop**				
F231	armature does not drop when the relay is no longer energised (mechanical causes)	make contacts do not open	wrong side failure, loss of dependencies	Type N relay: M106 Type C relay: M207	M302, M313, M441 Type N relay: M207
F232	armature does not drop when the relay is no longer energised (armature sticks)	make contacts do not open	wrong side failure	M112 and M113 Type C relay: M207	M302, M313 Type C relay: M112 and M113 Type N relay: M207
F233	armature does not drop when the relay is no longer energised	if no measures taken: see F201	none (if measures implemented against F201)	M207	M302, M313, M441
F234	armature does not drop within the usual time-span when the relay is energised (due to ponderousnes	malfunction if the NO circuit is applied	none (if measures implemented against F201 and F212)	M201, M202, M306, M307, M441	M109, M302, M446

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F235	armature does not drop for mechanical reasons (e.g., relay installed wrongly)	make contacts remain closed	wrong side failure, loss of dependencies	M441	
F240	**failure to pick up**				
F241	armature does not pick up when the relay is energised	malfunction if the NO circuit is applied	none (if measures implemented against F201 and F212)	M212	M201, M202, M441
F242	Armature does not pick up within the usual timespan when the relay is energised (due to ponderousness)	malfunction if the NO circuit is applied	none (if measures implemented against F201 and F212)	M441	M109, M120, M201, M202, M212, M306, M307, M446
F243	incorrect spring force (of the return spring)	low contact pressure or the relay does not pic up when energised	none (if measures implemented against F201 and F212)	M120, M122, M308	M201, M202
F250	**bi-stable relay**				
F251	relay does not attain the opposite end position (relay remains in the intermediate or central position)	malfunction if the NO circuit is applied	none (if measures implemented against F201 and F212)	M201, M202, M210, M211, M213, M306, M307	M209
F252	incorrect position proving for bistable relays	possible failure are may be not detected	possible wrong side failure	M209, M210, M211, M213	
F253	ponderousness of the supporting mechanism with interlocked relay	mailfunction	none	M306, M307	M209, M210, M211, M213, M441
F260	**various**				
F261	wear, contact burn, pollution, over-voltage	loss of electrical insulation	possible wrong side failure	M116, M443, M446	
F262	insufficient length of contact spring / blade (e.g., too short)	dissociation / exit of the contact spring / blade	possible wrong side failure	M101, M102, M109, M118, M119, M120, M301, M309, M443	M103, M111, M303
Insulation faults (failure 300 - 399)					
F301	plus influence	possibly untimely energising of the relay	wrong side failure, loss of dependencies	M207, M231, M233, M234, M237, M251, M254, M255, M256, M273, M401, M403, M421, M423, M426, M427, M445, M446, M447	M116, M201, M202, M203, M206, M212, M232, M235, M236, M238, M253, M257, M313, M402, M405, M406, M407, M408, M443, M448
F302	minus influence	malfunction as a result of short-circuits (worst case: untimely energising of the relay)	possible wrong side failure, possible loss of dependencies	M207, M231, M232, M233, M234, M237, M251, M255, M256, M273, M405, M406 for IT, M407, M421, M423, M426, M427, M445, M446, M447	M116, M201, M202, M203, M206, M212, M235, M236, M238, M257, M313, M401, M408, M443, M448

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F303	brittle core insulation	possible plus or minus influence	possible wrong side failure, possible loss of dependencies	M116, M301, M406 for IT, M408, M421, M423, M426, M427, M443, M445	M207, M212, M313, M401, M402, M403, M405, M446, M447, M448
F304	material migration (e.g., irisation of multiple contact plug)	insulation failure	possible wrong side failure,	M301	
F305	short-circuit in coils	malfunction	none (if measures implemented against F201, F202 and F212)	M201, M202, M203, M275	M254, M271
F306	cold soldering spot on the coil (repeated drop-outs)	sporadic malfunctioning	none	M201, M202, M203	
Faults in the power supply (failure 400 - 499)					
F400	**current / voltage below threshold value**				
F401	current / voltage below threshold value(at the coil)	malfunction if the NO circuit is applied	none (if measures implemented against F201, see also M206)	M201, M202, M203, M271, M423, M425, M426, M427	M302
F402	current / voltage below threshold value (at the coil)	malfunction if the NC circuit is applied	none	M271, M423, M425, M426, M427	M302
F403	short feed interruption	possible rute release as a result of a drop and re-energised of track circuit relay	possible wrong side failure for track circuits	M208	M209, M210, M211, M213, M271, M423, M425, M426, M427
F410	**current / voltage above threshold value**				
F411	current / voltage above threshold value	possible loss of electric insulation	possible wrong side failure	M116, M271, M302, M444	M423, M425, M426, M427, M445
F412	over-voltage (e.g., lightning), destruction of parts of the insulation	non-permissible high contact voltages (e.g., on the relay housing)	safe working conditions not guaranteed	M116, M271, M401, M402, M403, M404, M445	M257, M405, M406
F420	various				
F421	inductive / capacitative stray voltages	worst case: untimely energising of the relay	possible wrong side failure	M116, M254, M256, M401, M402, M403, M404, M445, M447	M257, M405, M406,
F422	transient voltages / currents	malfunctions resulting from changed electrical properties	none if the NO circuit is applied		M201, M202, M203, M212
F423	transient voltages / currents	failure to drop owing to transient voltages / currents	possible wrong side failure in case a NC circuit is applied		M205, M212

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
Faults / maintenance incidents (failure 500 - 599)					
F500	**use of a wrong type of relay**				
F501	use of a wrong relay type	wrong type of contact (make, break or change over contacts)	wrong side failure, loss of dependencies	M108, M309, M425, M426, M449	
F502	use of a wrong relay type	changed electrical properties of the coil	possible wrong side failure	M108, M302, M309, M425, M426, M449	
F503	use of relays with incorrect electrical components (e.g., diodes)	changed electrical properties of the coil	possible wrong side failure	M108, M309, M425, M426, M449	M302
F510	**maintenance (excluding overhaul / repair)**				
F511	cleaning of contacts / contact elements if this is expressly prohibited by the manufacturer	see F212	possible wrong side failure	M304, M305, M421, M425, M426	
F512	incorrect cleaning of contacts / contact elements (e.g., using too much force or unsuitable tools)	see F212	possible wrong side failure	M304, M421, M425, M426	
F513	use of unknown cleaning products (e.g., contact spray)	physical / chemical damage (oxidation, etc.)	possible wrong side failure	M304, M310, M421, M425, M426	
F514	use of contact spray that has not been approved	jeopardizes electrical insulation (see also F261)	possible wrong side failure	M310, M421, M425, M426	
F515	use of unknown type of oil. (Please note: to be observed for interlocked relays, amongst others)	possible failure due to loss of viscosity (see also F231 and F242)	none	M306, M307, M310, M421, M425, M426	
F516	use of oil if this is expressly prohibited. (Please note: only to be observed for interlocked relays)	possible malfunction (see also F231 and F242)	none	M306, M307, M310, M425, M426	
F520	**relay housing / cover**				
F521	removal of relay housing	possible malfunction function, triggers F651 (see also F107 and F122)	none	M426, M449	M446
F522	incorrect mounting of relay housing	triggers F221	possible wrong side failure	M426	M446
F523	incorrect marking of relay	triggers F501, F502 and F503	none (if the measure against F501 is observed)	M426, M449	

