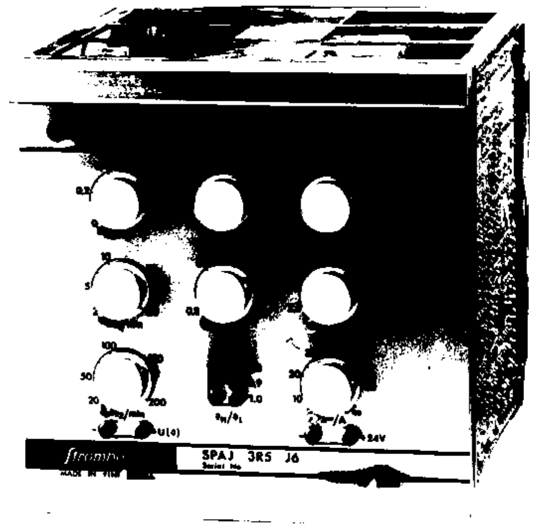
Three-phase combined MOTOR PROTECTION RELAY

SPAJ 3R1 J6
SPAJ 3R5 J6

Static current relay — SPAJ
Number of phases — 3
Spacing letter — R
Rated current in amps — 1 / 5
Mechanical construction code — J6

Main features



The relay plug-in unit type SPAJ 3R5 J6

- multi-relay protection for motors and generators
- also applied for protection of transformers and cable feeders
- used for motor protection, the relay provides instantaneous short-circuit protection, thermal overload protection, single-phasing and unbalanced load protection, incomplete phase sequence protection and protection against prolonged starting
- used for protection of generators, transformers and feeders, the relay provides instantaneous short-circuit protection, definite time overcurrent protection, thermal overload protection and unbalanced load or single-phasing protection
- continuously adjustable wide range current settings
- two separately and continuously adjustable time-constants of the thermal unit enable the thermal characteristic of the relay to be adapted close to that of the protected object
- output on the front panel for a load indicating instrument for checking the thermal replica of the relay
- thermal unit partial reset facility enables hot restarting, if required, by the motor drive
- an operation of the thermal unit can be postponed, if required, by the process
- selectable prewarning level indicates an approaching thermal operation
- negligible thermal overshoot, due to digital information processing
- stabilized negative sequence current unit
- low burdening of current transformers, < 0,5 VA per phase
- low transient overreach, < 5 %
- robust mechanical design
- self-regulated supply unit for any d.c. supply within the range 40...275 V
- high-duty output contacts for direct tripping of circuit-breakers
- relay cases available for flush mounting, semi-flush mounting or projecting mounting or the relay can be enhoused in a 19 inch subrack

Contents

Area of application

The motor protection relays SPAJ 3R1 J6 and SPAJ 3R5 J6 are integrated multi-relay protections, the former on 1 A rated c.t. secondary level and the latter on 5 A rated c.t. level. One motor protection relay comprises three functional units, i.e. a three-phase definite time overcurrent unit with an additional high set element, a three-phase thermal overload unit with two separately adjustable time-constants and an unbalanced load unit, based on measuring the negative sequence current.

The motor protection relay provides short-circuit, thermal overload, single-phasing and stalling protection for motors. Applied on big generators the motor protection relay provides short-circuit, overcurrent and thermal overload protection and for small generators also unbalanced load protection. The motor protection relay is also used in other applications, in which a definite time overcurrent protection, combined with a thermal overload protection and a single-phasing protection is required, e.g. for protection of power transformers and feeders.

The motor protection relay is provided with three energizing current inputs, but it can also be two-phase or single-phase connected. When single-phase connected, the negative sequence current protection is out of operation.

Principle of operation

Thermal overload unit

The thermal overload unit measures the load currents of the protected object and by means of this information and the information about the rated load current of the protected object and its thermal time-constants, the motor protection relay forms a replica of the thermal situation of the protected object as a function of time. The thermal replica, as seen by the relay, is available from the relay in the form of a voltage $U(\vartheta)$, which is directly proportional to the heating of the protected object. The operation of the thermal overload unit is mathematically characterized by the following expression:

$$U(\vartheta) \sim \left(\frac{I}{I_{MN}}\right)^2 \left[1 - K e^{-t/\tau_1} - (1 - K)\, e^{-t/\tau_2}\right] \qquad (1)$$

where $U(\vartheta)$ = a voltage proportional to the heating ϑ of the protected object
- I = the load current of the protected object, variable
- I_{MN} = the rated load current of the protected object
- τ_1 = shorter time-constant of the protected object
- τ_2 = longer time-constant of the protected object
- K = weighting factor of the exponential functions
- t = integrating time, i.e. the time of the protected object being in service

By means of the time-constants τ_1 and τ_2 and the weighting factor K, the exponential function (1) is given a form, which as closely as possible conforms with the heating curve of the object to be protected. The setting I_{MN} defines the rated load current of the protected object, i.e. I_{MN} is the c.t. secondary current, when the protected object runs with rated loading.

The tripping heating ϑ_L is continuously adjustable and it is set in proportion to the nominal heating ϑ_N. The nominal heating ϑ_N is the heating level obtained at rated current I_{MN} after an infinite range of time. The thermal overload unit delivers a prewarning for an approaching thermal tripping. The prewarning level ϑ_L is selectable in steps by means of a plug selector on the relay front panel.

As the protected object is running, the relay measures the load currents and forms a thermal replica of the heating of the protected object according to expression (1), adding up a voltage U (ϑ) in its memory. The voltage U (ϑ) is proportional to the heating of the protected object and when the protected object is heavy-loaded, the voltage U (ϑ) increases and when the protected object is moderately loaded, the voltage U (ϑ) decays, continuously following the thermal situation of the object to be protected.

The voltage U (ϑ), proportional to the heating of the protected object as seen by the thermal unit, is available in a measuring outlet on the relay front panel. The voltage is so calibrated that the voltage value U (ϑ), corresponding to the nominal heating ϑ_N, equals 1,0 V. The voltage U (ϑ), measured in the outlet on the relay front panel, at any moment thus indicates the heating level reached, or mathematically expressed:

$$\vartheta = \frac{U(\vartheta)}{1,0\ V} \cdot \vartheta_N \qquad (2)$$

When the thermal unit has operated and the protected object has been disconnected, the voltage U (ϑ) starts decaying with a speed, which depends on the set time-constants τ_1 and τ_2. As the voltage U (ϑ) goes below the level corresponding to the set tripping heating level ϑ_L, the output relay of the thermal unit drops out and the protected object can be restarted.

As the heating has exceeded the set prewarning level ϑ_H, it can be intentionally and manually lowered just below the prewarning level ϑ_H, i.e. the thermal unit can be partially reset, which enables a thermal trip to be postponed or if the thermal unit already has operated, enables a hot restarting of the protected object.

As the thermal unit reaches the set prewarning level ϑ_H, an auxiliary output relay picks up and the indicator T_1 of the thermal units turns on, glowing with a green colour, thus indicating that the thermal prewarning level ϑ_H has been exceeded and that a thermal tripping is to be expected, unless the load is not decreased. As the set tripping heating level ϑ_L is reached, an other high-duty output relay picks up and the operation indicator T_1 turns red.

Definite time overcurrent unit

The overcurrent unit is a three-phase definite time overcurrent element, provided with an additional high set instantaneous stage. The overcurrent unit starts, as the input energizing current of one or more of the phases exceeds the set operating current $I>$. After a preset delay of 100 ms, the starting output relay picks up. After a set time-lag t, the overcurrent unit operates, its high-duty auxiliary output relay picks up and the operation indicator T_2 turns on, glowing with a red colour. If the input energizing current exceeds the set high set current level $I>>$, the overcurrent unit operates instantaneously, i.e. the high-duty auxiliary output relay picks up without any intentional delay and the operation indicator T_2 turns red. The time-lag stage and the instantaneous stage operate a common output relay. The high set stage can be set out of operation by selecting the setting $I>> = \infty$, infinite.

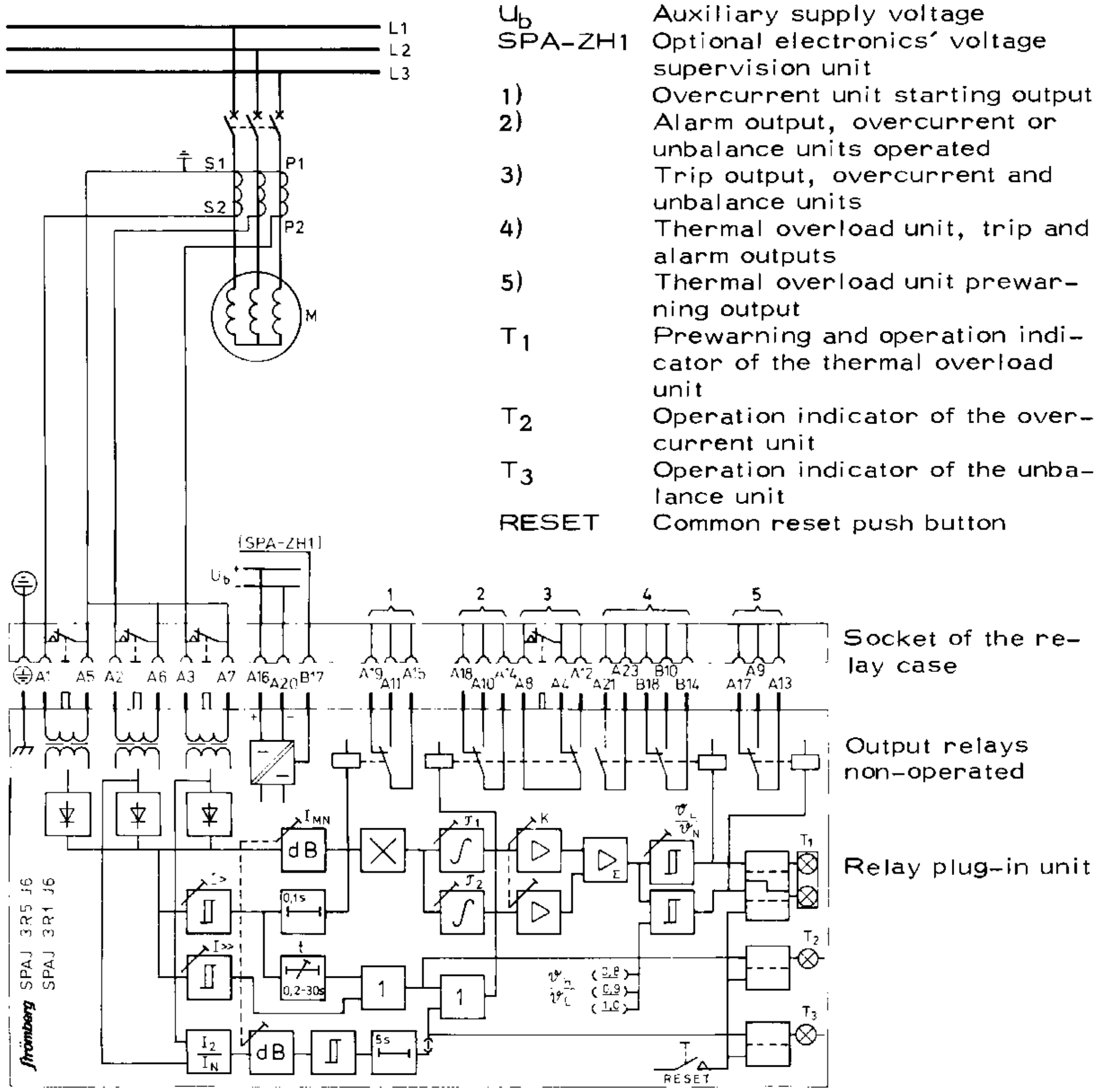
Unbalanced load unit

The unbalanced load unit is based on measuring the negative sequence current I_2, which, when present, indicates a phase current unbalance. Severe negative sequence currents appear upon loss of one phase and during unsymmetrical faults in the network. An unbalanced loading of the stator winding of a rotating machine causes additional losses in the machine and if the situation is permitted to persist, heavy local overheating may appear. The unbalanced load unit starts, if the negative sequence current I_2 exceeds a preset starting level of 15 % of the set rated current I_{MN} of the protected object. After a preset time-lag of 5 s, the unit operates and the heavy-duty output relay, common to that of the overcurrent unit, picks up and the operation indicator T_3 turns on, glowing with a red colour. The unbalanced load unit is stabilized against maloperation in heavy through-fault conditions. As the load current exceeds the set rated load current I_{MN}, the stabilizing function is effected and the starting level of the unbalanced load unit is raised proportionally to the load current. The unbalanced load unit can be set out of operation by replacing a plug selector on the P.C. board of the unit.

Thermal replica outlet $U(\vartheta)$

The thermal overload unit forms a voltage $U(\vartheta)$, which is proportional to the heating of the protected object. This voltage is fed to a measuring outlet, marked $-\odot\odot+ U(\vartheta)$, on the relay front panel. The outlet is protected against short-circuiting and overloading. The voltmeter, used for measuring the voltage $U(\vartheta)$, should have a relatively high input resistance, i.e. $R_{in} \geq 20$ kΩ/V. Too low an input resistance of the measuring instrument gives too low a meter reading. A recorder can also be connected to the measuring outlet. In this way a graph can be plotted, showing the thermal loading of the protected object in service over a period of time. The method can also be used for controlling the relay settings.

Block schematic diagram



U_b	Auxiliary supply voltage
SPA-ZH1	Optional electronics' voltage supervision unit
1)	Overcurrent unit starting output
2)	Alarm output, overcurrent or unbalance units operated
3)	Trip output, overcurrent and unbalance units
4)	Thermal overload unit, trip and alarm outputs
5)	Thermal overload unit prewarning output
T_1	Prewarning and operation indicator of the thermal overload unit
T_2	Operation indicator of the overcurrent unit
T_3	Operation indicator of the unbalance unit
RESET	Common reset push button

Block schematic diagram and connection diagram for the motor protection relays SPAJ 3R1 J6 and SPAJ 3R5 J6

Connections

The motor protection relay is usually three-phase energized, the input A1-A5 from phase L1, the input A2-A6 from phase L2 and the input A3-A7 from phase L3. The relay type SPAJ 3R1 J6 is rated 1 A and the type SPAJ 3R5 J6 is rated 5 A. The energizing inputs are equipped with automatically operating bridge contacts, which short-circuit the c.t. secondaries, when the relay unit is withdrawn from its case. The relay can be withdrawn from and pushed into its case during operation.

The motor protection relay can also be two-phase or single-phase connected. The thermal overload unit and the overcurrent unit can be two-phase or single-phase energized, while the unbalance unit requires two-phase connection for proper operation. If the motor protection relay is single-phase energized, the unbalance unit should be set out of operation by means of a selector plug on the printed circuit board, see also page 15.

When the motor protection relay is two-phase connected, the phases and energizing inputs correspond to each other as listed in table 1.

Energizing current from phases	Energizing input on relay	
	A2–A6	A3–A7
L1 and L2	L1	L2
L2 and L3	L2	L3
L3 and L1	L3	L1

Table 1.
Two-phase connection with cycling of phases and energizing phase c.t.s

As the overcurrent unit starts, the starting output relay, A11–A15–A19, picks up, after a preset time-lag of 100 ms. As the definite time stage $I>$ or the high set stage $I>>$ of the overcurrent unit operates, the output relay, A4–A8–A12 and A10–A14–A18, picks up. The change-over contacts A11–A15–A19 and A4–A8–A12 are high-duty contacts, capable of directly controlling a circuit-breaker trip circuit, while the change-over contact A10–A14–A18 is a light-duty contact for signalling purposes.