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F524	incorrect marking of relay housing	triggers F501, F502 and F503	none (if the measure against F501 is observed)	M426, M449	M446
F530	**relay resp. contact fixing (anchoring)**				
F531	no securing of the relay in the relay holder	malfunction	none (possible wrong side failure in case of 'locking via current flow')	M110, M426	M201, M202, M203
F532	attachment of relay placement / position (e.g., wedging)	contact/contact member does not follow the energis-ing condition of the relay; triggers F104 and F123	wrong side failure, loss of dependencies	M310, M421, M422, M423, M425, M426	M309
F533	attachment of relay placement/position with 'crocodile clamps'	short-circuits as a result of material separation at the galvanised parts of the coil core	possible wrong side failure	M421, M422, M423, M425, M426	
F534	attachment of contacts / contact members	contact/contact member does not follow the energising condition of the relay; triggers F101, F107, F121 and F122	wrong side failure, loss of dependencies	M421, M422, M423, M425, M426	
F535	insulation of contacts (e.g., using an insulation tube)	Contact / contact member does not follow the energising condition of the relay, could trigger F641	possible wrong side failure, loss of dependencies	M310, M421, M422, M423, M425, M426	
F540	**transport damage**				
F541	transport damage	changed mechanical / electrical properties	possible wrong side failure	M421, M426, M442	
F550	**overhaul / repair**				
F551	non-qualified / unskilled repair work	changed mechanical / electrical properties	possible wrong side failure	M421, M423, M425, M426	M424
F552	incorrect adjustment of contacts / contact members	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	M308, M421, M422, M425, M426	
F553	incorrect mounting (e.g., bolt securing is missing)	make and break contacts can be closed at the same time	wrong side failure, loss of dependencies	M309, M421, M422, M425, M426	
F554	use of incorrect or unsuitable test equipment	changed mechanical / electrical properties are not detected	possible wrong side failure	M302, M421, M423, M425, M426	M422, M424
F555	incorrect / unsuitable test of relay properties (e.g., testing K factor)	changed mechanical / electrical properties are not detected	possible wrong side failure	M302, M421, M422, M423, M425, M426	

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
Environment-related faults / incidents (failure 600 - 699)					
F600	**vibrations and shocks**				
F601	(non-permissibly strong) vibrations and shocks	closed contacts open or open contacts close	possible wrong side failure	M110, M122	M107, M124, M426
F610	temperature				
F611	temperature range non-permissible	failures as a result of changed mechanical or electrical properties	none if the NO circuit is applied	M111, M443	M207, M426
F620	**air humidity**				
F621	low air humidity together with high temperature	triggers F303	possible wrong side failure, possible loss of dependencies	M111, M443	
F622	(excessively) high air humidity	loss of electrical insulation / insulation strength	none (if the limit values are observed according to [1])	M116, M443	
F623	oxidation of the contact spring (as a result of high air humidity and/or temperature fluctuations)	mailfunctions due to changed mechanical or electrical properties	none if the NO circuit is applied	M443	
F630	**effect of water**				
F631	influence of water	loss of electrical insulation	possible wrong side failure, possible loss of dependencies	M313, M426, M427, M450	M116, M301, M302, M304, M443
F632	pollution / residue following the effects of water (e.g., after flooding)	loss of electrical insulation due to electrically conducting residue	possible wrong side failure, possible loss of dependencies	M313, M426, M427, M450	M116, M301, M302, M304, M443
F640	**influence of silicone**				
F641	material containing silicone in combination with - high ozone concentration - reduced contact cleaning and - no-load switching (no contact burn up)	(slow) formation of SiO_2 mono crystals (diodes) on the contacts	possible wrong side failure, (triggers F161, F201 and F212)	M310, M426	
F642	cleaning agents containing silicone in combination with - high ozone concentration - reduced contact cleaning and - no-load switching (no contact burn up)	(slow) formation of SiO_2 mono crystals (diodes) on the contacts	possible wrong side failure, (triggers F161, F201 and F212)	M310, M426	

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F650	**pollution / dust**				
F651	high dust concentration	malfunction (possible wrong side failure in case of 'locking via current flow')	none (if measures implemented against F201 and F212)	M426, M443, M446	M123
F652	influence of aerosols	loss of electrical insulation	possible wrong side failure, loss of dependencies	M426, M443	M116
F660	**over-voltage (e.g., lightning)**				
F661	over-voltage (higher than the protection measures taken)	short-circuits between contacts, insulation faults, etc.	possible wrong side failure	M116, M254, M401, M403, M404, M426	M402, M405
F670	insects				
F671	influence of insects (spiders, cockroaches, etc.)	loss of electrical insulation / insulation strength (reduced air and expansion gaps) through electrically conducting residue	possible wrong side failure, loss of dependencies	M446, M450	
F672	core / cable insulation damaged by rodents	possible plus or minus influence	possible wrong side failure, possible loss of dependencies	M446, M450	
F680	**various**				
F681	influence of tin ('tin threads')	possible short-circuits	possible wrong side failure	M425, M246, M443	M116, M301
Malfunctions / incidents when using other components (failure 700 - 799)					
F700	**general**				
F701	malfunction of a delaying unit (any type)	malfunctions due to changed electrical properties	none	M425, M426, M427	
F710	**resistors and varistors**				
F711	use of a wrong resistor	worst case: relay is energised at the wrong time	possible wrong side failure, possible loss of dependencies	M276, M425, M426, M427	
F712	failure of a varistor (e.g., for limiting voltage)	triggers F261	possible wrong side failure,	M425, M426, M427	
F720	**capacitors**				
F721	failure of a capacitor	mailfunctions due to changed electrical properties	none	M425, M426, M427	

No.	failure / incident	possible consequence	assumed hazard	effective measures	conditionally effective measures
F730	**diodes**				
F731	failure of a diode (rectification)	malfunctions due to changed electrical properties	none	M425, M426,	M427
F732	failure of a arc suppressor diode	mailfunctions due to changed mechanical and/ or electrical properties	none	M257, M425, M426	M427
F733	failure of a diode as a functioning component in relay circuits (blocking diode)	mailfunctions due to changed electrical properties	possible wrong side failure	M273, M425, M426	
F734	failure of a Z-diode (e.g., for limiting voltage)	triggers F261	possible wrong side failure	M425, M426,	M427
F740	**fuses**				
F741	incorrect dimensioning of fuses for special applications	no evidence of defects / failures	wrong side failure, loss of dependencies	M254, M425, M426,	M444
F750	transformers				
F751	short-circuit in trans-former (transformer coil)	worst case: untimely energising of relay	possible wrong side failure, possible loss of dependencies	M275, M425, M426	
F752	incorrect dimensioning of transformer core	no evidence of a lamp failure for flashing lights	no immediate hazard	M274, M425, M426	

APPENDIX D ‘FAILURE RATES’

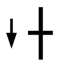
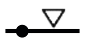
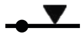
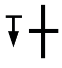
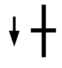
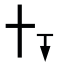
Please note: Failure rates were collected within the scope of the UIC SEG ‘Use of Signalling Relays’ project. Since some of the data is commercially sensitive, only data that is publicly accessible will be published in this report. The data given below are taken from [21]. Although the data no longer represent the ‘current state of the art’, they can still serve as a guideline in terms of the estimated orders of magnitude. For further details see section 6.7.1.