As the thermal overload unit reaches the set prewarning heating level ϑ_H, the output relay, A9–A13–A17, picks up. As the set thermal trip level ϑ_L is reached, the output relay, A21–A23 and B10–B14–B18, picks up. The normally open contact A21–A23 and the change-over contact B10–B14–B18 are high-duty contacts, capable of directly controlling a circuit-breaker trip circuit. The change-over contact A9–A13–A17 is a light-duty signalling contact.

The unbalance unit operates the same output relay as the overcurrent unit, i.e. A4–A8–A12 and A10–A14–A18.

The auxiliary supply voltage of the relay is fed to the terminals 16 and 20, the terminal 16 being positive and the terminal 20 negative. The internal supply unit withstands a reversed polarity of the supply voltage, but the supply unit does not start.

A label on the relay plug-in unit states the auxiliary voltage range, for which the relay unit is intended.

If a continuous supervision is required for the internal electronics' voltage of the relay, an optional electronics' voltage supervision unit can be connected to the terminal 17. The supervision unit provides an alarm signal over a normally closed contact, if the internal voltage of the electronics turns abnormal.

Operation indicators and reset push button

The three functional units of the motor protection relay are each provided with their operation indicators on the front panel.

The operation indicator T_1 of the thermal overload unit is a dual colour indicator, which turns green, as the set prewarning heating level ϑ_H is exceeded and automatically changes to red, if the thermal unit operates, i.e. the set tripping heating level ϑ_L is exceeded. The indications are memory controlled, i.e. the indications persist, until they are reset by pushing the common reset push button on the relay front panel. The green indication of the indicator T_1 resets also automatically, if the heating goes below the prewarning level ϑ_H.

The operation indicator T_2 turns red, if either the definite time stage $I>$ or the high set stage $I>>$ operates, and the indication persists, until it is reset by pushing the common reset push button.

The operation indicator T_3 turns red, if the unbalanced load unit operates and the indication persists, until the common reset push button is pressed.

The reset push button on the relay front panel has three different functions.

For the first the reset push button is pressed for acknowledging the operation indications.

For the second the reset push button can be used for a partial resetting of the thermal unit, which enables a hot restarting of the protected object. This feature is not effected before the heating has exceeded the set prewarning level ϑ_H. When the reset push button is pressed, the heating level, as stored in the memory of the thermal unit, falls down to a level 70 % of the set thermal tripping level. Thus the reset push button can also be used for postponing an approaching thermal tripping, if the reset push button is pressed after that the heating level ϑ_H has been exceeded. The partial resetting possibility should be used exercising great caution, because a hot restarting of a protected object can be accompanied by considerable risks.

For the third the reset push button can be used for a rapid check of the internal electronics' voltage of the relay. Whenever the relay is connected to a proper auxiliary supply source and the reset push button is pressed, the indicator T_1 should turn on, glowing weakly with a green colour, thus indicating the presence of a proper internal electronics' voltage. If the indicator does not turn on, the electronics' voltage is to be measured in the measuring outlet on the relay front panel.

Auxiliary supply voltage

For proper operation the static protective relays require a continuous supply of auxiliary energy, fed from a suitable d.c. or a.c. source. The level and the type of auxiliary voltage, i.e. a.c. or d.c., intended for supply of the protective relays, is to be part of the order statements.

Normally, the protective relays each are equipped with an internal power unit, intended for supply from any station battery, the level of which is within the range 40...275 V d.c. This standard power unit covers most of the voltage levels commonly used in power plants and transforming stations. A protective relay, provided with the standard self-regulated power unit, is interchangeable between different stations, as long as their station battery voltage levels are within the range 40...275 V d.c.

On request the relay is provided with an internal supply unit, rated for a supply voltage within the range 17...40 V d.c.

A label on the left side of the relay plug-in unit states the supply voltage range, for which the relay is specified.

The internal power unit galvanically isolates the auxiliary supply network from the electronics of the relay and forms a stabilized 24 V d.c., which is the internal feed voltage level of the electronics.

The internal 24 V d.c. can be checked roughly by pushing the reset push button on the relay front panel, see page 7, section "Operation indicators and reset push button". The internal electronics' voltage is also brought out to the outlet, marked -⊙ ⊙+ 24 V, on the relay front panel. From this outlet the voltage can be measured using a voltmeter, the input impedance of which is $\geq 20\ k\Omega/V$, to provide an accurate meter reading. Too low an input impedance of the meter renders too low a meter reading. The internal electronics' voltage level is to be 23...25 V d.c. The measuring outlet is short-circuit and overload protected.

The internal electronics' voltage can be continuously monitored with an optional monitoring relay type SPA-ZH 1. The monitor delivers an alarm signal through a normally closed contact, if the monitored voltage takes an abnormal level, if the relay supply voltage disappears or if the relay unit is withdrawn from its case during operation.

Relay settings

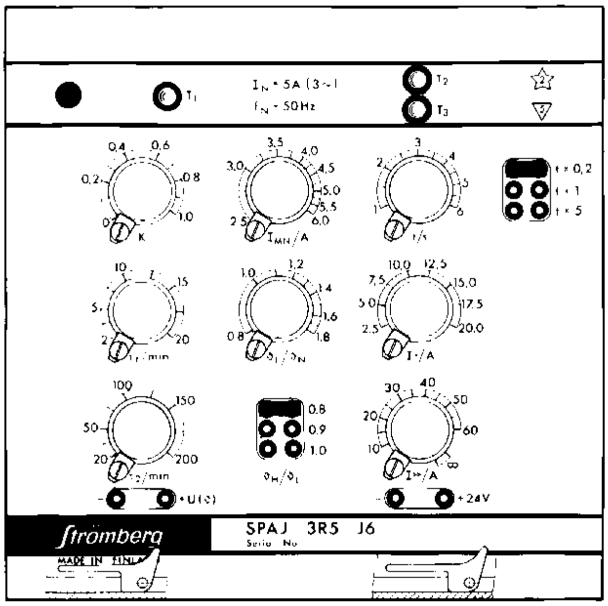
The operating values of the motor protection relay are set by means of setting knobs and range selector plugs on the relay front panel. There is also a selector plug on the relay printed circuit board, by means of which the unbalance unit can be set out of operation. For settings, see also the section "Examples of applications" and Appendix 1 and 2.

Draw-out handle
Reset push button
Operation indicators
T_1 = thermal overload unit
T_2 = overcurrent unit
T_3 = unbalance unit

Settings:
- Balansing constant K
- Rated load current I_{MN}/A
- Time-lag t/s setting knob and range selector plug, stage I >
- Shorter time-constant τ_1/min
- Tripping heating ϑ_L/ϑ_N
- Operating current I >/A
- Longer time-constant τ_2/min
- Prewarning heating ϑ_H/ϑ_L
- High set current I >>/A

Measuring outlets for:
- the voltage U (ϑ)
- the electronics´ voltage

Draw-out handle and locking latches



Front view of the motor protection relay type SPAJ 3R5 J6. The setting knobs are mechanically lockable by means of locking screws.

Thermal overload unit

The thermal overload unit is provided with six settings. The setting I_{MN}/A is a correction setting, by means of which the actual rated load current of the protected object is defined. I.e. the setting I_{MN}, expressed in amps, is equal to the current, measured or calculated, which flows in the c.t. secondary circuit, as the protected object runs at its nominous load. The function of the thermal overload unit and the unbalance unit is based on the setting I_{MN}. For the thermal overload unit, the setting I_{MN} defines the nominous heating level ϑ_N and for the unbalance unit the setting I_{MN} defines the actual operating level and the point, where the stabilization feature is activated in through-fault situations. The actual load current setting I_{MN} is continuously adjustable within the range 0, 5... 1, 2 A for the relay SPAJ 3R1 J6 and within the range 2, 5... 6, 0 A for the relay SPAJ 3R5 J6.

The shorter time-constant τ_1 is continuously adjustable within the range 2...20 min and the longer time-constant τ_2 is continuously adjustable within the range 20...200 min. Note! For τ_1 the dial starts 2; 3, 5; 5; 7, 5 etc. and for τ_2 the dial starts 20; 35; 50; 75 etc.

By means of the weighting factor K, the relative weight of the two exponential functions in the expression (1), on page 3, on the total thermal function is determined. I.e. the thermal behaviour of the protected object is the sum of two exponential functions with different time-constants and in different applications and for different protected objects the two exponential functions are of different importance. How much importance the two exponential functions will have on the total exponential function (1), is defined by the setting K. The factor K is continuously adjustable within the range 0, 0... 1, 0. If K is set 0, 0, the exponential function with the time-constant τ_1 is set out of meaning and if K is set 1, 0, the exponential function with the time-constant τ_2 is set out of meaning. In these two cases, the thermal behaviour of the unit is defined by a simple exponential function with only one time-constant. In all other cases, when K is set anywhere between 0 and 1, the thermal behaviour of the overload unit is defined by two exponential functions, which is close to the physical reality for all rotating machines.

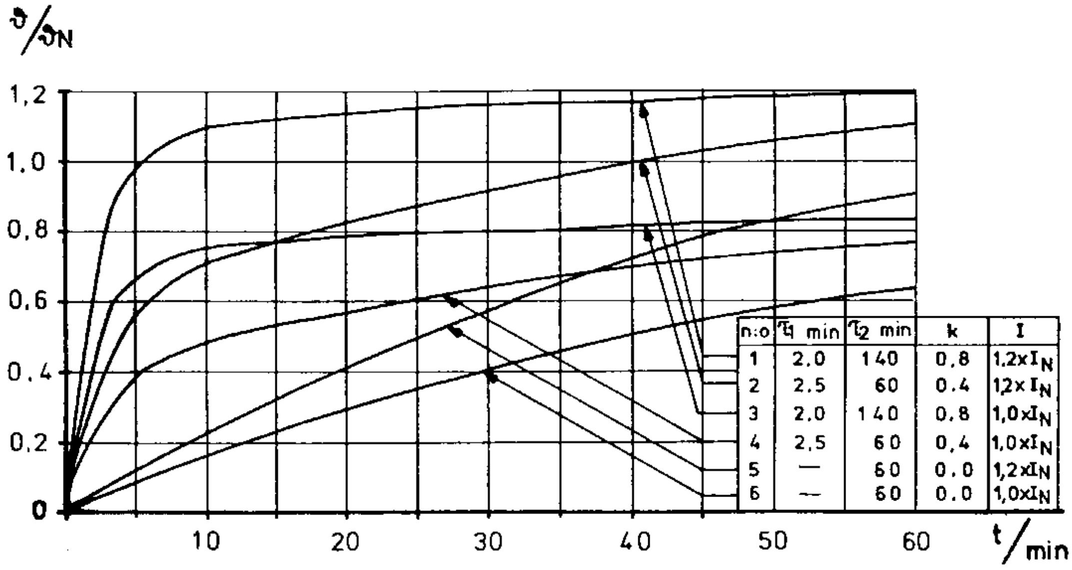
The tripping heating level ϑ_L is set as a relative value, based on the nominous heating ϑ_N and the setting is continuous within the range ϑ_L/ϑ_N = 0, 8. . . 1, 8. A prewarning before an approaching thermal tripping is obtained at 80 %, 90 % or 100 % of the set thermal tripping level ϑ_L. The prewarning level is set by means of a plug, the positions of which are marked 0, 8; 0, 9 or 1, 0, corresponding to 80 %, 90 % or 100 % of the tripping heating level ϑ_L. In the position 1, 0 the prewarning is obtained simultaneously with the thermal tripping.

When giving the thermal overload unit a proper setting, an overload protection can be realized for any object to be protected, the thermal behaviour of which can be described by an exponential function with one or two time-constants.

By means of the time-constants τ_1 and τ_2 and the weighting factor K, the thermal overload unit can be given a setting, which follows any heating curve of a protected object, which with a sufficient accuracy can be described by one simple or two superponed exponential functions, see fig. 1. If the protected object is sensitive to short-time overloads, the shorter time-constant τ_1 and the weighting factor K should be emphasized, when setting the thermal unit, see fig. 1, curves 1 and 3. A small set value of τ_1 and a high set value of K means that the thermal unit reacts rapidly to variations of the load current. If the protected object is less sensitive to short-time overloads, the effect of the weighting factor K can be forced towards the exponential function with the longer time-constant τ_2 by giving K lower settings. The curves 2 and 4 in fig. 1 are thermal load curves, where the longer time-constant is dominant.

Thermal load curves for motors, generators and transformers are typical thermal load curves, composed of two superponed exponential functions with different time-constants. For these objects, the shorter time-constant mainly defines the flow of heat from the copper to the iron, while the longer time-constant defines the flow of heat from the iron to the cooling medium. The weighting constant K defines the over-all effect of the flow of heat in the protected object. The above description is a simplification of the thermal behaviour of an object to be protected. In practice the flow of heat in an object is defined by a great number of time-constants, of which one, the longer, is usually well defined, while a great number of shorter time-constants in practice can be substituted with one short time-constant. By doing so in a thermal overload relay, the relay can be set very close to the actual thermal behaviour of a motor, generator or transformer.

By giving the weighting factor K the setting 0 (zero) or 1, the thermal overload unit acts as a thermal relay with only one time-constant, see expression (1) on page 3. If K = 1, the time-constant τ_1 defines the behaviour of the thermal unit and if K = 0, the time-constant τ_2 alone defines the performance of the thermal unit. Cable feeders are typical objects of protection, the heating curves of which are defined by only one time-constant, see fig. 1, curves 5 and 6.



n:o	τ_1 min	τ_2 min	k	I
1	2,0	140	0,8	$1,2\times I_N$
2	2,5	60	0.4	$1,2\times I_N$
3	2,0	140	0,8	$1,0\times I_N$
4	2,5	60	0,4	$1,0\times I_N$
5	—	60	0.0	$1,2\times I_N$
6	—	60	0.0	$1,0\times I_N$

Fig. 1. Typical heating curves for some objects to be protected

No. 1 and 3: Generator curves
No. 2 and 4: Asynchronous motor curves
No. 5 and 6: Cable curves

Fig. 2 illustrates the behaviour of the thermal overload in two situations, where the protected object is loaded up to a certain heating level and then unloaded. The thermal overload unit is set K = 0,4, τ_1 = 2,5 min and τ_2 = 60 min. In case A the protected object has been operated with a load current of 1,14 x I_{MN} for so long a period of time, that the heating has stabilized on the level 1,3 x ϑ_N (Note! $1,14^2 \approx 1,3$). As the heating has stabilized on this level, the protected object is disconnected and the thermal unit starts cooling according to the time-constants and settings of the relay. In case B the protected object has been operated with a load current of 0,9 x I_{MN} for so long a period of time, that the heating has stabilized on the level 0,81 x ϑ_N. Then the load current is increased to 1,5 x I_{MN} and the protected object is disconnected, as the heating reaches the level 1,3 x ϑ_N and the relay starts cooling. When comparing the cooling curves A and B, it can be seen that the cooling curves do not concur, although the cooling starting level and the settings are the same in both cases. This means that the thermal overload unit also takes account of the thermal situation prior to the thermal tripping.

While the operation of the thermal overload unit is based on a direct measurement of the phase currents and on mathematical calculations, carried out in the relay digital circuits, the thermal overload unit will be extremely fast operating and adaptively following the load current variations. Hence the thermal overload unit can also be applied for protection of such objects, the load of which varies rapidly and irregularely.