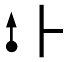
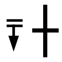
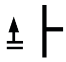
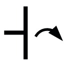
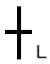
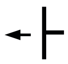
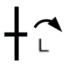
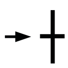
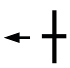
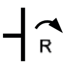
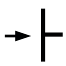
failure / incident	component	hint	probability of failure / incident	
			average failure rate	unit
Relay system				
armature does not open when the relay is no longer energised (mechanical causes)	normal relay type II WSSB	mono-stable relay type C	0.2 * 10 Exp -8	per actuation
	small relay type II WSSB	mono-stable relay type C	0.2 * 10 Exp -8	per actuation
armature does not close when the relay is energised (mechanical causes)	normal relay type II WSSB	mono-stable relay type C	1 * 10 Exp -8	per actuation
	small relay type II WSSB	mono-stable relay type C	0.5 * 10 Exp -8	per actuation
interruption in coils	normal relay type II WSSB	mono-stable relay type C	2.1 * 10 Exp -7	per 24 h
short-circuit in coils	normal relay type II WSSB	mono-stable relay type C	0.3 * 10 Exp -8	per 24 h
all or nothing relay - interruption in coils	‘post relay’ type 48	mono-stable relay, not a signalling relay	0.2 * 10 Exp -8	per 24 h
all or nothing relay - short-circuit in coils	‘post relay’ type 48	mono-stable relay, not a signalling relay	0.2 * 10 Exp -8	per 24 h
Relay contact				
signalling relay - contact does not open	normal relay type II WSSB	relay type C, series contacts	0.2 * 10 Exp -10	per actuation
signalling relay - contact does not close	normal relay type II WSSB	relay type C, series contacts	0.2 * 10 Exp -8	per actuation
all or nothing relay - contact does not open	‘post relay’ type 48	single contact with redundant contact elements	0.2 * 10 Exp -9	per actuation
all or nothing relay - contact does not close	‘post relay’ type 48	single contact with redundant contact elements	0.2 * 10 Exp -9	per actuation

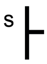
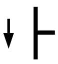
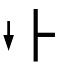
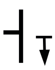
failure / incident	component	hint	probability of failure / incident	
			average failure rate	unit
Wiring (cores)				
wire break	jumper wire	no double insulation	0.5 * 10 Exp -8	per 24 h
intercore contact (short-circuit)	jumper wire	no double insulation	0.5 * 10 Exp -9	per 24 h
short to plus potential	jumper wire	no double insulation	0.5 * 10 Exp -9	per 24 h
short to minus potential	jumper wire	no double insulation	0.5 * 10 Exp -9	per 24 h
wire break	wiring in relay groups	no double insulation	0.1 * 10 Exp -9	per 24 h
intercore contact (short-circuit)	wiring in relay groups	no double insulation	0.1 * 10 Exp -9	per 24 h
short to plus potential	wiring in relay groups	no double insulation	0.1 * 10 Exp -9	per 24 h
short to minus potential	wiring in relay groups	no double insulation	0.1 * 10 Exp -9	per 24 h
Cables				
interlocking internal cable - wire break	interlocking internal cable	double insulation	0.1 * 10 Exp -8	per 24 h
interlocking internal cable - core contact	interlocking internal cable	double insulation	0.1 * 10 Exp -8	per 24 h
interlocking internal cable - short to plus potential	interlocking internal cable	double insulation	0.1 * 10 Exp -8	per 24 h
interlocking internal cable - short to minus potential	interlocking internal cable	double insulation	0.1 * 10 Exp -8	per 24 h
interlocking external cable - wire break	external cable (layered stranding)	double insulation	1 * 10 Exp -7	per 24 h
interlocking external cable – intercore contact	external cable (layered stranding)	double insulation	0.3 * 10 Exp -8	per 24 h
interlocking external cable – short to plus potential	external cable (layered stranding)	double insulation	0.3 * 10 Exp -8	per 24 h
interlocking external cable - short to minus potential	external cable (layered stranding)	double insulation	0.3 * 10 Exp -8	per 24 h
Connections				
soldered point - interruption		manual soldering (by hand)	0.3 * 10 Exp -8	per 24 h
contact point - interruption		manual attachment (by hand)	3 * 10 Exp -8	per 24 h
Other components				
fuse blows out	conventional safety fuse		3.7 * 10 Exp -7	per 24 h

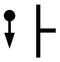
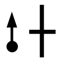
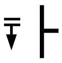
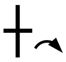
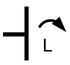
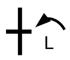
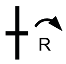
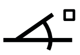
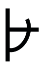
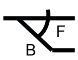
APPENDIX E 'SYMBOLS'

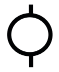
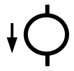
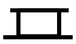
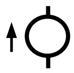
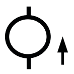
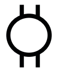
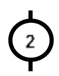
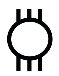
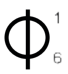
Please note: this summary overview shows a selection of symbols used in connection with relay circuits. For time and cost reasons, no attempt has been made to list exhaustively the symbols used in specific interlockings.

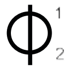
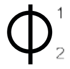
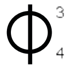
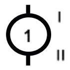
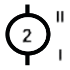
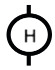
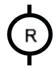
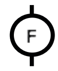
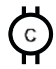
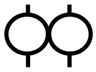
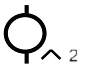
Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
make contacts (NO contacts)								
DC signal relays – normal design								
	make contact, signal relay, relay drops down in default position	x	x	x	x			
	make contact, signal relay, relay drops down in default position			x				high voltige contact
	make contact, signal relay, relay drops down in default position	x	x		x			
	make contact, signal relay, relay picks up in default position		x	x	x			
	make contact, signal relay, relay picks up in default position	x						
	make contact, signal relay, relay picks up in default position	x						DR symbol
	make contact, signal relay, relay drops down in default position	x						option: mark relay's default position
	make contact, signal relay, relay drops down in default position	x			x	x		in DE, only used in old signal-box designs
	make contact, signal relay, relay picks up in default position				x	x		
	make contact, signal relay, relay drops down in default position						x	
	make contact, signal relay, relay picks up in default position						x	
DC signal relays – relays with memory effect								
	make contact, interlocked relay relay drops down in default position	x	x	x	x			
	make contact, interlocked relay relay drops down in default position		x					
	make contact, interlocked relay relay drops down in default position	x						DR symbol
	make contact, interlocked relay relay held in default position	x	x	x	x			

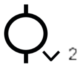
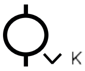
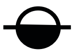
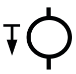
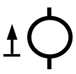
Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	make contact, interlocked relay relay held in default position	x						DR symbol
	make contact, latched relay, relay drops down in default position	x	x		x			
	make contact, latched relay, relay picks up in default position	x	x		x			
	make contact, remanence relay, relay drops down in default position			x				
	make contact, remanence relay, relay picks up in default position			x				
AC signal relay								
	make contact, two-layer motor relay, relay picks up	x						in FI, same as signal relay make contact
	make contact, two-layer motor relay, relay picks up		x					
	make contact, three-layer motor relay, L or R system, relay drops down		x					L = left-hand system, R = right-hand system
	make contact, three-layer motor relay, Left-hand system, relay drops down	x						
	make contact, three-layer motor relay, L system, relay in left-hand position	x						L = left-hand system
	make contact, three-layer motor relay, L system, relay in left-hand position		x					L = left-hand system
	make contact, three-layer motor relay, L system, relay in right-hand position	x						L = left-hand system
	make contact, three-layer motor relay, L system, relay in right-hand position		x					L = left-hand system
	make contact, three-layer motor relay, R system, relay in left-hand position	x						R = right-hand system
	make contact, three-layer motor relay, R system, relay in left-hand position		x					R = right-hand system
	make contact, three-layer motor relay, R system, relay in right-hand position	x						R = right-hand system
	make contact, three-layer motor relay, R system, relay in right-hand position		x					R = right-hand system
'All or nothing' relays								
	make contact, general relay, relay drops down in default position					x		"all or nothing" relay