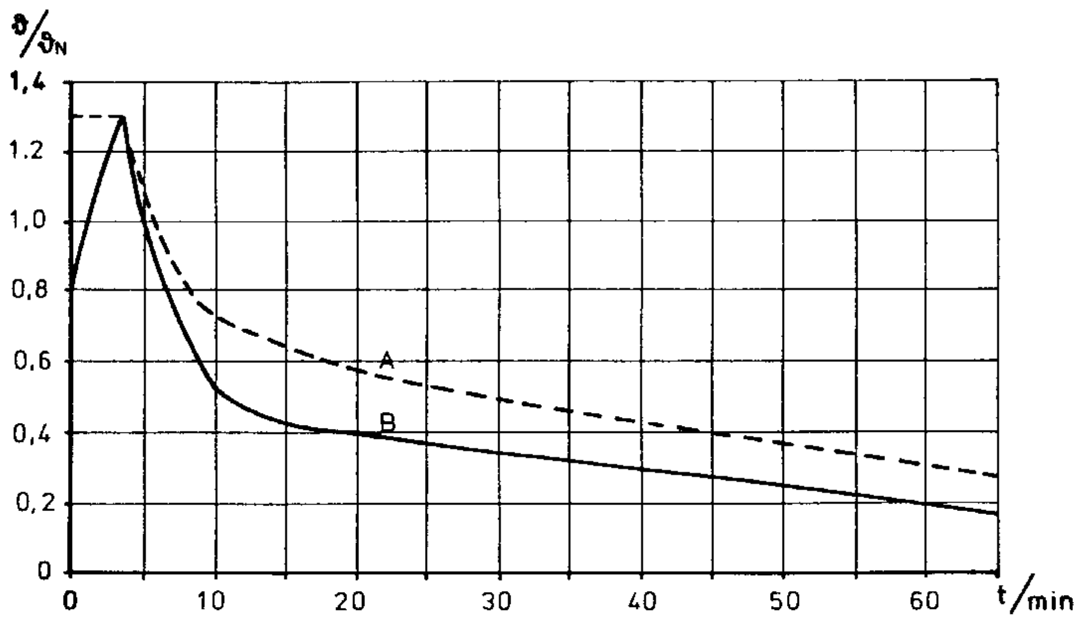


Fig. 2. The function of the thermal overload unit in a cooling situation. The cooling takes place after two different previous loading conditions.

The thermal trip level ϑ_L and the thermal prewarning level ϑ_H are set according to the requirements, set up by the protected object and the drive. When setting the thermal overload unit, it must be kept in mind that the heating is proportional to the load current squared. E.g. a thermal load of 1,3 x ϑ_N corresponds to a 14 % overcurrent (= $\sqrt{1,3} \sim 1,14$). If the prewarning level is set ϑ_H = 0,8 x ϑ_L, this means a 2 % overcurrent in the previous example ($\sqrt{0,8} \times 1,3 \approx 1,02$), as the set tripping level was ϑ_L = 1,3 x ϑ_N .

Examples of characteristics, which can be given to the thermal unit of the motor protection relay

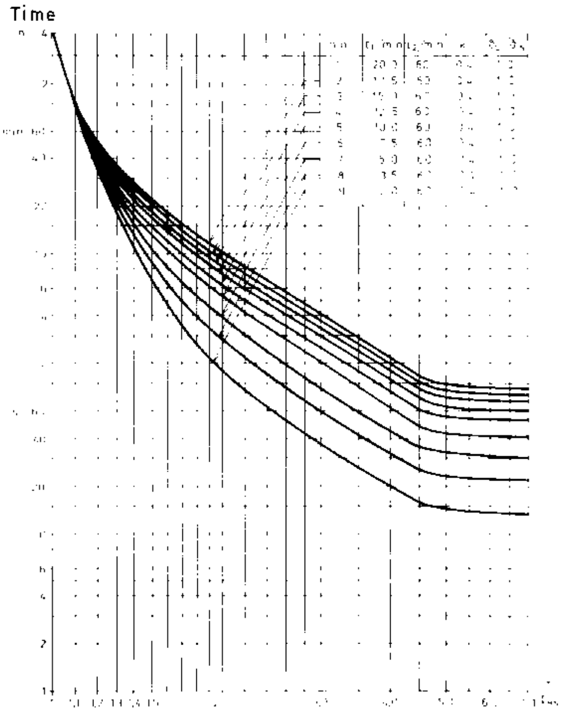


Fig. 3. The effect of the time-constant τ_1 on the current/time characteristic of the thermal unit.

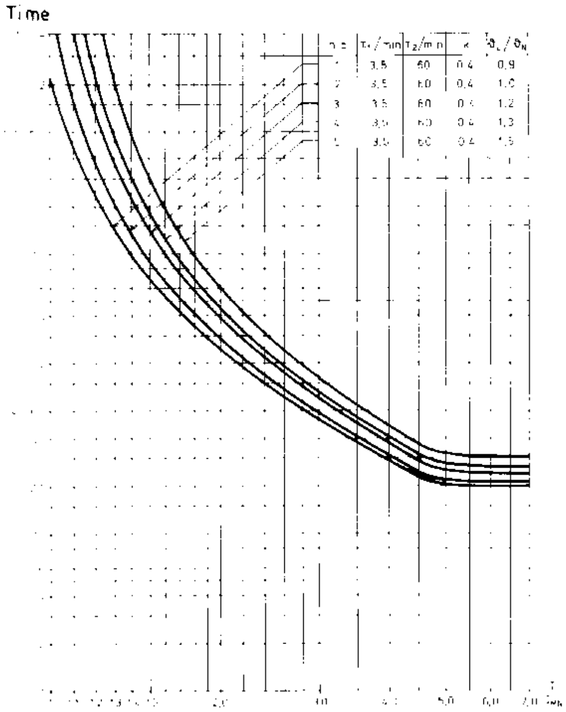


Fig. 4. The effect of the set thermal trip level ϑ_L/ϑ_N on the current/time characteristic of the thermal unit.

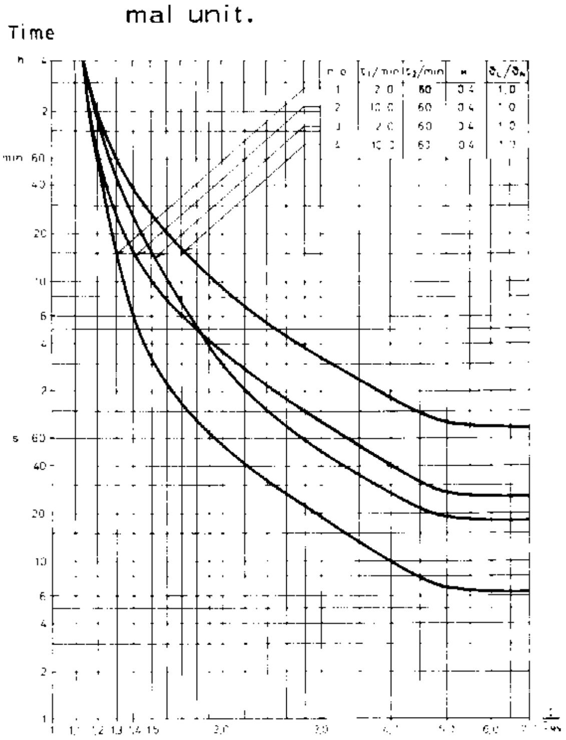


Fig. 5. The effect of a prior load on the current/time characteristic of the thermal unit.
Curves 1 and 2: The protected object has been preloaded with 0,9 x I_{MN}, until a thermal steady state has been reached.
Curves 3 and 4: The protected object has not been preloaded.

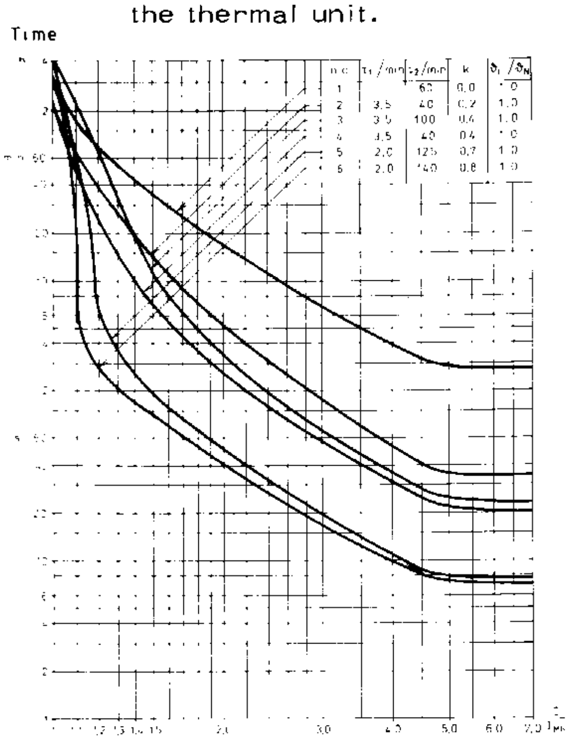


Fig. 6. Typical current/time characteristics for various protected objects.
Curve 1: Cable feeder.
Curves 2, 3 and 4: Asynchronous motors.
Curves 5 and 6: Generators.

Definite time overcurrent unit

The starting current I > of the definite time stage is continuously adjustable within the range 0, 5. . . 4, 0 A for the relay type SPAJ 3R1 J6 and within the range 2, 5. . . 20, 0 A for the relay type SPAJ 3R5 J6. The dial of the setting is graded directly in amps.

The time-lag t of the definite time stage is continuously adjustable within the total range 0, 2. . . 30, 0 s. The setting range is divided in three partial ranges by means of a range selector plug, i.e. 0, 2. . . 1, 2 s; 1, 0. . . 6, 0 s and 5, 0. . . 30, 0 s, corresponding to the selector plug positions t x 0, 2; t x 1 and t x 5 respectively. If the range selector is missing, the dial multiplier is t x 5. The time-lag, expressed in seconds, is obtained by multiplying the dial reading by the multiplier, corresponding to the range selector plug position.

The high set current I >> is continuously adjustable within the range 2. . . 12 A for the relay type SPAJ 3R1 J6 and within the range 10. . . 60 A for the relay type SPAJ 3R5 J6. The dial of the high set current setting is graded directly in amps. The high set stage operates instantaneously, the operating time including the output relay being < 40 ms. If the high set current is set for ∞, infinite, the operation of the high set stage is set out of operation.

The high set stage I >> is used for short-circuit protection. The definite time stage I > is used in applications, requiring two-level overcurrent protection. In motor protection the definite time stage I > is used for supervision of the motor starting time.

The starting output relay operates after a preset delay of 100 ms, after the definite time stage starting current I > having been exceeded.

Unbalance unit

The unbalance or the negative sequence current unit is preset to operate after a delay of 5 s, as the negative sequence current I_2 (or I_-) exceeds 0, 15 x I_{MN}.

The unbalance unit is stabilized against maloperation, caused by high through-fault currents. The stabilisation is effected, if the load current exceeds the level 1 x I_{MN}, and the starting level I_2/I_{MN} is increased. The stabilizing feature prevents relay maloperation in heavy through-fault conditions and during startings, see fig. 7.

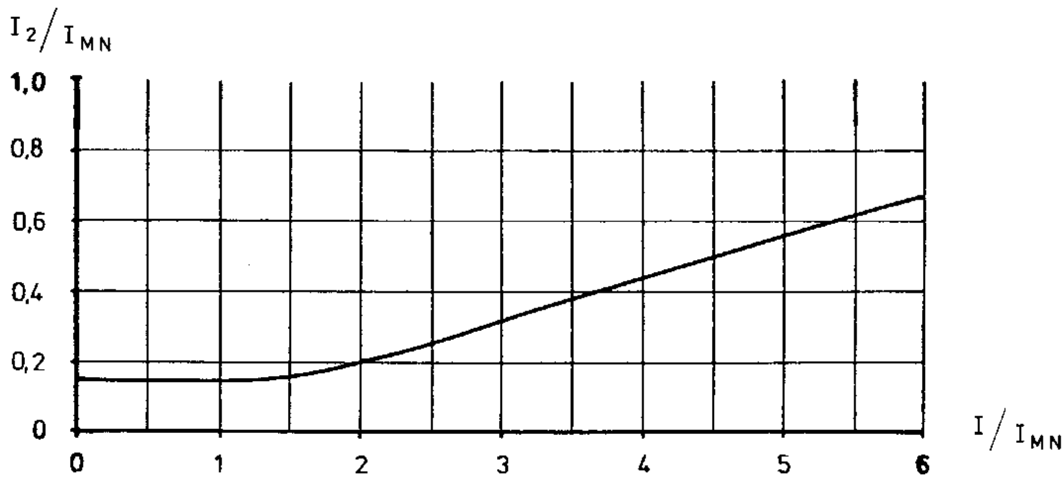


Fig. 7. The negative sequence current I_2, required for operation as a function of the load current I_{MN}

The unbalance unit can be set out of operation, if the protected object is provided with a separate negative sequence current relay, which is usually the situation for power plant generators.

The unbalance unit is set out of operation by means of a selector plug on one of the printed circuit boards of the motor protection relay. As the plug is in the position S2, the unbalance unit is out of operation, see fig. 8. Access to the selector plug is obtained by turning the left side printed circuit board of the motor protection relay aside. This can be done, after unwinding two screws in the upper corners of the printed circuit board. When the printed circuit board is opened, it should be handled with care.

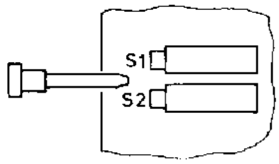


Fig. 8. Selector plug for disconnection of the unbalance load unit

Technical data

	SPAJ 3R1 J6	SPAJ 3R5 J6
Energizing inputs		
Rated current I_N	1 A	5 A
Thermal withstand capability, continuously/for 10 s/for 1 s	3/30/100 A	15/150/500 A
Input impedance	$\leq$ 150 mΩ	$\leq$ 20 mΩ
Rated frequency f_N	50 Hz	50 Hz
" " " , on request	60 Hz	60 Hz
Overcurrent unit		
Low current I > setting range	0,5...4,0 A	2,5...20,0 A
High current I >> setting range	2...12 A, ∞	10...60 A, ∞
Transient overshoot	$\leq$ 5 %	
Time-lag setting range for the low current I > stage	0,2...30,0 s	
Dial accuracy, applies over full setting range and for any setting	± 5 %	
Repetitive accuracy	± 2 %	
Starting output relay time-lag, preset	100 ms ± 10 %	
High set stage I >> operating time including the output relay	< 40 ms	
Drop-off time including the output relays	$\leq$ 60 ms	
Drop-off/pick-up ratio	$\geq$ 0,95	
Thermal overload unit		
Setting range for the rated load current I_{MN}	0,5...1,2 A	2,5...6,0 A
Dial accuracy, applies over full setting range and for any setting	± 2 %	
Balancing constant K setting range	0...1,0	
Setting range for the tripping thermal level ϑ_L/ϑ_N	0,8...1,8	
Dial accuracy, applies over full setting range and of any setting	± 5 %	
Repetitive accuracy	± 2 %	
Selectable thermal prewarning levels ϑ_H/ϑ_L	0,8 (80 %) 0,9 (90 %) 1,0 (100 %)	
Setting range for the shorter time-constant τ_1	2...20 min	
Setting range for the longer time-constant τ_2	20...200 min	
Dial accuracy, applies over full setting range and for any setting	± 10 %	
Repetitive accuracy	± 5 %	
Calibration of the thermal replica voltage U (ϑ)	$\frac{\vartheta}{\vartheta_N} \cdot 1{,}00$ V	
Accuracy of the voltage U (ϑ)	± 0,02 V	
Unbalance unit		
Setting range for the rated load current I_{MN}	0,5...1,2 A	2,5...6,0 A
Operating level of the negative phase sequence current I_2/I_{MN}	13...18 %	
Preset operating delay	4...6 s	
Drop-off/pick-up ratio	$\geq$ 0,95	
Drop-off time including the output relay	$\leq$ 60 ms	

Auxiliary supply voltages

Standard relay	40...275 V d.c.
Relay on request	17...40 V d.c.
Auxiliary supply burdens, relay under standby/tripping conditions	~ 7 W/~ 18 W
Influence on the relay operating values of the auxiliary supply within its permitted range of variation	± 0,5 %
Permitted ripple in d.c. supply as per IEC 255-11	≤ 12 %

Output contacts

Making and breaking voltage, d.c. or a.c.	250 V	250 V	250 V
Making capacity for 0,5 s	30 A	20 A	10 A
Continuous carry	10 A	7 A	5 A
Breaking capacity for d.c. with the load time-constant L/R ≤ 40 ms at 48/110/220 V d.c.	7 A/3 A/1 A	7 A/3 A/1 A	1 A/0,75 A/ 0,15 A
Terminal numbers	A11-A15-A19, B10-B14-B18, A21-A23	A8-A12, A9-A13	A13-A17, A4-A8, A10-A14-A18

Test voltages

Insulation test voltage, inputs and outputs between themselves and to the framework as per IEC 255-5, series C	2 kV, 50 Hz, 1 min
Impulse test voltage, inputs and outputs transverse, and inputs/outputs to the framework as per IEC 255-4, appendix E, class III	5 kV, 1,2/50 μs, 0,5 J
High frequency test voltage, inputs and outputs transverse, inputs/outputs to the framework as per IEC 255-6, appendix C, class III	2,5 kV, 1 MHz
Spark interference test voltage, inputs and outputs transverse, inputs/outputs to the framework as per SEN 36 15 03 class 3	4...8 kV

Environmental conditions

Relative humidity as per DIN 40040 class F	≤ 95 %, max. 30 d/a at +35°C
Specified operation temperature range	-10...+55°C
Temperature influence on the operating values of the relay over the operation temperature range	< 0,2 %/°C
The relay maintains its operating capability over the ambient temperature range	-25...+55°C
Storage temperature range	-40...+70°C
Degree of protection of the relay cases	IP 40
Mass of the relay unit	4,9 kg

Examples of applications

Example 1: The motor protection relay applied for protection of standard asynchronous motors (induction motors)

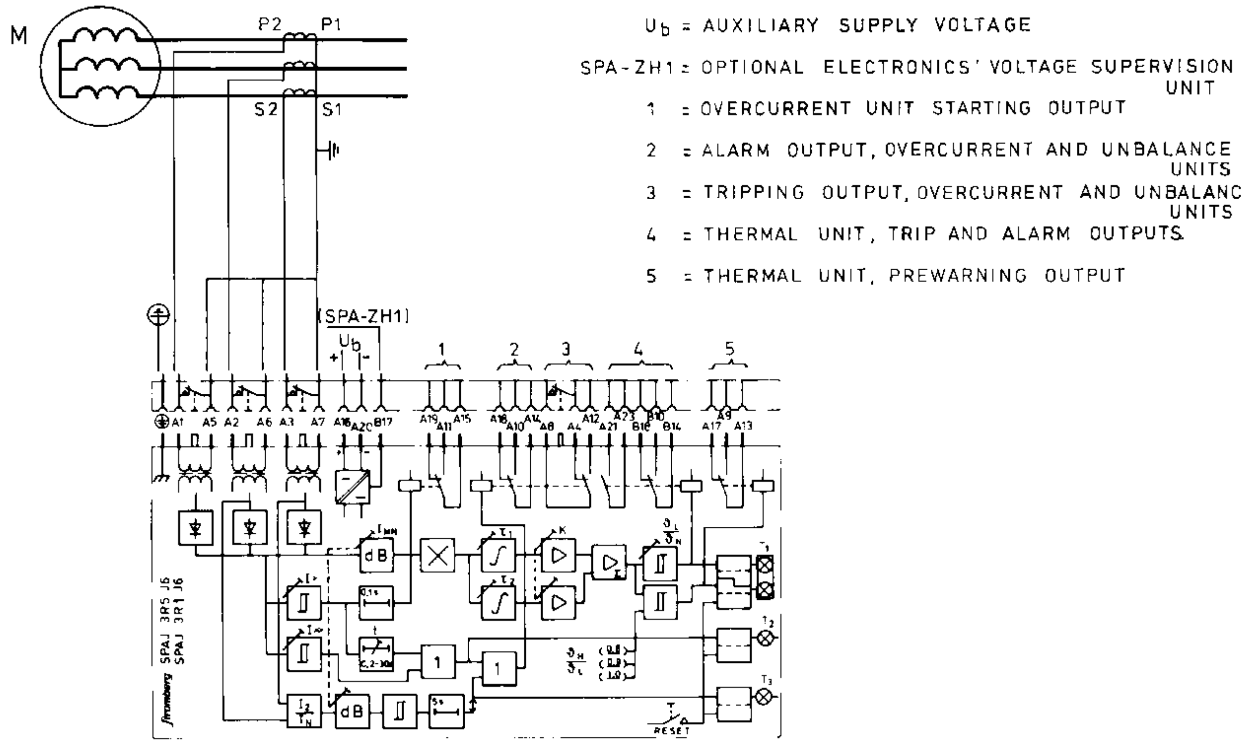


Fig. 9. The motor protection relay and its connection to the line current transformers

These setting instructions for protection of standard asynchronous motors apply to motor installations, where:

- the motor supply voltage is equal to the motor rated voltage +10...±0 % at the moment the motor is started
- the ambient temperature of the protected motor does not exceed +40°C
- the motor is allowed to be started twice from cold-motor-state and once from hot-motor-state

If the motor drive differs from what is specified above, i.e. if three successive cold starts are permitted, if the motor is allowed to be started during undervoltage in the supply network, or if the motor supply can be changed over from one network to an other after a short break in the supply, the settings should be selected with care and, if necessary, the motor manufacturer or the relay manufacturer should be consulted.

If a motor is replaced by a new one, the settings of the motor protection relay should be carefully checked to match the settings, according to the requirements on the new motor in the current application. The settings of the motor protection should also be checked, if the loading situation of the motor is change in a way, which effects the starting time of the motor in the particular drive.

Rated motor load current I_{MN}

The rated motor load current I_{MN} is defined as the current, flowing in the c.t. secondaries, as the motor runs at its rated load. The current is either calculated from the primary rated load current by means of the c.t. transforming ratio or the current is measured in the c.t. secondary circuit, as the motor runs at rated load. It is essential to set the current I_{MN} as accurately as possible.

Thermal overload unit

The thermal overload unit protects the motor from being overloaded in a way, which causes damage to the motor on account of too high temperatures in certain parts of the motor.

The longer time-constant τ_2 is set according to the loading time-constant of the motor as stated by the motor manufacturer.

Table 2. Loading time-constant for some Strömberg-manufactured l.v. and h.v. standard asynchronous motors

Motor type specification and construction	Rated voltage of the motor/kV	Loading time-constant/min
HXU 71 - 100 1)	0,38...0,66	60
HXU 71 - 100 1)	3...6	100
HTU 80 - 100 2)	3...6	40
HJU 12 3)	3...10	60
HSU 10 - 11 4)	3...10	60

1) - self-cooled
- totally enclosed construction
- cast iron frame

2) - self-cooled open construction or
- self-cooled totally enclosed construction, connected to a cooling air duct or to a heat-exchanger
- through-ventilated stator
- sheet-steel frame

3) - self-cooled or auxiliary cooled totally enclosed construction, connected to a cooling air duct or to a heat-exchanger
- self-cooled specially protected by enclosure
- stator and rotor through-ventilated
- sheet-steel frame

4) - self-cooled totally enclosed construction, connected to a heat-exchanger
- stator and rotor through-ventilated
- sheet-steel frame

The shorter time-constant τ_1 is selected from the diagrams in fig. 10.

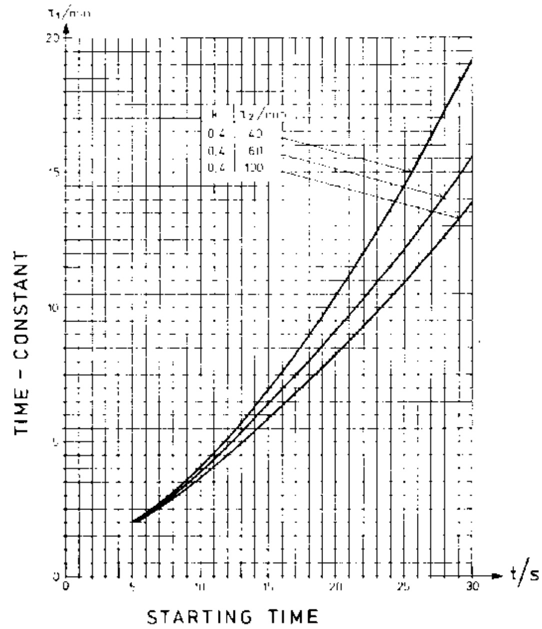


Fig. 10. The shorter time-constant τ_1 as function of the motor starting time and the longer time-constant τ_2

The curve, corresponding to the time-constant τ_2 is followed and the point on the curve, corresponding to the motor starting time on the horizontal axis, is looked for. By projecting the point on the curve, corresponding to the motor starting time, towards the vertical axis, the time-constant τ_1 is found.

For standard motors, the weighting factor K is set for 0,4. The tripping heating level ϑ_L/ϑ_N is set for 1,3 and the prewarning thermal level ϑ_H/ϑ_L is set for 0,8.

Fig. 11 a illustrates the waiting time, required before a hot motor can be successfully restarted. A hot motor is a motor, which has reached its rated heating level. Fig. 11 b illustrates the same waiting time, required before a motor can be successfully restarted, when the motor has been tripped by the thermal unit, i.e. the heating of the motor has reached the set level 1,3 x rated heating level ϑ_N.

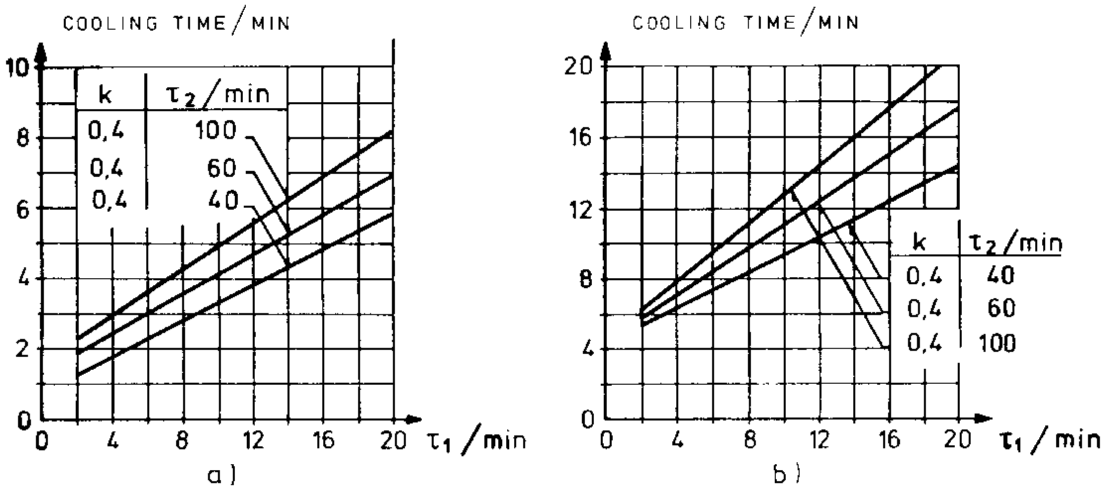


Fig. 11 a and b. Cooling times of the thermal overload unit as function of the settings of the unit

Overcurrent unit

High set current stage I >>

The high set current stage constitutes the motor short-circuit protection. The high set stage is set on a value, corresponding to 1,5 x the motor starting current. If the starting current of the motor is unknown, the high set stage is set on a value appr. 10 x the motor rated load current.

Low current stage I > and operating time-lag t

The definite time low current stage supervises the motor starting time. The low current I > is set high enough to permit the motor to be loaded up to the point of motor pull-out torque. For standard motors, the low current is set on a value, corresponding to 3 x the motor rated load current. The operating time-lag t is set on a level 10 % more or at least 1 s more than the measured starting time of the motor, including the load connected to the motor.

Thermal tripping and prewarning levels

If not otherwise stated by the motor manufacturer, the tripping heating level ϑ_L/ϑ_N is set at 1,3 and the prewarning heating level ϑ_H/ϑ_L is set at 0,8.

Unbalance unit

The unbalance unit supervises the presence of a negative sequence current in the phase currents. The most severe current unbalance appears at the loss of one phase of the motor supply.

The unbalance unit starts, if the negative phase-sequence current exceeds 15 % of the motor rated load current I_{MN}. The operating time-lag is preset to 5 s and the unbalance unit is stabilized against maloperation, caused by heavy through-fault currents.

Example of settings

Features of the protected motor:

- rated current I_N	275 A
- starting current I_s	$6 \times I_N$
- starting time t_s	13 s
- loading time-constant τ_2	60 min
Current transformers selected, ratio	300/5 A
Motor protection relay selected	SPAJ 3R5 J6

Settings of the motor protection relay:

I_{MN}	$= \frac{5 \cdot 275}{300} A \approx 4,6\ A$	(rated motor load current)
K	$= 0,4$	(page 19)
τ_1	$= 5,3$ min	(" 19, fig. 10)
τ_2	$= 60$ min	(given)
ϑ_H/ϑ_L	$= 0,8$	(page 19)
ϑ_L/ϑ_N	$= 1,3$	(" 19)
t	$= 1,1 \times 13\ s \approx 14,3\ s$	(" 20)
I >	$= 3 \times I_{MN} \approx 14\ A = 2,8 \times I_N$	(" 20)
I >>	$= 1,5 \times 6 \times I_{MN} \approx 42\ A = 8,4 \times I_N$	(" 20)

Example 2: The motor protection relay applied for protection of standard synchronous motors

These setting instructions for protection of standard synchronous motors apply to motor installations, where:
- the motor supply voltage is equal to the motor rated voltage +10...-5 % at the moment the motor is started
- the motor is directly on line started or started over a transformer
- the motor is started as a asynchronous motor over a starting transformer or reactor or directly on line
- the motor is allowed to be started twice from cold-motor-state and once from hot-motor-state
- the ambient temperature of the protected motor does not exceed +40°C

If the conditions on site differ from the above specified, the settings of the relay should be selected carefully and, if necessary, the motor manufacturer or the relay manufacturer should be consulted.

If a motor is replaced by a new one in a specified application, the settings of the motor protection relay should be checked and readjusted, if required, to meet the requirements of the new motor in the current application. The settings should be checked also, if the motor load is changed in a way, also altering the motor starting time in that particular drive.

Rated motor load current I_{MN}

The rated motor load current I_{MN} is calculated from the expression:

$$I_{MN} = \frac{I_N}{\mu_I}$$

where I_N = motor full load current
μ_I = current transformer ratio

If the c.t.s are located on the network side of a possible block transformer, the influence of this transformer on the motor current setting I_{MN} should be noticed. The current I_{MN} can also be measured in the c.t. secondary circuits, as the motor runs at full load.

Setting of the overcurrent unit

High set current stage I>>

The high set stage operating current I>> is set to a level, corresponding to 1,5 x the motor starting current. The motor starting current is calculated in the relaying point, i.e. the effect of a possible block transformer, starting transformer or starting reactor should be noticed.

Low current stage I> and operating time-lag t

The definite time low current stage I> is set to a level, corresponding to 1,2 x the motor rated current and the operating time-lag t is set 10 % or at least 1 s in excess of the motor starting time. If the motor is started with full load and the motor is of heavy design, the low current stage can be set higher, but not in excess of a level, corresponding to 0,7 x the motor starting current. The motor rated current is calculated, taking into account the location of the current transformers.

Setting of the thermal overload unit

The shorter heating time-constant τ_1

When protecting chopper motors, the shorter time-constant τ_1 is selected from fig. 12. For other synchronous motor drives, the shorter time-constant τ_1 is selected from fig. 13.