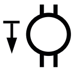
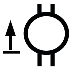
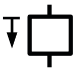
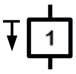
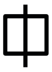
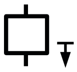
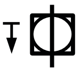
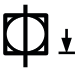
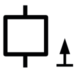
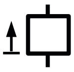
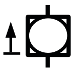
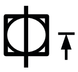
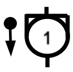
Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	make contact, general relay, relay drops picks up default position					x		"all or nothing" relay
Other NO contacts								
	make contact of a button	x	x	x	x			
Break contact (NC contacts)								
DC signal relay – normal design								
	break contact, signal relay, relay drops down in default position	x	x	x	x			
	break contact, signal relay, relay drops down in default position	x						DR symbol
	break contact, signal relay, relay drops down in default position			x				high-voltage contact
	break contact, signal relay, relay drops down in default position	x	x		x			
	break contact, signal relay, relay picks up in default position		x	x	x			
	break contact, signal relay, relay picks up in default position	x						DR symbol
	break contact, signal relay, relay drops down in default position	x						option: mark relay's default position
	break contact, signal relay, relay drops down in default position	x			x	x		in DE, only used in old signal-box designs
	break contact, signal relay, relay picks up in default position				x	x		
	break contact, signal relay, relay drops down in default position						x	
	break contact, signal relay, relay picks up in default position						x	
DC signal relays – relays with memory effect								
	break contact, interlocked relay relay drops down in default position		x	x	x			
	break contact, interlocked relay relay drops down in default position		x					
	break contact, interlocked relay relay drops down in default position	x						DR symbol
	break contact, interlocked relay, relay held in default position		x	x	x			

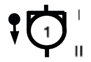
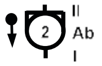
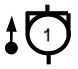
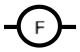
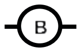
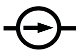
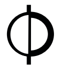
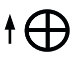
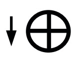
Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	break contact, interlocked relay, relay held in default position	x						DR symbol
	break contact, latching relay, relay drops down in default position	x	x		x			
	break contact, latching relay, relay picks up in default position	x	x		x			
	break contact, remanence relay, relay drops down in default position			x				
	break contact, remanence relay, relay picks up in default position			x				
AC signal relays								
	break contact, two-layer motor relay, relay picks up	x						in FI, same as signal relay break contact
	break contact, two-layer motor relay, relay picks up		x					
	break contact, three-layer motor relay, right-hand system, relay drops down	x						L = left-hand system, R = right-hand system
	break contact, three-layer motor relay, L system, relay in right-hand position	x						
	break contact, three-layer motor relay, L system, relay in left-hand position	x						
	break contact, three-layer motor relay, R system, relay in left-hand position	x						
	break contact, three-layer motor relay, R system, relay in right-hand position	x						
"All or nothing" relays								
	break contact, general relay, relay drops down in default position					x		"all or nothing" relay
	break contact, general relay, relay picks up in default position					x		"all or nothing" relay
Other NO contacts								
	break contact of a button			x	x			
Change-over contacts								
	change-over contact, signal relay	x	x		x			option: mark relay's default position and type
	change-over contact, signal relay, relay drops down in default position					x		front contact open, back contact closed

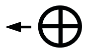
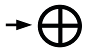
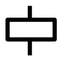
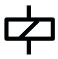
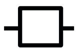
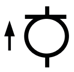
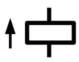
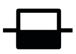
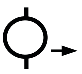
Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	change-over contact, general relay, relay drops down in default position					x		“all or nothing” relay
Signal relays								
DC signal relays								
	signal relay, 1 coil, default position: dropped down	x	x	x	x	x		
	signal relay, 1 coil, default position: dropped down	x	x					DR symbol as of 1966
	signal relay, 1 coil, default position: dropped down		x		x			
	Signal relay, 1 coil						x	relay’s default position not defined
	signal relay, 1 coil, default position: picked up	x	x	x	x			
	signal relay, 1 coil, default position: picked up	x						
	signal relay, default position: picked up	x	x		x			DR symbol as of 1966
	signal relay, 2 coils, default position: dropped down			x				
	signal relay, 2 coils, default position: dropped down	x						DR symbol as of 1966
	signal relay, 2 coils, relay picks up via coil 1	x						DR symbol as of 1966
	signal relay, coil 1, default position: dropped down	x						Symbol DR as of 1966
	signal relay, coil 2, default position: dropped down	x						Symbol DR as of 1966
	signal relay, 2 coils, relay picks up via coil 1	x						Symbol DR as of 1966
	signal relay, 2 coils, relay picks up via coil 2	x						DR symbol as of 1966
	signal relay, min. 2 coils, default position: dropped down	x	x	x	x			
	signal relay, 3 coils, default position: dropped down			x				
	signal relay, 1 coil, default position: dropped down	x	x					

Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	signal relay, 2 coils, default position: dropped down, pick-up coil	x	x					1st coil
	signal relay, 2 coils, default position: dropped down, pick-up coil	x	x					2nd coil
	signal relay, 3 coils, default position: dropped down, pick-up coil	x	x					1st coil
	signal relay, 3 coils, default position: dropped down, pick-up coil	x	x					2nd coil
	signal relay, 3 coils, default position: dropped down, pick-up coil	x	x					3rd coil
	signal relay, default position: dropped down, pick-up coil		x					
	signal relay, default position: dropped down, force-down coil		x					polarity is reversed on coil connector 6-5
	signal relay, default position: dropped down, force-down coil		x					polarity is reversed on coil connector II-I
	signal relay, default position: dropped down, pick-up coil	x						
	signal relay, default position: dropped down, holding coil	x						
	signal relay, default position: dropped down, force-down coil	x						
	signal relay with fault current coil	x	x					
	signal relay (dual-current relay), default position: dropped down			x				Energising condition: same polarity
	signal relay, 2 coils, default position: dropped down					x		usually shown vertically
	signal relay, 2 coils						x	relay's default position not defined
	signal relay, 2 coils, sensitive to current direction						x	relay's default position not defined
Signal relay with pick-up and/or drop relay								
	signal relay, 2-second pick-up delay	x	x		x			
	signal relay, 2-second pick-up delay	x			x			
	signal relay, 1 coil, pick-up delay					x		

Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	signal relay with pick-up delay						x	
	signal relay with pick-up delay (6 seconds)	x						DR symbol as of 1966
	signal relay, 1 coil, Drop delay (2 seconds)	x	x		x			
	signal relay, 2-second drop delay	x			x			
	signal relay, default position: dropped down, short-circuit coil	x	x					short-circuit coil creates drop delay
	signal relay, default position: dropped down, short-circuit coil	x			x			short-circuit coil creates drop delay
	signal relay, 1 coil drop delay					x		
	signal relay with drop delay	x						DR symbol as of 1966
	signal relay with drop delay						x	
	signal relay with pick-up and drop delay	x						DR symbol as of 1966
	signal relay (delay relay), 90-second delay						x	
DC signal relays with memory effect								
	signal relay with memory effect, drops down in default position	x						DR symbol as of 1966
	signal relay with memory effect, picks up in default position	x						DR symbol as of 1966
	signal relay with memory effect, coil 1, relay drops down	x						DR symbol as of 1966
	signal relay with memory effect, coil 2, relay drops down	x						DR symbol as of 1966
	signal relay with memory effect, relay picks up via coil 1	x						DR symbol as of 1966
	signal relay with memory effect, relay picks up via coil 2	x						DR symbol as of 1966
	interlocked relay, relay system drops down in default position			x				
	interlocked relay, relay system mechanically locked in default position			x				

Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	interlocked relay with 2 coils, relay system drops down in default position			x				
	interlocked relay with 2 coils, relay system mechanically locked			x				
	interlocked relay, relay system 1 drops down in default position		x		x			
	interlocked relay with min. 2 coils, relay system 1 drops down		x					
	interlocked relay, relay system 1 drops down in default position	x	x					
	interlocked relay, relay system 1 drops down in default position	x						
	interlocked relay, relay system 2 drops down in default position		x		x			
	interlocked relay, relay system 2 drops down in default position	x						
	interlocked relay, relay system 2 drops down in default position	x						DR symbols prior to 1966
	interlocked relay, relay system 1 held in default position	x						
	interlocked relay, relay system 1 mechanically locked in default position	x						
	interlocked relay, relay system 1 mechanically locked in default position	x						
	interlocked relay, relay system 2 mechanically locked in default position		x		x			
	interlocked relay, relay system 2 mechanically locked in default position		x		x			
	interlocked relay, relay system 2 mechanically locked in default position	x	x					
	interlocked relay, relay system 2 mechanically locked in default position	x						
	latched relay, pick-up coil, default position: dropped down	x			x			
	latched relay, drop coil, default position: dropped down	x			x			
	latched relay, pick-up coil, default position: dropped down	x	x		x			in DE, the arrows may also be located on the right-hand side

Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	latched relay, force-down coil default position: dropped down	x	x		x			
	latched relay, pick-up coil default position: dropped down		x					
	latched relay, force-down coil default position: dropped down		x					
	latched relay, pick-up coil default position: picked up	x	x		x			in DE, the arrows may also be located on the right-hand side
	latched relay, force-down coil default position: picked up	x	x		x			
	remanence relay, 2 coils, pick-up coil					x		relay with change-over contact
	remanence relay, 2 coils, drop coil					x		
	toggle relay, coil 1	x						DR symbol prior to 1966
	toggle relay, coil 2	x						DR symbol prior to 1966
	latched relay, 2 coils, default position: dropped down					x		
	polarised relay					x		
AC relays								
	AC relay	x						Relay with change-over contact
	AC signal relay						x	
	two-layer motor relay, relay drops down	x						DR symbol as of 1966
	two-layer motor relay, relay picks up	x						DR symbol as of 1966
	two-layer motor relay, relay picks up		x		x			
	three-layer motor relay, Relay drops down	x						DR symbols prior to 1966
	three-layer motor relay, Relay drops down		x					
	three-layer motor relay, relay in left-hand position	x						DR symbol as of 1966

Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	three-layer motor relay, relay in left-hand position		x					
	three-layer motor relay, relay in right-hand position	x						DR symbol as of 1966
	three-layer motor relay, relay in right-hand position		x					
	AC sequencer (block relay) Unblocked	x						
	AC sequencer (block relay) Blocked	x						
	AC sequencer (block relay)	x						
Other relays								
	"all or nothing" relay, default position: dropped down			x				
	"all or nothing" relay, default position: dropped down	x						
	"all or nothing" relay, default position: dropped down			x				
	"all or nothing" relay, 1 coil default position: dropped down					x		
	"all or nothing" delay element, 300-second delay						x	not a "fail-safe" relay
	"all or nothing" relay, default position: picked up			x				
	"all or nothing" relay, default position: picked up	x						
	"all or nothing" relay, default position: picked up			x				
	"all or nothing" relay with 2 coils acting in same direction			x				
	"all or nothing" relay with 2 coils acting in different directions			x				
	"all or nothing" relay, 1 coil, drop delay					x		
	"all or nothing" relay, 1 coil, pick-up delay					x		
	polarised relay	x						

Symbol	Explanation	used in						Notes
		DE	AT	CH	FI	SE	NL	
	(miniaturisised) polarised relay		x		x			
	three-position polarised relay with middle resting position	x						
	polarised relay with two resting positions	x						two-position polarised relay
	polarised relay with one resting positions	x						
	three-pole telegraph relay, default position left		x					three-position polarised relay
	three-pole telegraph relay, default position right		x					three-position polarised relay
	three-pole telegraph relay, default position: dropped down		x					three-position polarised relay
	contactor	x	x		x			

APPENDIX F 'DEVIATIONS FROM UIC 736 - EN 50578 - IEC 62912'

UIC 736 [1]	EN 50578 [5]	IEC 62912 [6]	notice
Scope			
none	monostable relays and as guide for other relays such as with bistable relays.	monostable relays of type N and type C.	change of scope
Generic requirements - contact guidance			
use of forcibly guided (linked) contacts	use of forcibly guided (mechanically linked) contacts		re-wording, enables more construction flexibility
direct link between the armature and the contact members which shall be rendered integral (indirect drive, by other contact members for example, is not allowed)	None		
Type N relays shall open make contacts on falling of the armature...			
under its own weight, together with that of a return spring,	under its own weight	under its own weight .... relays that open make contacts by only the force of return springs are not included in this Subclause.	major technical change for type N-relay
The material, the shape, arrangement and control of the contacts			
are left to the discretion of the railways	shall be chosen to guarantee normal and safe operation specified in environmental conditions including transport		improvement (additional requirements)
Environmental conditions			
are left to the railways	relays shall comply to EN 50125-3	relays shall comply to IEC 62498-3. conditions not covered by IEC 62498-3 shall be agreed between manufacturer and user.	improvement (reference to CENELEC / IEC standards)
Vibration & shocks			
requirements given are valid for type N & type C relays	same requirements but for N-Relays only, for type C relays, EN 50125-3:2003, 4.13, can be used.	same requirements but for N-Relays only, for type C relays, IEC 62498-3:2010, 4.13, can be used.	improvement (reference to CENELEC / IEC standards)
Magnetic system: during the entire service life prescribed, the air gap, in the energised position of the relay …			
shall not be less than 0,1 mm, to avoid residual energised of the armature	shall not be less than 0,1 mm, to avoid residual energised of the armature. A smaller dimension is allowed, if the air gap is completely filled with non-residual material		improvement, enables more construction flexibility

UIC 736 [1]	EN 50578 [5]	IEC 62912 [6]	notice
Minimum service life			
2 x 10 EXP 6 movements.	2 x 10 EXP 6 movements. For specific applications a lower value is allowed, but shall be documented.		improvement (handling of noncompliance)
mechanical: 10 x 10 EXP 6 movements	mechanical: 10 x 10 EXP 6 movements without contact load		improvement (more precisely)
Degradation of the pick-up current and drop away current			
none	Can be given alternatively as an absolute value. These values shall be specified and considered as a safety value and during lifetime may never be exceeded.		improvement (additional requirements)
Insulation - generic requirements			
none	Insulation shall be carried out according to EN 60664-1. Compliance to EN 50124-1 shall be satisfied depending on application relay specifications (i.e. connection to outdoor or indoor circuit allowed, working voltage, pollution).	Insulation shall be carried out according to IEC 60664-1. Compliance to IEC 62497-1 shall be satisfied depending on application relay specifications (i.e. connection to outdoor or indoor circuit allowed, working voltage, pollution).	improvement (reference to CENELEC / IEC standards)
Insulation - test voltage			
2 000 V rms, 50 Hz	2 000 V rms, 50 Hz	2 000 V rms, 50 Hz or 60 Hz.	improvement (60Hz as well)
Pollution			
IEC 60664-1, pollution degree 3 shall be assumed	EN 60664-1, pollution degree 3 shall be assumed	IEC 60664-1, pollution degree 3 shall be assumed	EN 60664-1 is based on IEC 60664-1
Contact - type			
single spacing with a single contact point, single spacing with double contact points, double spacing (two contacts in series),	single spacing with a single contact point, single spacing with double contact points, double spacing (two contacts in series), double spacing (two contacts in series), double spacing with double contact points (two set of parallel contacts points in series)		improvement (new contact type)
Contact pressure			
non-activated contact members shall rest on the support blades by pre-stressing	Compression force applicable for other combination of contact material shall be specified by the product specification.		improvement, enables more construction flexibility