For respective drives, a proper setting value is obtained as follows. A line is drawn at right angle to the horizontal axis and through the point on the axis, which corresponds to the motor starting current, and an other line is drawn at right angle to the vertical time axis through the point, which corresponds to the motor starting time. By means of the point of intersection of the two auxiliary lines drawn, the curve nearest to the intersection point is selected and the values of τ_1, K and ϑ_L/ϑ_N, related to this curve, are taken as set values for the thermal unit. If the point of intersection falls underneath the curve group, the curve No. 1 is selected. If the point of intersection falls in the middle between two curves, the value of τ_1 is interpolated from the τ_1 values of the adjacent curves.

No.	τ_1/min	K	ϑ_L/ϑ_N
1	2,0	0,6	1,3
2	2,5	0,6	1,3
3	3,5	0,6	1,3
4	5,0	0,6	1,3
5	7,5	0,6	1,3
6	10,0	0,6	1,3
7	12,5	0,6	1,3

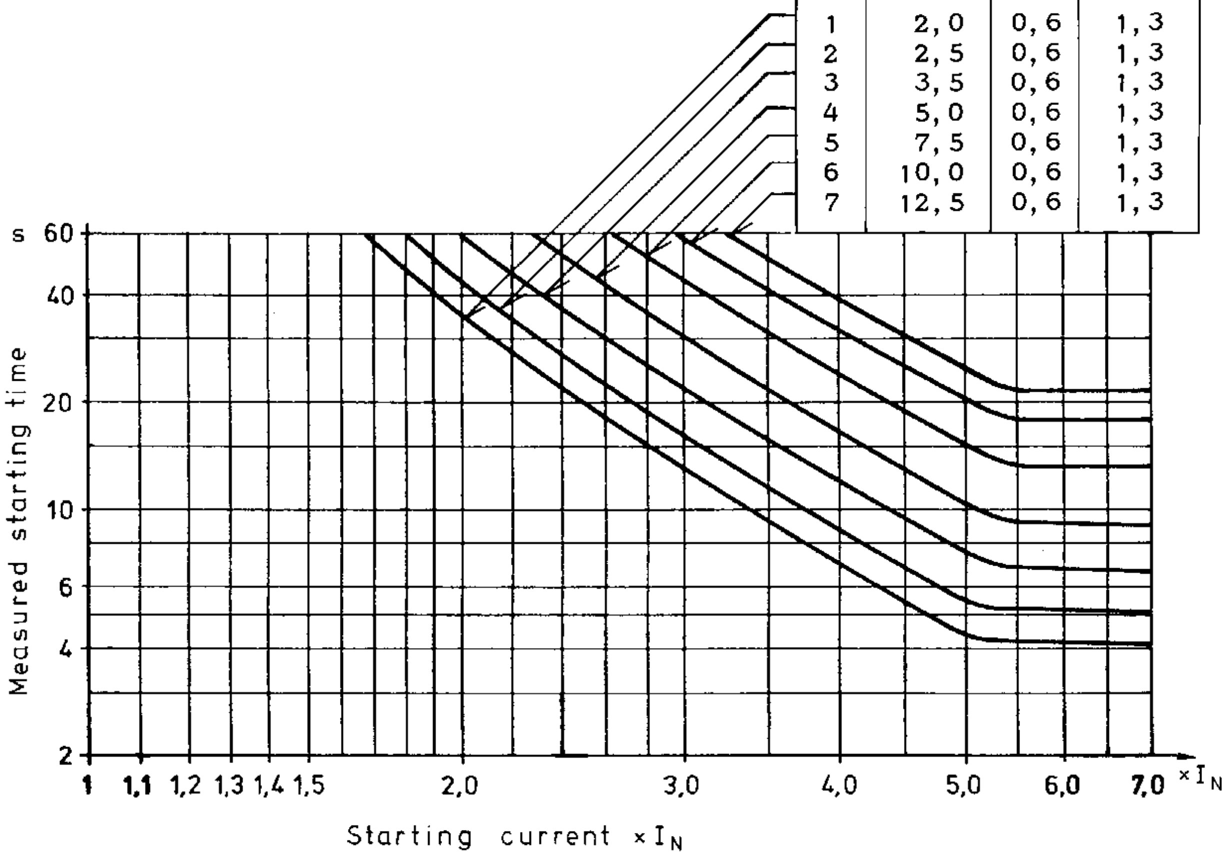
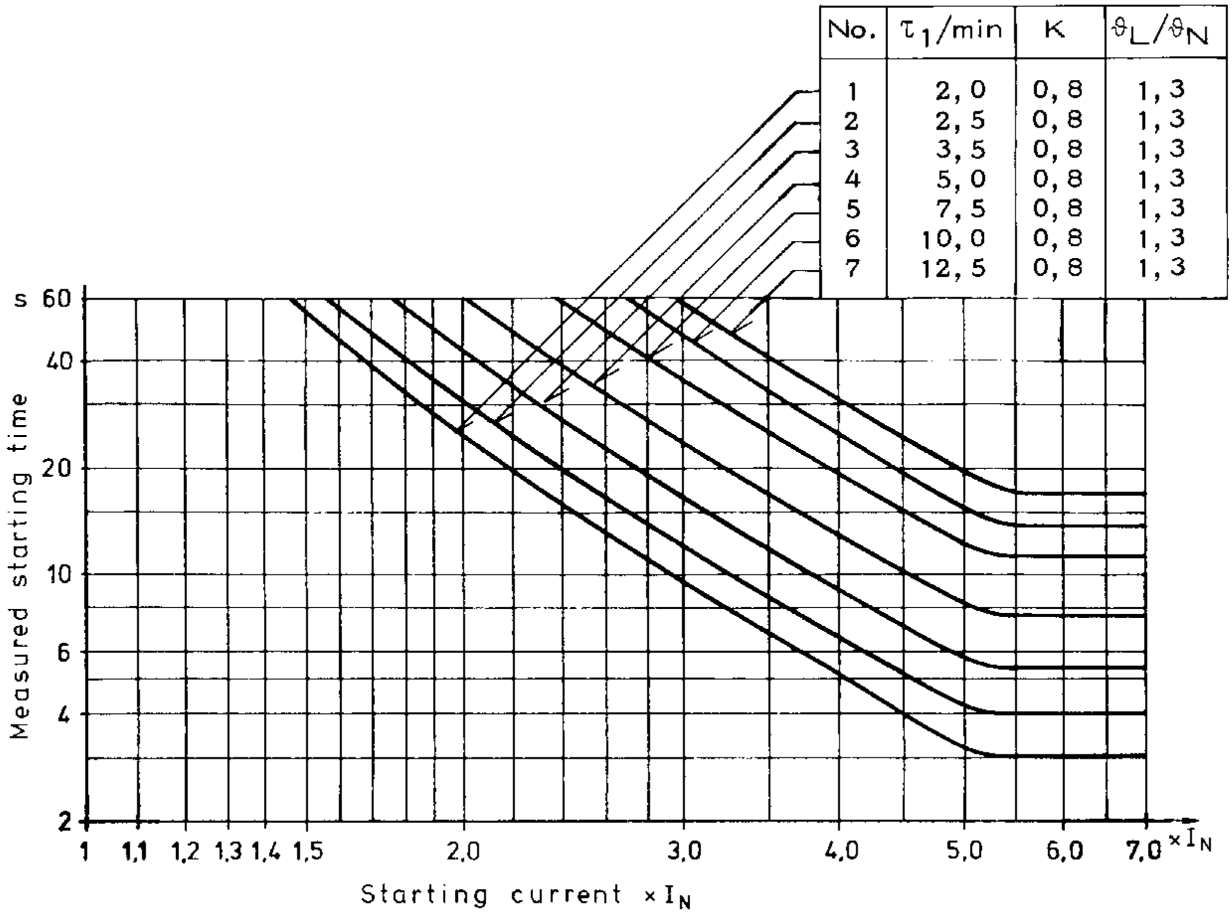


Fig. 12. Group of curves for determining the value of the shorter heating time-constant τ_1 for a chopper motor. The starting current I_N in the figure relates to the current transformer secondary side, taking account of the location of the current transformers.



No.	τ_1/min	K	ϑ_L/ϑ_N
1	2, 0	0, 8	1, 3
2	2, 5	0, 8	1, 3
3	3, 5	0, 8	1, 3
4	5, 0	0, 8	1, 3
5	7, 5	0, 8	1, 3
6	10, 0	0, 8	1, 3
7	12, 5	0, 8	1, 3

Fig. 13. Group of curves for determining the value of the shorter heating time-constant τ_1 for a standard synchronous motor. The starting current I_N in the figure relates to the current transformer secondary side, taking account of the location of the current transformers.

The longer heating time-constant τ_2

The longer time-constant τ_2 is set equal to the rated load heating time-constant of the protected motor. The rated load heating time-constant is stated by the motor manufacturer. If no information is obtained from the motor manufacturer, the rated load heating time-constant of a synchronous motor is set for a value 40... 60 min.

Weighting factor K

When protecting chopper motors, the weighting factor K is set for 0, 6. For other synchronous motor drives, such as pumps, wood mills, fans, compressors and grinding machines, the weighting constant is set for 0, 8.

Thermal tripping and alarm level

If not otherwise stated by the motor manufacturer, the thermal tripping level ϑ_L/ϑ_N is set for 1, 3 and the prewarning heating level ϑ_H/ϑ_L is set for 0, 8 (= 80 %).

Unbalance unit

The unbalance unit supervises the presence of a negative sequence current in the phase currents. The most severe current unbalance appears at the loss of one phase of the motor supply.

The unbalance unit starts, if the negative sequence current exceeds 15 % of the motor rated load current I_{MN}. The operating time-lag is preset to 5 s and the unbalance unit is stabilized against maloperation, caused by heavy through-fault currents.

Example of settings

Protected motor	Synchronous
Motor drive	Chopper
Consecutive starts	Two cold starts and one hot start are permitted for the motor.
Motor starting method, connection to the supply and location of the current transformers	The motor is started using a start-up transformer. After starting, the motor is connected directly on line. The c.t.s are located between the motor and the start-up transformer.
Motor rated current	275 A
Motor starting current	880 A (= 3,2 × I_N)
Full load starting time	12 s
Load heating time-constant	45 min
Winding temperature class	B (according to IEC)
Current transformer ratio	300/5 A

Recommended settings:

$$I_{MN} = \frac{275 \cdot 5}{300} \text{ A} \approx 4,6 \text{ A}$$

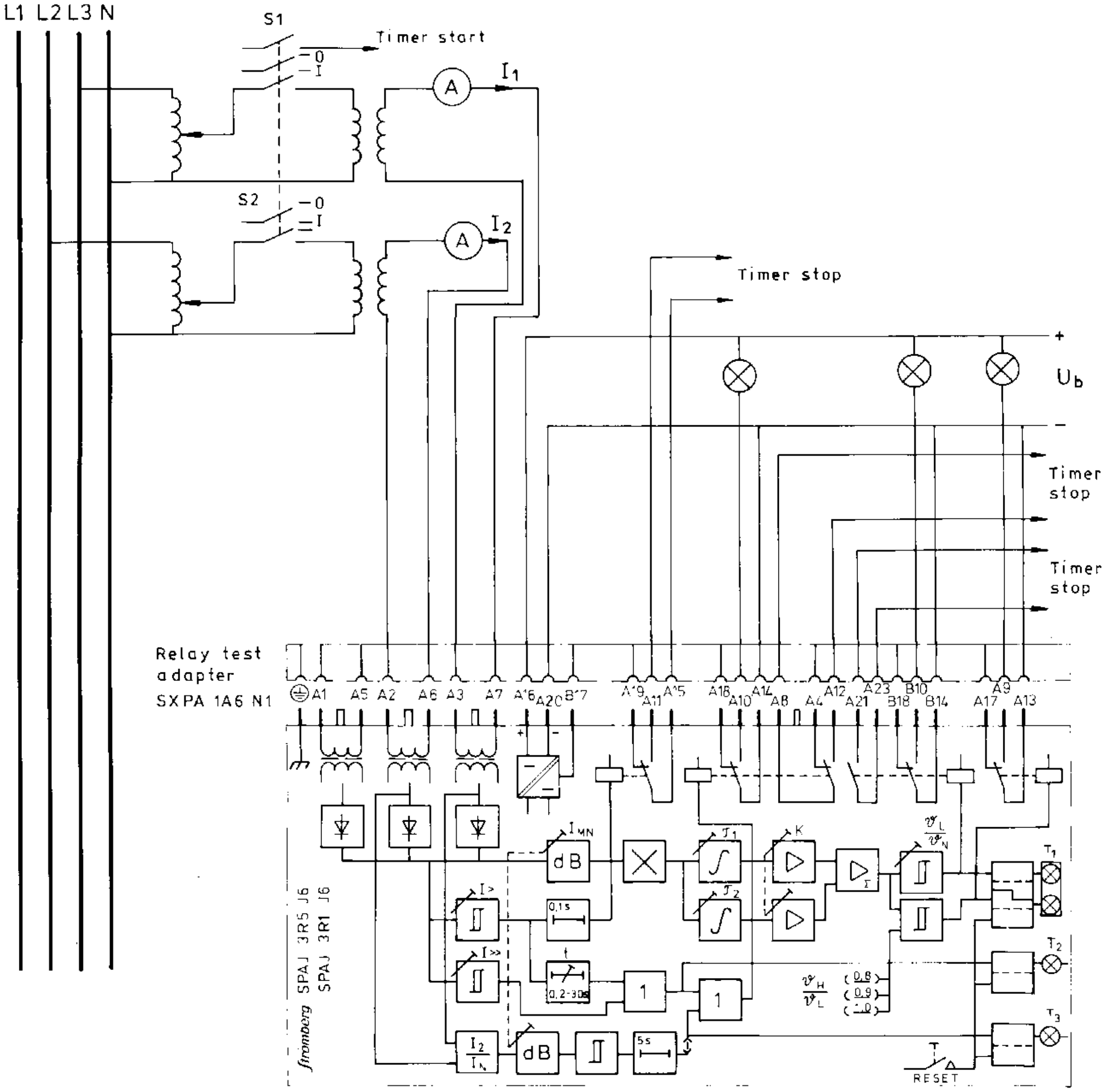
τ_1	= 2,3 min	(page 23, fig. 12)
τ_2	= 45 min	(given)
K	= 0,6	(page 24)
ϑ_L/ϑ_N	= 1,3	(" 24)
ϑ_H/ϑ_L	= 0,8	(" 24)
t	= 1,1 × 12 s = 13,2 s	(" 22)
I >	= 1,2 × I_{MN} ≈ 5,6 A	(" 22)
I >>	= 1,5 × 3,2 × I_{MN} ≈ 22,1 A	(" 22)

For other protected objects, such as generators, transformers and feeders, the motor protection relay is set from case to case, according to the requirements set up by the protected object in its actual application.

Secondary testing

The ability of a protective relay to properly perform its task is best verified by testing the relay at certain intervals. If not otherwise prescribed by local authority regulations or by the general practice of the company, it is recommended that the relays are tested every third year. Relays, operating under abnormal environmental conditions, are tested every second year or a visual check of the relay is included in the maintenance program of the installation.
For secondary testing of the relays, the universal relay test adapter type SXPA 1A6 N1 and a conventional relay test set, e.g. the type SXPA 260A120 N1 by Strömberg or any other suitable manufacture, is used. The relay test set is, if necessary, supplemented with or completely substituted by the following testing accessories:

- regulating transformer, e.g. 0...260 V, 8 A, 2 pces
- isolating transformer, e.g. 220 V/4...20 V, 300 VA, 2 pces
- digital multimeter, 1 pce, and ampere-meter, 2 pces
- timer with start/stop function
- auxiliary voltage source, e.g. the station battery
- switches and indicator lamps



Principle secondary test circuit for the motor protection relays SPAJ 3R1 J6 and SPAJ 3R5 J6

Definite time overcurrent unit

Control of the low current setting I > and the high current setting I >>

Relay settings:

$t = 0,2$ s
$I>> = \infty$

Test switches:

$S1 = I$
$S2 = 0$

All other settings are insignificant.

x) The drop-off/pick-up ratio is measured at this setting.