APPENDIX G ‘TERMS’

No.	English	English explanations	German	French	Finnish	Swedish
1	All-or-nothing relay	Electrical relay, which is intended to be energized by a quantity, the value of which is either within its operative range or effectively zero.	Normal-Relais (alt: Klasse III)	Relais de tout ou rien	Kytkinrele	Neutralt relä (telefonrelä)
2	Armature	Moveable part of a relay that controls contact members.	Anker	Armature	Ankkuri	Ankare
3	Bent contact member	A contact which closes/opens before/after the other contacts closes/opens.	vor- resp. nacheilender Kontakt	Contact séquentiel	Juontokosketin	Beroende kontakt
4	Biased relay (polarized relay)	DC Relay which will operate with a supply of the specified polarity (two position Relay).	polarisiertes 2-Lagen Relais	Relais polarise	Polarisoitu rele	Permapolariserat relä
5	Bi-stable relay	Electrical relay which, having responded to an energising quantity and having changed its condition, remains in that condition after the quantity has been removed; a further appropriate energisation is required to make it change its condition.	bi-stabiles Relais (Relais mit Speicherwirkung)	Relais bistable	Bistabiili rele	Remanent relä
6	Bounce time	For a contact which is closing/opening its circuit, time interval between the instant when the contact circuit first closes/opens and the instant when the circuit is finally closed/opened.	(Kontakt-) Prellzeit	Rebonds, temps de rebondissement	Värähtelyaika	Tillslagstid eller frånslagstid
7	Break contact (for elementary relays)	Contact which is open when the relay is in its operate condition and which is closed when the relay is in its release condition.	Ruhestromkontakt (Öffner)	Contact de repos	Katkokosketin	Backkontakt
8	Change-over contact	Combination of two contact circuits with three contact members, one of which is common to the two contact circuits; such that when one of these contact circuits is open, the other is closed.	Wechsler	Contact inverseur	Vaihtokosketin	Beroende kontakter
9	Circuit dimensioning	Combination of measures in order to avoid malfunctions and/or possible wrong side failure.	Schaltungsdesign resp. Schaltungs-dimensionierung	Circuit design, dimensionnement	Virtapiirin mitoitus	Krets-dimensionering
10	Coil	A number of turns of insulated conductors connected in series and surrounded by common insulation, arranged to link or produce magnetic flux. Usually equipped with a soft-iron core.	Spule	Bobine de relais	Käämi	Spole
11	Contact blade	Non-flexible part of the contact system, designed to operate the associated contact points	Kontaktsteg	Lame de contact	Kosketinlevy	Fasta kontaktfjädrar

No.	English	English explanations	German	French	Finnish	Swedish
12	Contact bridge	Mechanical construction linked to armature for guiding or closing the contacts	Kontaktbrücke	Pont de contact	Kosketinsilta	Kontakt brygga
13	Contact (s)	Agreement of contacts members, with their insulation, which close / open their contact circuit by their relative movement.	Kontakt (e)	Contact	Kosketin	Kontakt
14	Contact force	Force which two contact members exert against each other at their contact points in the closed position.	Kontaktkraft	Force de contact	Kosketinvoima	Kontaktkraft
15	Contact gap	Gap between the contact points when the contact circuit is open. Gap between the contact tips, under specified conditions, when the contact circuit is open.	Kontaktabstand	Course neutre, intervalle de contact	Kosketinrako	Kontaktöppning
16	Contact member (for elementary relays)	Conductive part designed to co-act with another to close or open the output circuit. A conductive part or a contact assembly that is electrically isolated from other such parts when the contact circuit is open.	Kontaktglied	Pièce de contact, élément de contact	Kosketinvarsi	Rörliga kontaktfjädrar
17	Contact pin	Part of the armature system closing the contacts.	Kontaktstift	Broche de contact	Kosketintappi	Kontaktpinne
18	Contact point	Part of a contact member at which the contact circuit closes or opens.	Kontakt (punkt)	Point de contact, pièce de contact	Kosketinkärki	Kontaktpart
19	Contact pressure	The force that two contact tips exert against each other in the closed position under specified conditions.	Kontaktdruck	Pression de contact	Kosketinpaine	Kontaktkraft
20	Contact spring	Conductive part of the contact member, holds the contact points,	Kontaktfeder	Ressort de contact	Kosketinjousi	Kontaktfjäder
21	Contact tip	A conductive part of a contact member designed to co-act with another to close or open the circuit.	Kontakt (-stück)	Grain de contact	Kosketinkärki	Kontaktpart
22	Contact wipe	Relative rubbing movement of contact points after they have touched. During contact, the relative rubbing movement of contact tips when they have just touched.	Kontakt-Reibungsweg	Course d'auto nettoyage, glissement d'un contact	Koskettimen pyyhkimisliike	Kontakt glidning
23	De-energised position	For a monostable relay, specified condition of the relay when it is not energised.	nicht erregter (d.h. stromloser Zustand)	Position repos	Päästänyt tila	Frånslag
24	Drop-away current	Maximum current through the coil that, starting from the nominal current value, produces the opening of all the make contacts.	Abfallstrom	Courant de chute	Päästövirta	Frånslagström

No.	English	English explanations	German	French	Finnish	Swedish
25	Drop-down	The intended function followed by switching current off from the relay coil	(Relais-) Abfall	Chute	Päästö	Fall
26	Electromechanical relay	Electrical relay in which the intended response results mainly from the movement of mechanical elements.	elektro-mechanisches Relais	Relais électromécanique	Sähkömekaani-nen rele	Elektromekaniskt relä
27	Elementary relay	All-or-nothing relay which operates and releases without any intentional time delay.	Normalrelais (ohne Anzugs- / Abfallverzögerung)	Relais neutre (élémentaire)	Perusrele, kytkinrele	Neutralt relä
28	Energised position	For a monostable relay, specified condition of the relay when it is energised by the specified energising quantity and has responded to that quantity.	erregter Zustand (stromdurchflossener Zustand)	Position travail	Vetänyt tila	Tillslag
29	Failed to drop down	A relay cannot change into release condition because of a fault.	Abfallversagen	Relais ne tombe pas	Päästö estynyt (rele juuttunut)	Misslyckades att falla
30	Forcibly guidance	See relay with forcibly guided (mechanically linked) contacts.	Zwangsführung	Manœuvre effectuée positivement	Pakko-ohjaus	Beroende
31	Forcibly guided (mechanically linked) contacts	See relay with forcibly guided (mechanically linked) contacts.	Zwangsgeführte Kontakte	Contact guidés	Pakko-ohjatut koskettimet	Beroende kontakter
32	Interlocked relay	A relay composed of two or more coils, each with its own armature and associated contacts, so arranged that movement of one armature or the energising of its coil is dependent on the position of the other armature.	Stützrelais	Relais accolés	Tukirele	(Polariserat relä)
33	Interlocking	Interdependent liaison between the control levers or the electrical control circuits of different apparatus such as points, signals, which makes it impossible to place them in positions which are unsafe.	Abhängigkeit (siehe auch „signal dependence“)	Enclenchement	Riippuvuus (sana tarkoittaa myös asetinlaitetta)	Säkerhets-beroende
34	Latched relay	A relay which once energized will remain in the operated stat until it is intentionally unlatched, usually by energising a separate “un-latching” coil winding.	Haftrelais oder Remanenzrelais	Relais de verrouillage / rémanence	Magneettirele, remanenssirele	Polariserat relä
35	Line relay	Any relay used for the control of one circuit by another over a line or wire.	Signalrelais	Relais de ligne	Linjarele	No translation (line relay are not used in Sweden)
36	Make contact (for elementary relays)	Contact which is closed when the relay is in its operate condition and which is opened when the relay is in its release condition.	Arbeitsstromkontakt (Schliesser)	Contact de travail	Sulkukosketin	Frontkontakt