Set operating current $I>/I_N$	Test results I/A
0,5	=
2,0 x)	=
4,0	=
Drop-off/pick-up ratio	=

Relay settings:

$t = 5$ s

Test switches:

$S1 = I$, $S2 = 0$

All other settings are insignificant.

Set operating current $I>>/I_N$	Test results I/A
2	=
6	=
(12)	=

The tests can be performed as single pole tests, energizing the inputs A3-A7, A2-A6 and A1-A5 one by one. When testing the high set stage I >>, the limit current level should be observed, i.e. 100 x the relay rated current for no more than 1 s.

Control of the definite time setting t and the starting relay delay

Relay settings:

$I>> = \infty$
$I> = 0,5 \times I_N$

Test switches:

$S1 = 0 \rightarrow I$
$S2 = 0$

All other settings are insignificant.

x) The drop-off time is measured at this setting.

Set time-lag t/s	Test results t/s
1 x 0,2 = 0,2	=
3 x 0,2 = 0,6	=
6 x 0,2 = 1,2 x)	=
3 x 1 = 3	=
3 x 5 = 15	=
Delay of starting relay	=
Drop-off time	=

The test current $I_1 = I_N$ and it is fed to the energizing input A1-A5. The timer is started by closing the switch S1 and stopped by the N.O. contact A8-A12 closing, when the time-lag t is measured. As the delay of the starting output relay is measured, the timer is started by closing the switch S1 and stopped by the N.O. contact A11-A15 closing. If the test current is fed to any of the other energizing inputs, the unbalance unit will operate after its preset 5 s delay. As the unbalance unit and the overcurrent unit have their output relay, A4-A8-A12 and A10-A14-A18, in common, delay times longer than 5 s can not be measured by energizing any other input than A1-A5.

The drop-off time measurent of the delayed output relay is started by opening the test switch S1 and the timer is stopped by the contact interval A8-A12 closing.

Control of the high set stage $I \gg$ operating time

Relay settings:

$t = 6$ s
$I \gg = 2 \times I_N$

Test switches:

S1 = 0→I
S2 = 0

All other settings are insignificant.

Set operating current $I \gg / I_N$	Measured operating time t/s
2	=
6	=
(12)	=

The test current $I_1 = 2 \ldots 6 \ldots 12 \times I_N$.
The timer is started by closing the test switch S1 and the timer is stopped by the N.O. contact A8–A12 closing. The operating time is short (< 40 ms), i.e. a fast operating and accurate timer is required.

Unbalance unit

Control of the operation of the unbalance unit

Relay settings:

$I_{MN} = I_N$
$I > = 2 \times I_N$
$I \gg = 2 \times I_N$

Test switches:

S1 = I
S2 = I

All other settings are insignificant.

Set load rated current I_{MN}/I_N	Test results I_1/I_N	Test results t/s
1	= (0,62 × I_N)	=
0,5	= (0,37 × I_N)	=

The test current I_2 is set equal to the rated load current I_{MN}. The testing of the unbalance unit requires two currents, I_1 and I_2, see the principle test circuit. Both test currents are set at $I_1 = I_2 = I_{MN}$ and in this situation the unbalance unit should not operate. Then the test current I_1 is lowered to the level and the relay should operate after a delay of 5 s. As the unbalance unit has operated, the current is increased, until the unit resets.

The operating time of the unbalance unit is measured as follows. The test currents are set $I_1 = I_2 = I_N$. Then the timer is started by opening e.g. the switch S2 and the timer is stopped by the N.O. contact A8–A12 closing.

If the unbalance unit does not operate, please first check the selector plug on the left side printed circuit card, seen from the front side of the relay. If the selector plug is in the position S1, the unbalance unit should operate and if it is in the position S2, the unbalance unit is set out of operation. If the selector plug is missing, the unbalance unit is also out of function. After finishing the test, the selector plug is placed in its appropriate position.

Thermal overload unit

Control of the shorter load time-constant τ_1

Relay settings:

$K = 1,0$
$I_{MN} = 0,5 \times I_N$
$\vartheta_L/\vartheta_N = 1,0$
$\vartheta_H/\vartheta_L = 0,8$
$I> = 4 \times I_N$

Test switches:

$S1 = 0 \rightarrow I$
$S2 = 0$

Test current I_1/I_N	Set time-constant τ_1/min	Measured operating time t/min	Calculated operating time t/s
0, 75	2	=	71
2, 00	20	=	78

All other settings are insignificant.

Control of the longer load time-constant τ_2

Relay settings:

$K = 0,0$
$I_{MN} = 0,5 \times I_N$
$\vartheta_L/\vartheta_N = 1,0$
$\vartheta_H/\vartheta_L = 0,8$
$I> = 4 \times I_N$

Test switches:

$S1 = 0 \rightarrow I$
$S2 = 0$

Test current I_1/I_N	Set time-constant τ_1/min	Measured operating time t/min	Calculated operating time t/s
2	20	=	78
2	200	=	780

All other settings are insignificant.

When controlling the time-constants τ_1 and τ_2, the auxiliary supply voltage should be cut off for a while, before every new measurement, in order to completely reset the memory of the relay. The control of the time-constants is based on measuring the operating time for the thermal overload unit at referenced settings and a specified energizing current level.

While the test is going on, the test current is kept as constant as possible, as the operating time is reversed proportional to the square of the energizing current. The measurement is started by closing the switch S1 and the timer is stopped by the N.O. contact A21-A23 closing.

Simultaneously with the time-constants being controlled, the voltage U (ϑ), formed by the relay and proportional to the thermal behaviour of the protected object, can be measured in the output on the relay front panel. At the same time, the prewarning level ϑ_H/ϑ_N can be checked. For measuring the voltage U (ϑ), a high input impedance digital meter is used. The meter is set on its range, e.g. 0...2 V d.c., and it is connected to the output, marked -⊙ ⊙+ U (ϑ), on the front panel. The voltage U (ϑ) is so calibrated, that at the setting $\vartheta_L/\vartheta_N = 1,0$ the voltage U (ϑ) = 1,00 V, as the relay operates. As the prewarning output relay A9-A13-A17 picks up and the indicator T_1 turns on glowing green, the voltage U (ϑ) = 0,80 V, if the setting $\vartheta_H/\vartheta_L = 0,8$.

Control of the tripping heating level ϑ_L/ϑ_N

Relay settings:

$I_{MN} = 0,5 \times I_N$
$K = 1,0$
$\tau_1 = 20$ min
$I> = 4 \times I_N$

Test switches:

S1 = 0→I
S2 = 0

Set tripping heating level ϑ_L/ϑ_N	Measured operating time t/s	Calculated operating time t/s
0,8	=	62
1,8	=	143

All other settings are insignificant.

The test current I_1, energizing the relay, is set $I_1 = 2 \times I_N$.

Control of the weighting constant K

Relay settings:

$I_{MN} = 0,5 \times I_N$
$\tau_1 = 20$ min
$\tau_2 = 20$ min
$\vartheta_L/\vartheta_N = 1,0$
$I> = 4 \times I_N$

Test switches:

S1 = 0→I
S2 = 0

Set value of the weighting constant K	Measured operating time t/s	Calculated operating time t/s
0,0	=	78
0,5	=	78
1,0	=	78

All other settings are insignificant.

The test current I_1, energizing the relay, is set $I_1 = 2 \times I_N$. The test is started by closing the switch S1 and the timer is stopped by the N.O. contact A21-A23 closing. The test current is kept as constant as possible, during the test going on. Before each test, the auxiliary supply voltage of the relay is cut off for a moment to empty the relay thermal memory.

Control of the rated load current setting I_{MN}

Relay settings:

$K = 1,0$
$\tau_1 = 2$ min
$\vartheta_L/\vartheta_N = 1,8$

Test switches:

S1 = I
S2 = 0

All other settings are insignificant.

Test current I_1/I_N	Set rated load current I_{MN}/I_N	Measured voltage $U(\vartheta)/V$	Theoretical voltage $U(\vartheta)/V$
0,5	0,5	=	1,00
1,0	1,0	=	1,00
1,2	1,2	=	1,00

A test current I_1, equal in level to the set rated load current I_{MN}, is used for energizing the relay. The relay is energized for abt. 5 × the set time-constant τ_1 (i.e. abt. 10 min), after which the voltage $U(\vartheta)$ is measured with a digital voltmeter. Within the test time, the voltage $U(\vartheta)$ should have to rise to the final level 1,00 V, corresponding to the nominous heating level ϑ_N at the set values of the relay. During the test going on, the test current I_1 is kept as constant as possible, as the test current effects the thermal behaviour of the relay with its squared value.

AFTER THE TESTS BEING PERFORMED, THE RELAY IS TO BE CAREFULLY SET, AS REQUIRED BY THE RELAY APPLICATION.

Maintenance and repairs

When the protective relay is operating under the conditions specified in the section "Technical data", the relay unit is practically maintenance-free. The relay unit includes no parts or components, which are subject to an abnormal physical or electrical wear under normal operating conditions.

If the environmental conditions at the relay operating site differ from those specified, as to ambient temperature, humidity or if the atmosphere around the relay holds chemically active gases or dust, the relay plug-in unit ought to be visually inspected in association with the relay secondary test being performed or whenever the relay unit is withdrawn from its case. At the visual inspection the following things should be noted:
- Check the relay unit for signs of mechanical damage; framework, contact plugs and also the relay case
- Shake the relay unit carefully to detect loose parts, such as screws, bolts, nuts, auxiliary relays or foreign metal particles. Note! The contact plugs of the relay unit are self-centering and should be loose
- Accumulation of dust inside the relay unit; remove by blowing air carefully
- Rust spots on framework, component legs and cups and signs of erugo on the printed circuit board copper foil
- Signs of tarnish on the silver-coated contact plugs
- Dirt inside the covers of the internal auxiliary relays. May indicate pitted or burned contacts, these should be cleaned or replaced.

On request, the relay can be specially treated for protection of the equipment against the stress on materials, caused by abnormal environmental conditions.

If the relay fails in operation or if the operating values are remarkably diverse from the relay specifications, the relay should be given a proper overhaul. Minor measures can be taken by the customer by personnel from the companys instrument repair-shop, i.e. replacement of indicator LED:s, auxiliary output relays, contact plugs or the supply unit. For spare parts, refer to the spare part sets. Major measures, involving overhaul of the electronics, are to be made by the manufacturer. Please, put yourself in contact with the manufacturer or his nearest representative, who take care of the checking, overhaul and recalibration of the relay.

Note! Static protective relays are measuring instruments and should be handled with care and protected against moisture and mechanical stress, especially during transport.

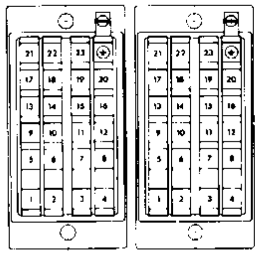
Exchange and spare parts

	Type
- d.c./d.c. converter	
U_{in} = 40...275 V d.c.	SPA-ZU 1
U_{in} = 17...40 V d.c.	SPA-ZU 2
- set of spare parts (holds mechanical spare parts for the relays)	SPA-ZM 1
- set of spare parts (holds semiconductor spare parts and electromechanical spare parts for the relays)	SPA-ZM 3
- electronics' voltage supervision unit	SPA-ZH 1

Dimensions and instructions for mounting

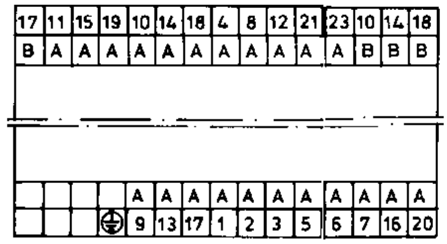
The relay can be supplied with a case for flush mounting, for semi-flush mounting or with a case for projecting mounting. Several relay plug-in units can also be housed in a 19 inch subrack, which can be mounted in a 19 inch framework of an instrument cabinet or flush-mounted as the separate relay cases. All dimensions are in mm.

Fig. a



Terminal arrangement, see the text

Fig. b

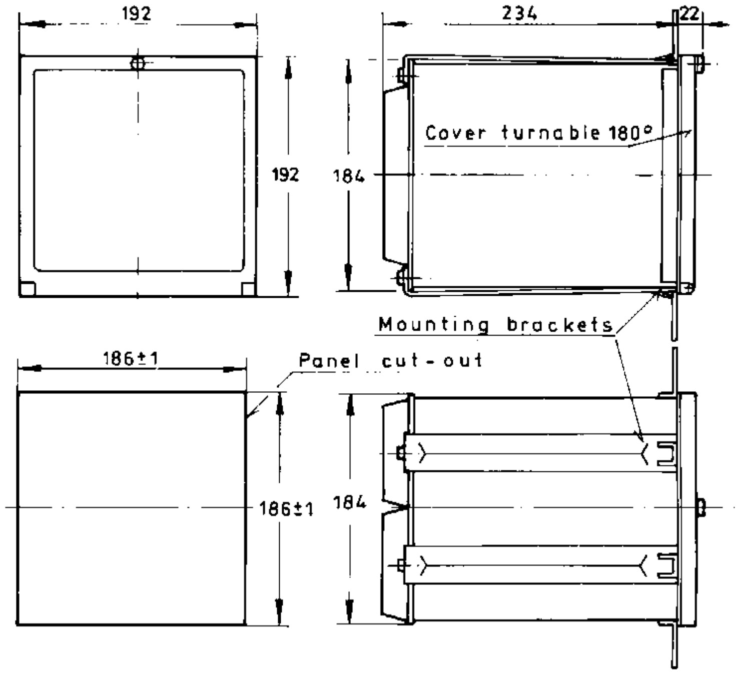


Terminal arrangement, see the text

Terminal arrangement

To the terminals of the cases for flush mounting, semi-flush mounting and projecting mounting with rear connection and to the terminals of the 19 inch subrack one or more wires with the cross section of 1,5 ... 4 sqmm can be connected, see fig. a. These cases are all rear connected.

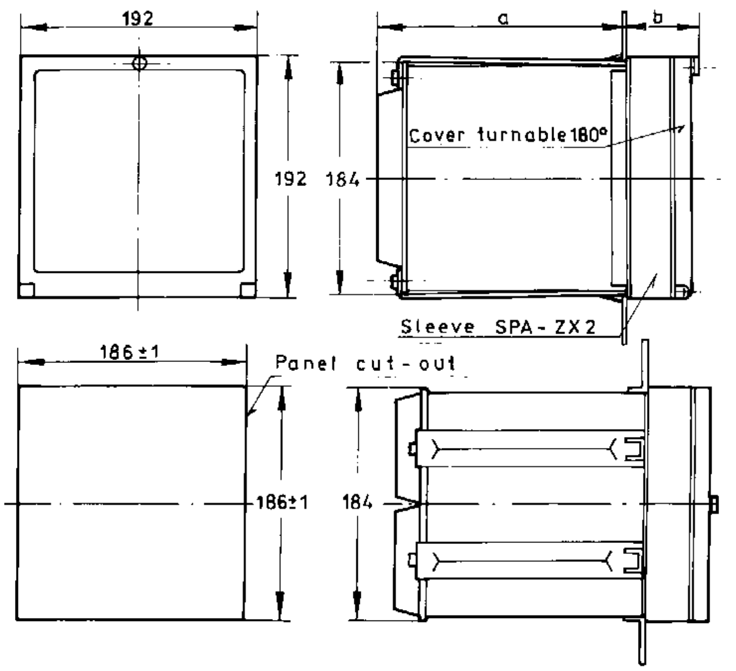
The case for projecting mounting is front-connected and the terminals (max. 4 sqmm) are arranged at the base of the case on the upper and lower side of the case, see fig. b.