No.	English	English explanations	German	French	Finnish	Swedish
37	Malfunctions	A situation for which the electrical equipment does not perform the intended function due to a variety of reasons.	Fehlfunktion	Dysfonctionnement	Virhetoiminta	Felfunktion
38	Mono-stable relay	Electrical relay which, having responded to an energising quantity and having changed its condition, returns to its previous condition when that quantity is removed.	Normalrelais	Relais monostable	Normaalirele	Neutralt relä
39	Nominal current	(The) current passing through the coil of the relay when the coil is supplied with nominal voltage	Nennstrom	Courant nominal	Nimellisvirta	Märkvärde
40	Normally closed circuit	Circuit in which the used relay is normally energised.	Ruhestromkreis, Ruhestromprinzip	Circuit normalement fermé	Lepovirtaperiaate	Normalt dragen krets
41	Normally open circuit	Circuit in which the used relay is normally de-energised	Arbeitsstromkreis, Arbeitsstromprinzip	Circuit normalement ouvert	Työvirtaperiaate	Normalt fallen krets
42	Operate condition (for elementary relays)	For a mono-stable relay, specified condition of the relay when it is energised by the specified energising quantity and has responded to that quantity; for a bi-stable relay, the condition other than the release condition as declared by the manufacturer.	Arbeitsbedingungen	Etat de travail	Toimintatila	Märkvärde
43	Pick-up	The intended function followed by switching current to the relay coil	(Relais-) Anzug	Attraction	Veto	Drag
44	Pick-up current (compression)	Minimum current through the coil that, starting from a null value, is necessary to move the armature from the release position to the operate position and apply the specified contact force, closing all the make contacts.	Anzugsstrom	Courant de compression (attraction)	Vetovirta	Tillslagsström
45	Pick-up current (service value)	Minimum current through the coil that, starting from a null value, is able to move the armature closing all the make contacts.	Haltestrom	Courant d‘attraction	Pitovirta	Märkvärde
46	Polar relay	Relay which will operate to one of two states depending on the supply polarity and release to a third state (tree position relay).	polarisiertes 2- oder 3-Lagenrelais	Relais polarise	Polarisoitu rele	No translation (polar relay are not used in Sweden)
47	Relay	See electromechanical relay.	Relais	Relais	Rele	Relä
48	Relay function time	Pick-up or drop-down time of a relay i.e. time between switching the current to the coil until the armature has reached its activated end position or time between switching the current off from the coil until the armature has reached its basic end position	Relaisreaktionszeit (Anzugs- resp. Abfallzeit)	Temps de fonctionnement	Releen toiminta-aika	Drag och fall tid

No.	English	English explanations	German	French	Finnish	Swedish
49	Relay with forcibly guided (mechanically linked) contacts	Elementary relay with at least one make contact and at least one break contact and including mechanical measures to prevent any make contact(s) and any break contact(s) being in the closed position simultaneously.	Relais mit Zwangsgeführten Kontakten (Signalrelais)	Relais à contacts guidés	Pakko-ohjatuilla koskettimilla varustettu rele (turvalaiterele)	Relä med beroende kontakter
50	Release condition (for elementary relays)	For a mono-stable relay, specified condition of the relay when it is not energised; for a bi-stable relay, one of the conditions, as declared by the manufacturer.	Abfallbedingungen	État de repos	Päästöarvo	Frånvärde
51	Residual sticking	Condition of a relay when the relay is not energised but the armature does not drop down due to the remaining magnetic force within the relay system. Malfunction for normal relays, normal function remanent type relay.	Klebenbleiben des Ankers (ggf. gewollt, Rest-Remanenz)	Rémanence	Ankkurin jumiutuminen	Ankarklibbning
52	Return spring	A spring in the armature system increasing the force for the drop-down of the relay	Rückstellfeder	Ressort de rappel	Palautusjousi	Retur fjäder
53	Safety apparatus	Apparatus intended to perform its functions safely	Sicherungsanlage	Appareil de sécurité	Turvalaitos	Säkerhets-anläggning
54	Safety relay	Relay with forcibly guided (mechanically linked) contacts.	Sicherheitsrelais	Relais de sécurité	Turvarele	Säkerhetsrelä
55	SAR (German term)	Safety (orientated) Application Rule.	Sicherheitsbezogene Anwendungsregel	Règles d'application de sécurité	Turvallisuuteen liittyvä käyttöehto	Teknisk säkerhetstyrning
56	Signal dependence	A signal is only allowed to show a free aspect, if all elements (e.g. a switch) are in the correct position, these element are locked as long as the signal show a free aspect.	Signalabhängigkeit	Dépendance de signalisation	Turvallisuusehto	Signalberoende
57	Signalling relay	Direct current relays for signalling installations.	Signalrelais	Relais de signalisation	Turvalaiterele	Signalrelä
58	Type C relay	Proved relays, Relays for which the safety conditions are guaranteed by control of operations in the circuit.	C-Relais (alt: Klasse II Relais)	Relais contrôlé	C-tyypin rele	Typ C-relä
59	Type N relay	Non-proved relays, Relays themselves fulfilling all the safety conditions without the aid of other relays or without control of operations in the circuit.	N-Relais (alt: Klasse I Relais / Schwerkraftrelais)	Relais non contrôlé	N-tyypin rele	Typ N-relä
60	Vane Relay	AC Relay operated by an inductive vane mechanism.	Scheibenrelais	Relais à cage (relais disque)	Levyrele	Skivrelä

Please note: the following pictures show selected relay components. The numbering corresponds to the relevant line(s) in the "terms" table