Case for flush mounting

Case type: SPAJ-ZK 7
Mass of the case: 3,4 kg

When the terminals of the relay case are to be protected against accidental touch, please refer to the terminal protection set type SPA-ZX 7.



Case for semi-flush mounting

The case for flush mounting type SPAJ-ZK 7 is provided with a sleeve type SPA-ZX 2 or type SPA-ZX 10 and their corresponding mounting brackets.

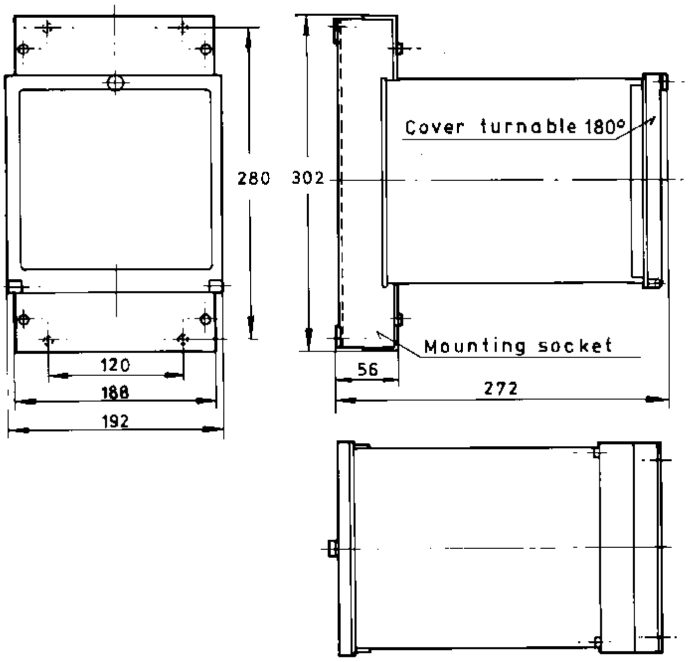
Sleeve type	a	b
SPA-ZX 2	194	62
SPA-ZX 10	154	102

When required, please refer to the terminal protection set type SPA-ZX 7.

Case for projecting mounting with front connection

Case type: SPAJ-ZK 8
Mass of the case: 4,4 kg

The block terminals of the relay case are to be found under covers in the upper and lower edge of the mounting socket.

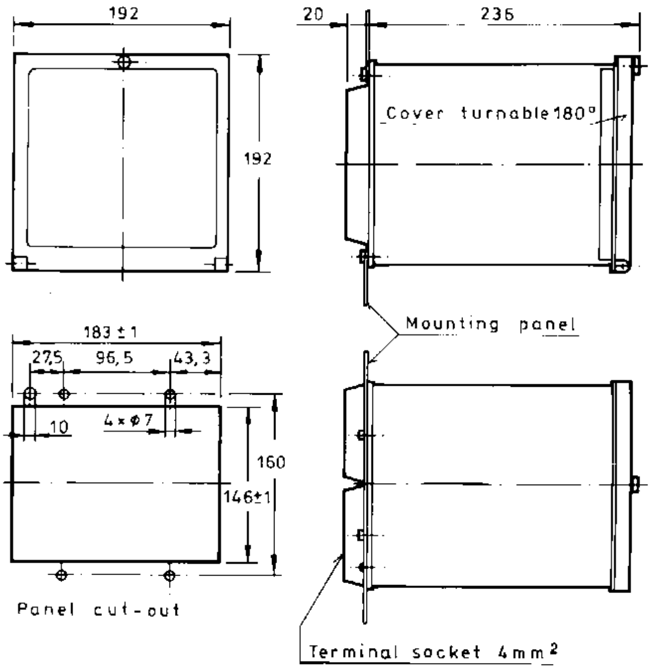


Case for projecting mounting with rear connection

Case type: SPAJ-ZK 7
Mass of the case: 3,4 kg

The relay case for flush mounting can also be used for projecting mounting, if rear connection is required. The panel cut-out is illustrated in the adjacent figure.

When the terminals are to be protected, please refer to the terminal protection set type SPA-ZX 2.



19 inch relay subrack

Several protective relays can be enhoused in a common relay case, i.e. a 19 inch relay subrack. This is mainly used, when the protective relays are mounted in 19 inch instrument cabinets according to the IEC Publication 297.

The 19 inch subrack can also be applied for flush mounting or semi-flush mounting, please refer to separate description file No. 34 SPA 21 EN 1.

Information required with order

	Example
1. Amount and type of relay	10 pces relay type SPAJ 3R5 J6
2. Amount and type of relay case	10 pces relay case type SPAJ-ZK 7
3. Ratings	I_N = 5 A, f_N = 50 Hz
4. Auxiliary supply voltage	48 V d.c.
5. Accessories	E.g. 10 pces electronics' voltage monitor type SPA-ZH 1
6. Special requirements	-

Motor starting time measurement

For determining the motor protection relay settings, the starting time of the motor in the concerned application is to be known.

The starting time of the motor to be protected can be measured using the starting output relay of the motor protection relay overcurrent unit and a timer or clock with start/stop function, or with the relay test set SXPA 260A120 N1. The measurement is based on the function of the starting output relay, which picks up, as the motor starting current exceeds the low current setting I > and drops out, as the starting current goes below the setting I >.

A principle connection for the starting time measurement, when using the relay test set SXPA 260A120 N1, is illustrated in fig. 1. The timer of the relay test set is controlled by the N.O. starting contact A11-A15 of the motor protection relay.

The measurement is to be performed with the motor stressed according to the most demanding requirements, that might be applied to the drive during normal service. The motor load, the supply voltage level and other loads of the supply network must be noticed.

For measuring the starting time, the low current stage of the overcurrent unit is set for 3 x the motor rated current I_{MN}. The starting time measurement is started by closing the starting switch of the relay test set. The motor starting current makes the starting output relay to pick up, which starts the timer. The timer runs, until the starting output relay drops out.

The starting time of the motor can also be roughly measured with a hand operated timer, if an indicator lamp is connected to the starting output contact.

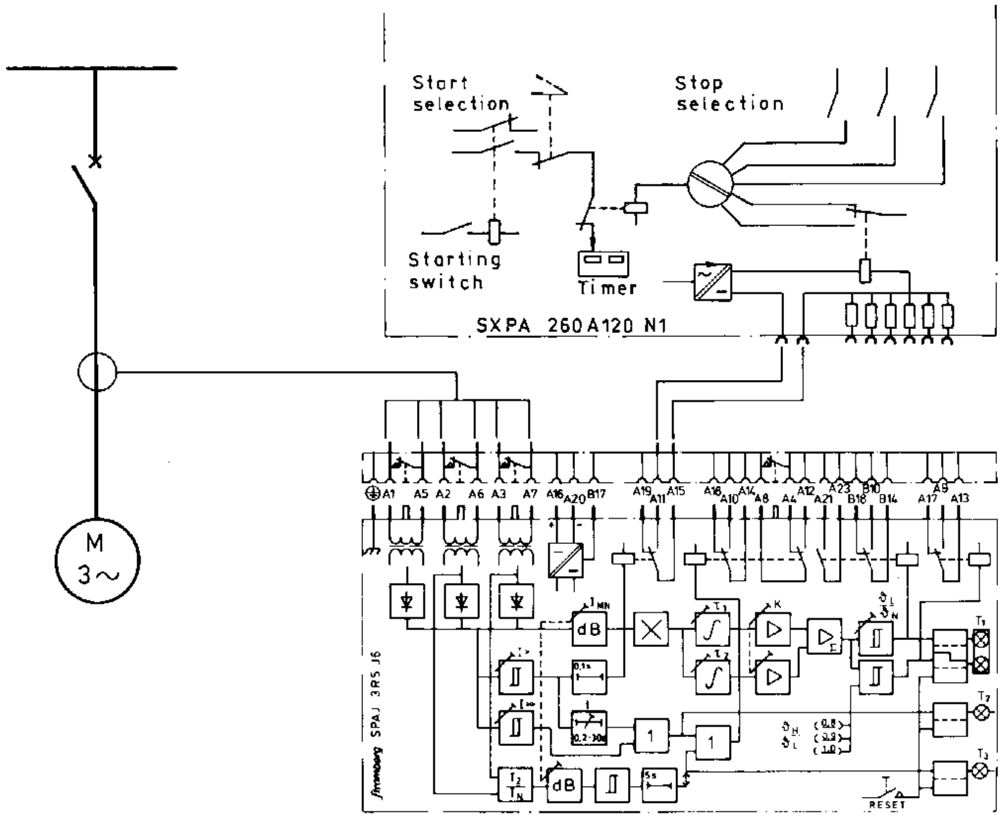


Fig. 1. Principle connection for measuring the starting time of a motor by means of the relay test set SXPA 260A120 N1

Method for determining the time-constants τ_1 and τ_2 and the weighting factor K for motors and generators

The thermal replica, formed by the motor protection relay, is mathematically defined by the expression (1) below. The expression consists of a product of two terms, one is the relative load current of the motor squared, $(I/I_{MN})^2$, and the other a double exponential function with the time-constants τ_1 and τ_2. The double exponential function consists of two simple exponential functions, with their own time-constants, and these exponential functions are superponed (= added graphically) in the thermal unit of the motor protection relay. Before the exponential functions are added, they are given a relative weight by means of the weighting factor K. As the time-constants τ_1 and τ_2 are adjustable within wide ranges and as the relative importance of the separate simple exponential functions can be determined by the setting K, the thermal characteristic of the overload unit can be set very close to the characteristic of any motor or generator. The expression (1) is based on the physical reality, that the heating curve of a rotating machine does not follow a simple exponential function, but shows anomalism, because the flow of heat in a machine is determined by a great number of thermal resistances, i.e. time-constants. In the motor protection relay, these time-constants have been substituted with two time-constants, which both are adjustable. In practice two time-constants already render a perfect replica of the thermal behaviour of a protected object. Mathematically the characteristic of the thermal overload unit of the motor protection relay is defined by the expression (1):

$$\frac{\vartheta}{\vartheta_N} \sim \left(\frac{I}{I_{MN}}\right)^2 \left[K\left(1 - e^{-t/\tau_1}\right) + (1 - K)\left(1 - e^{-t/\tau_2}\right)\right] \qquad (1)$$

$\frac{\vartheta}{\vartheta_N}$ = relative heating of the protected object

$\frac{I}{I_{MN}}$ = relative load current of the protected object

K = weighting factor

t = integrating time

τ_1 = shorter time-constant

τ_2 = longer time-constant

The time-constants τ_1 and τ_2 and the weighting factor K can be extracted by graphical means, either from a heating curve for the protected object or from a curve, based on the overcurrent/time characteristic of the protected object.

When the time-constants τ_1 and τ_2 and the weighting factor K are determined from a measured heating curve of the protected object, the heating curve is at first corrected by eliminating possible faults in the curve, caused by the inaccuracy of the measuring principle, used for obtaining the heating curve. The corrected heating curve is then reversed in order to obtain a simplification of the graphical manipulation. The curve is reversed by constituting the highest point on the curve to be the reference value and from this value all other points on the heating curve are subtracted one by one. The new points, obtained from the subtractions, are plotted on a semi-logarithmic paper, with the vertical heating axis being logarithmic and the horizontal time axis being linear. Through the points plotted, a new heating curve is drawn and this curve is used for extracting the time-constants and the weighting factor.

When the time-constants τ_1 and τ_2 and the weighting factor K are to be extracted from an overload curve, based on the overcurrent/time characteristic of the protected object, the process is started by constructing the current/time curve. The overloadability of a motor or generator is often given in the form of a table, which states certain overcurrent levels and the corresponding periods of time, for which the protected object is able to withstand the overcurrent without damage, see table 1 on page 37. The overload curve is constructed by means of the expression (2), in which the overcurrent/time pairs are inserted one by one. The points, defined in this way, are plotted on a semi-logarithmic paper, the vertical f (t) axis being logarithmic and the horizontal time axis being linear. The expression (2) has the form:

$$f(t) = 1 - \left(\frac{\vartheta_L}{\vartheta_N}\right) \cdot \left(\frac{I_{MN}}{I(t)}\right)^2 \quad \text{, where} \qquad (2)$$

$\frac{\vartheta_L}{\vartheta_N}$ = relative tripping heating level defined by the manufacturer of the motor/generator

$\frac{I_{MN}}{I(t)}$ = relative overcurrent of the motor/generator

t = overload time

The overload curve, constructed by means of expression (2), has the same form as the heating curve of the protected object, as the heating of the protected object is proportional to the square of the load current.

Regardless of how the heating curve of the protected object is obtained, it is regarded as double exponential function, which can be split up in two simple exponential functions. The heating curve ϑ_K obtained is split up in two simple heating curves ϑ_{K1} and ϑ_{K2}. The curve ϑ_{K1} comprises the initial curved part of the basic curve ϑ_K and the curve ϑ_{K2} comprises the final straight part of the basic curve ϑ_K, see fig. 1 on page 38. The curve ϑ_{K2} is always a straight line, when drawn on a semi-logarithmic paper, although it sometimes must be constructed using the smallest quadrature sum method. All points on the final part of the basic curve do not always fall on a straight line. This depends on the fact, that a heating curve of a motor or a generator in practice is composed of a sum of more than two simple exponential functions, as was presumed. The presumption made does not, however, cause any remarkable inaccuracy to the settings of the thermal overload relay. If the initial part of the curve ϑ_K is notably curved, the curve ϑ_{K2} should be drawn with care, in order to avoid points of the curve ϑ_{K1}, being included in the curve ϑ_{K2}. The curve ϑ_{K2} continues straight forward to the vertical axis of the co-ordinate system. The curve ϑ_{K1} is obtained by subtracting graphically the curve ϑ_{K2} from the basic heating curve ϑ_K, point by point. From the relay setting point of view a sufficient accuracy for the curve ϑ_{K1} is obtained, when the curve ϑ_{K1} is drawn as a straight line between the two points defined, $\hat{\vartheta}_K - \hat{\vartheta}_{K2}$ on the vertical axis and the point on the horizontal axis, corresponding to the point $\vartheta_K - \vartheta_{K2} = 0$, i.e. the point where ϑ_K and ϑ_{K2} join each other.

The longer time constant τ_2 is determined from the curve ϑ_{K2}. The maximum value of ϑ_{K2}, i.e. $\hat{\vartheta}_{K2}$, is divided by e = 2,718... and from the so defined point on the vertical axis, a horizontal line is drawn, until the point of interception is obtained with the curve ϑ_{K2}. The horizontal co-ordinate of this point of interception is equal to the longer time-constant τ_2.

The shorter time constant τ_1 is determined from the curve ϑ_{K1}. The method for obtaining τ_1 is the same as above described for τ_2, i.e. the value $\hat{\vartheta}_{K1}/e$ is calculated and the point $\vartheta_{K1} - \hat{\vartheta}_{K1}/e = 0$ on the curve $\hat{\vartheta}_{K1}$ is projected against the horizontal axis, on which the shorter time-constant τ_1 is to be read.

The weighting factor is determined as follows. If the setting calculations are based on a list, defining the overcurrent/time characteristic of the protected object, which by means of expression (2) has been transformed into an overloadability curve, the weighting factor is easily obtained. In this case the weighting factor K is simply equal to the maximum value of the curve ϑ_{K1}, i.e. $K = \hat{\vartheta}_{K1}$.

If the setting calculations are based on a real heating curve for the protected object, the weighting factor K is defined:

$$K = \frac{\hat{\vartheta}_{K1}}{\hat{\vartheta}_K} \qquad (3)$$

i.e. the ratio between the maximum values of the curves ϑ_{K1} and ϑ_K, see fig. 1 on page 38.

The smallest value of the time-constant τ_1, that can be set on the overload unit, is 2 min. If the value of τ_1, calculated above, falls out to be < 2 min, the setting τ_1 on the thermal unit is set equal to 2 min, but simultaneously the weighting factor K is given a value slightly higher than what has been calculated. In this way the shorter time-constant is given a higher intensity in order to compensate too high a setting of τ_1.