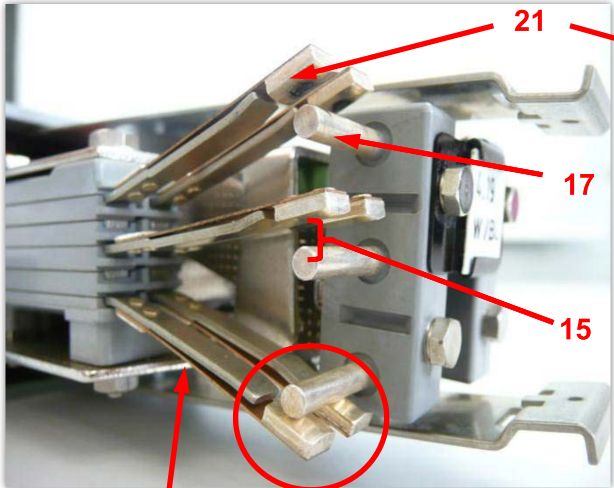


Figure 76: Details of TM relay

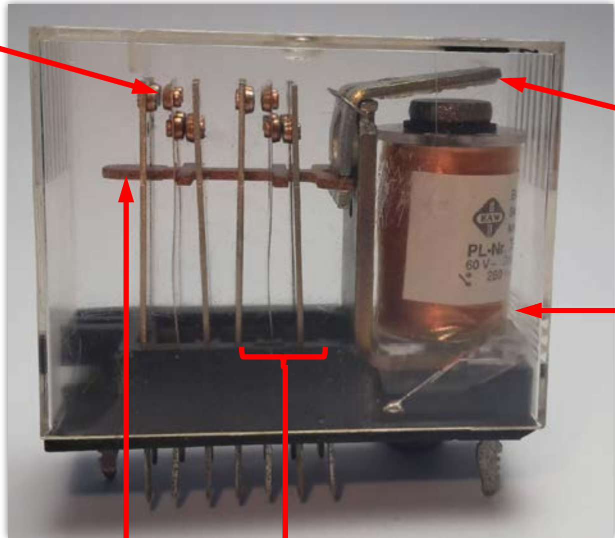


Figure 77: General relay with forced contact guidance

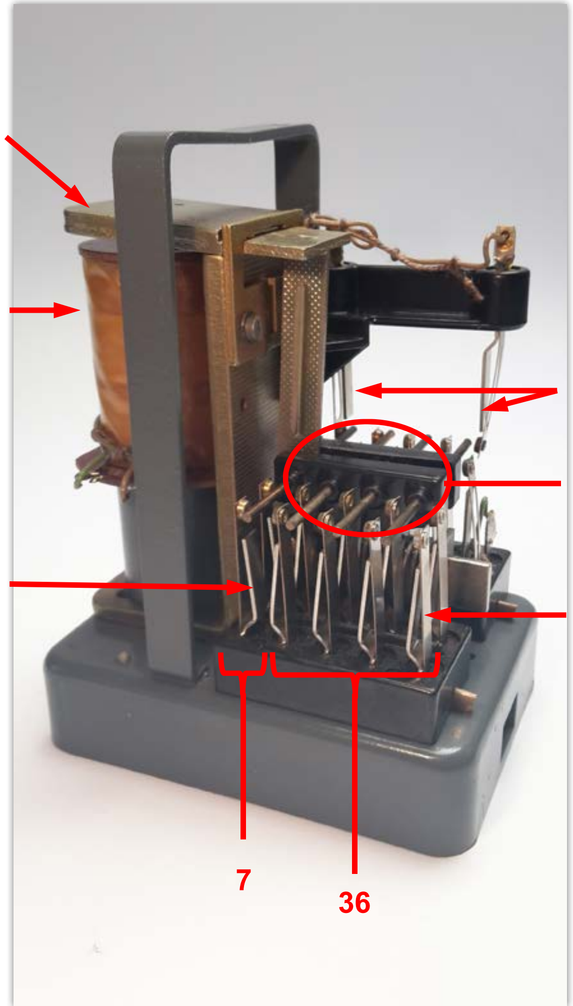


Figure 78: Latched relay of design II WSSB (relay not shown in fitting position)

APPENDIX H ‘PICTURES – USE OF RELAYS IN INTERLOCKINGS’

Figure 79: Relay groups of design SpDr S60

Figure 80: Two-layer motor relays in an SpDr S60

Figure 81: Relay groups of design SpDr S600

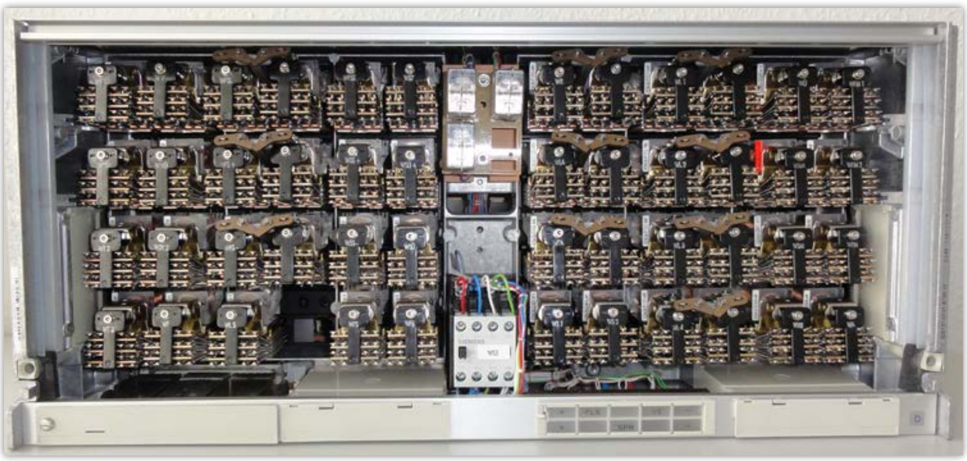


Figure 82: Relay groups of design SpDr S600

Figure 83: Relay groups of design WSSB II

Figure 84: Relay group of design WSSB III

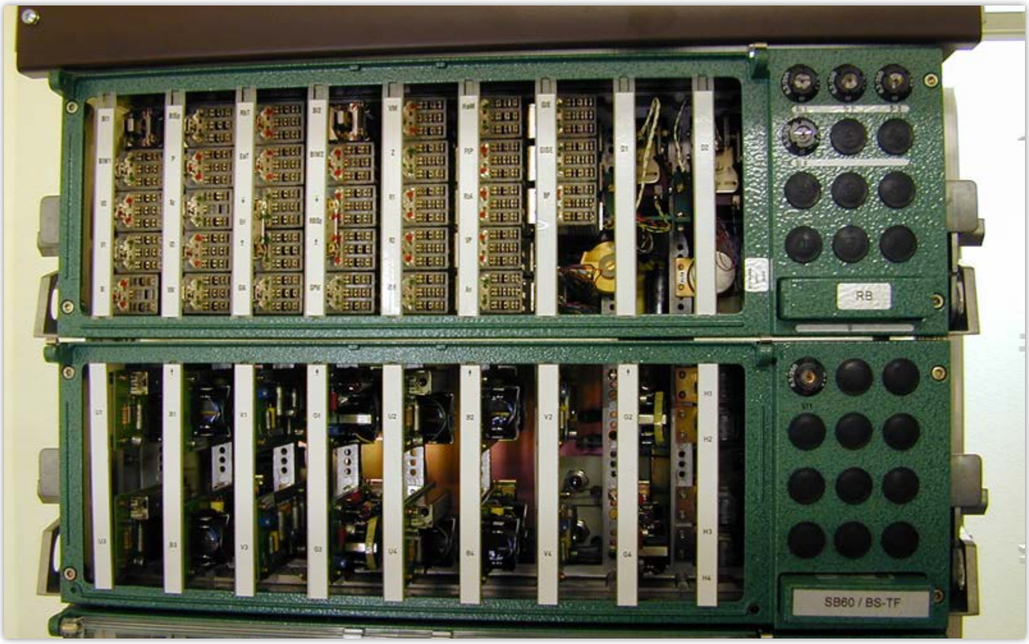


Figure 85: Relay block group with relays of type SEL L72

Figure 86: Relay groups of design SpDr L 60

Figure 87: Relay groups of design Do 67

Figure 88: Relay groups in an electronic interlocking of type ESTW IL 90

Figure 89: Relay control devices in an electronic interlocking of type ELEKTRA

Please note: The control devices had been removed for testing purposes, i.e. they are not in their end position

Figure 90: Relay groups in an electronic interlocking of type SIMIS-C

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Editions Techniques Ferroviaires
Railway Technical Publications
Eisenbahntechnische Publikationen

16 rue Jean Rey - F 75015 PARIS
www.shop-etf.com

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Design and production:
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A. Mignot and L. Wattignies

October 2018
ISBN 978-2-7461-2690-9