The cooling characteristic of the thermal unit also follows the settings given to the unit.

Example 1: The settings of the thermal overload unit derived from the overcurrent/time characteristic of an asynchronous motor

In the example the time-constants τ_1 and τ_2 and the weighting factor K are derived from the overcurrent/time information of the motor, given in table 1 below. The function f (t), according to expression (2) on page 36, is also calculated and listed in table 1. Fig. 1 on page 38 shows the graph of the function f (t), which conforms with the heating curve ϑ_K. From this curve the simple curves ϑ_{K1} and ϑ_{K2} have been constructed. From these curves the time-constants τ_1 and τ_2 and the weighting factor K are determined. The thermal tripping level, recommended by the motor manufacturer, in this example, is $\vartheta_L = 1,0 \times \vartheta_N$.

I/I_N	t/min	f (t)
3, 00	1	0, 89
2, 25	2	0, 80
1, 80	4	0, 69
1, 60	6	0, 61
1, 53	8	0, 57
1, 47	10	0, 54
1, 33	20	0, 43
1, 25	30	0, 36
1, 20	40	0, 31
1, 15	60	0, 24

Table 1.

The overcurrent/time characteristic of an induction motor in the form of a list of associated current and time values. The corresponding points of the function f (t), defined on page 36, are also included in the list.

The shorter time-constant τ_1

The shorter time-constant τ_1 is derived from the curve ϑ_{K1} in fig. 1. The maximum value of ϑ_{K1} is $\hat{\vartheta}_{K1} = 0,45$. The vertical co-ordinate for the point on ϑ_{K1}, which defines the time-constant τ_1, is:

$$\frac{\hat{\vartheta}_{K1}}{e} = \frac{0,45}{2,71} \approx 0,165 \qquad \text{which corresponds to } \tau_1 \approx 4,0 \text{ min}$$

The longer time-constant τ_2

The longer time-constant τ_2 is derived from the curve ϑ_{K2} in fig. 1. The maximum value of ϑ_{K2} is $\hat{\vartheta}_{K2} = 0,55$. The vertical co-ordinate for the point on ϑ_{K2}, which defines the time-constant τ_2, is:

$$\frac{\hat{\vartheta}_{K2}}{e} = \frac{0,55}{2,71} \approx 0,20 \qquad \text{which corresponds to } \tau_2 \approx 72 \text{ min}$$

The weighting factor K

The weighting factor K is derived from the curve ϑ_{K1} in fig. 1. In this case, as the calculations are based on the overcurrent/time characteristic of the protected object, the weighting factor K is equal to the maximum value of the curve ϑ_{K1}, i.e. $K = \hat{\vartheta}_{K1} \approx 0,45$.

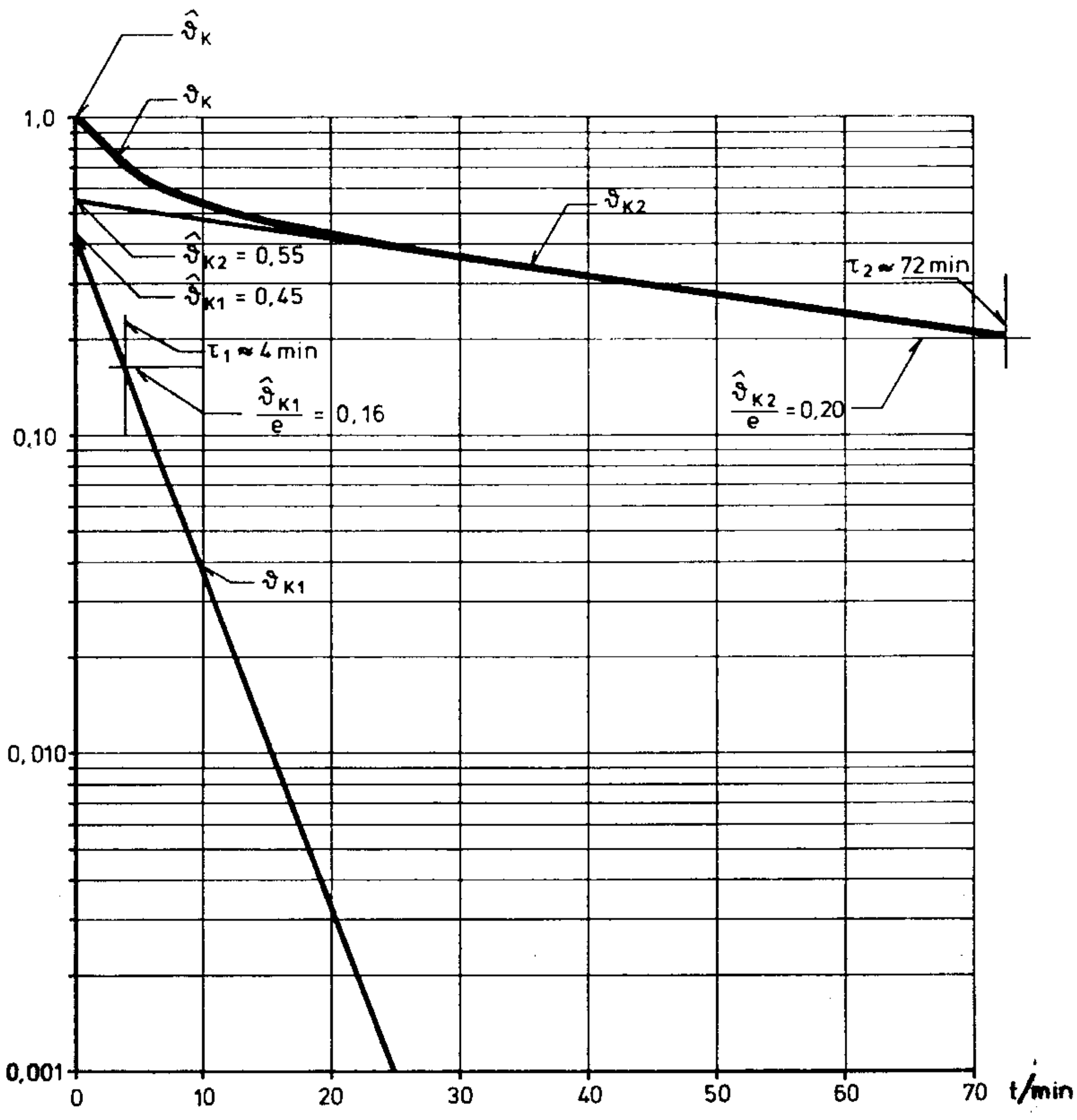


Fig. 1. Determination of the time-constants τ_1 and τ_2 and the weighting factor K for the induction motor in example 1. The thermal behaviour of the motor was specified through a list, stating the permitted overcurrents for the motor for specified periods of time.

Example 2: The settings of the thermal overload unit derived from a heating curve for the asynchronous motor

The time-constants τ_1 and τ_2 and the weighting factor K are derived from a heating curve of the motor. The heating curve has been measured using thermo-couples, located in the end of the stator windings, on the surface of the insulating material. The heating curve is illustrated in fig. 2. Measuring errors, caused by the insulation and the thermo-couples themselves, are eliminated from the curve. In fig. 3 on page 40 the curve is reversed and drawn on a semi-logarithmic paper. That is, from the maximum heating level ϑ_∞ in fig. 2 all the other points of the heating curve ϑ_K are subtracted one by one, and the new points, obtained after the subtractions, are plotted on a semi-logarithmic paper, and the curve ϑ_K in fig. 3 is obtained. This curve is split up in two simple curves, ϑ_{K1} and ϑ_{K2}, as described earlier. The time-constants τ_1 and τ_2 are calculated as in example 1. The weighting factor is calculated by means of expression (3) on page 37.

In example 2, the shorter time-constant $\tau_1 \approx 2$ min, the longer time-constant $\tau_2 \approx 60$ min and the weighting factor $K \approx 0,4$.

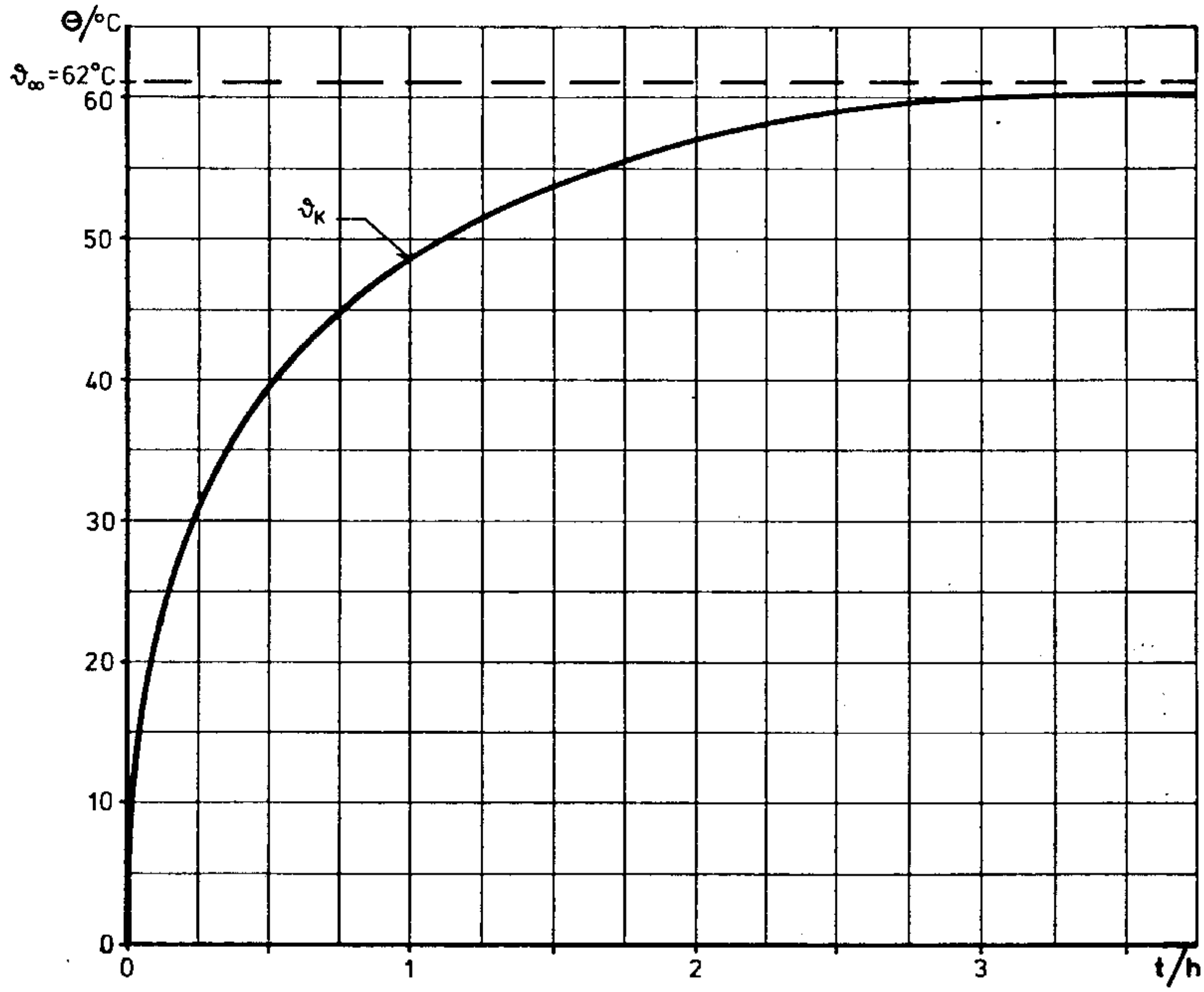


Fig. 2. The measured and corrected heating curve ϑ_K of the motor in example 2

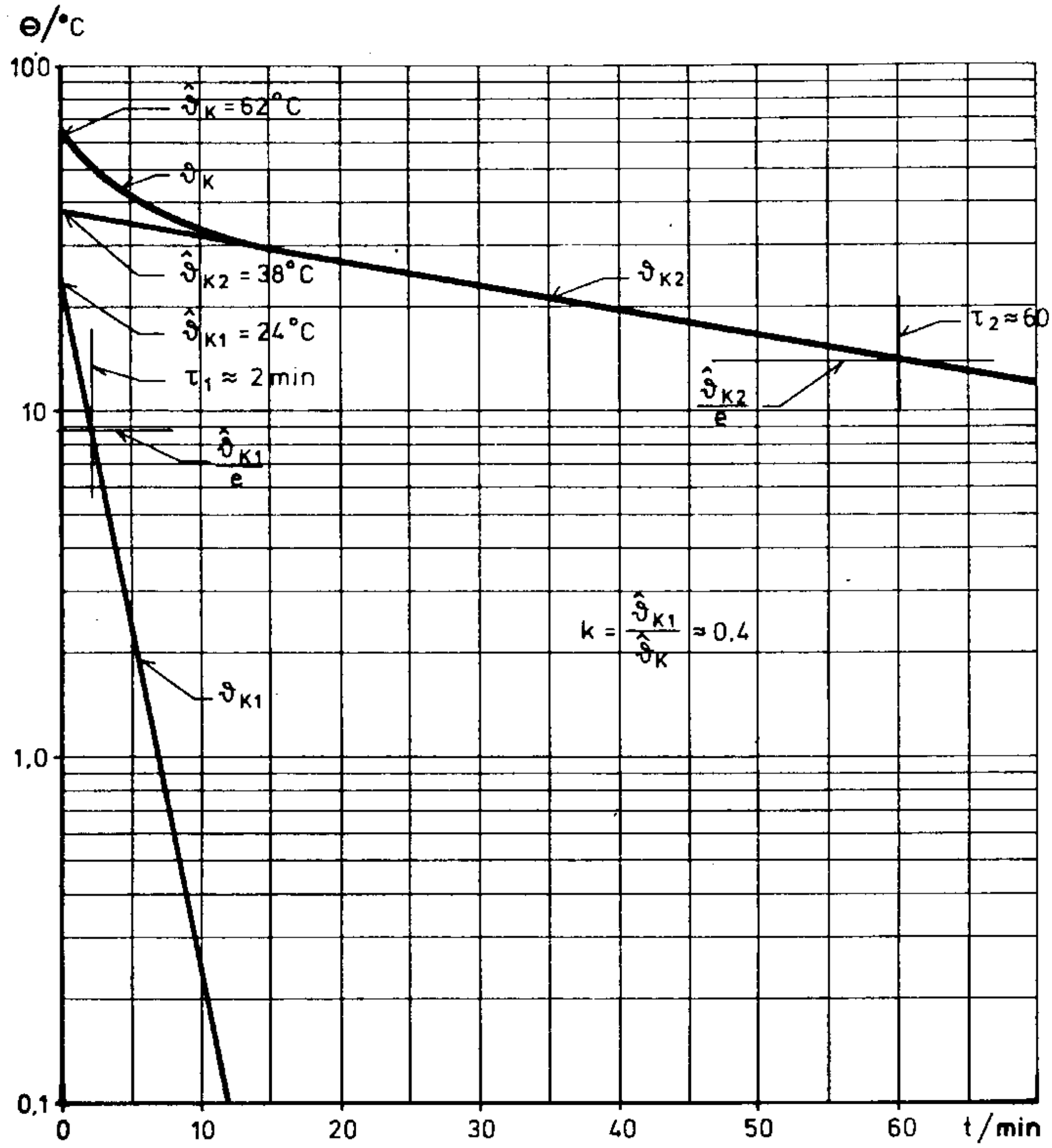


Fig. 3. Determination of the time-constants τ_1 and τ_2 and the weighting factor K for use as set values for the thermal overload unit of the motor protection relay of the induction motor in example 2. The settings are in this case derived from a measured heating curve for the motor to be protected.