Introduction

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E-T-A Choice – Circuit Breakers to Ensure the Best Protection

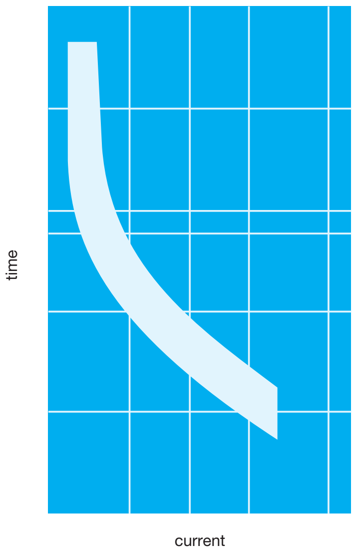
A number of factors arise in choosing a circuit breaker to protect against overloads and short circuits. E-T-A specialists can advise on your requirement, according to the specific field application.

Five types of tripping operation cover most situations.

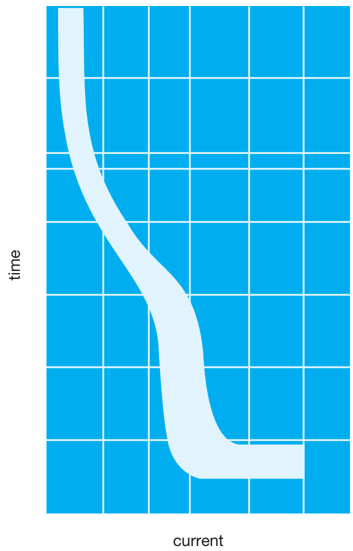
- Thermal Circuit Breakers (TO).
- Thermal-Magnetic Circuit Breakers (TM).
- Magnetic Circuit Breakers (MO or HM).
- High Performance Circuit Breakers.
- Electronic Overcurrent Protection.

Typical Time/Current Characteristic Curves

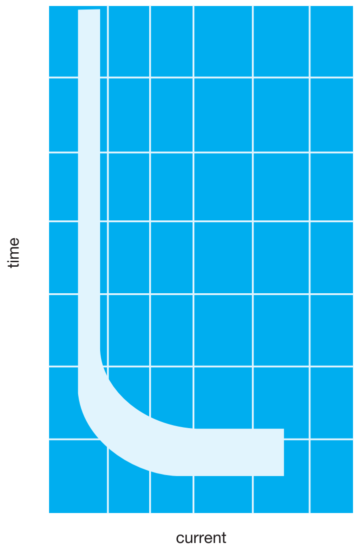
thermal (TO)



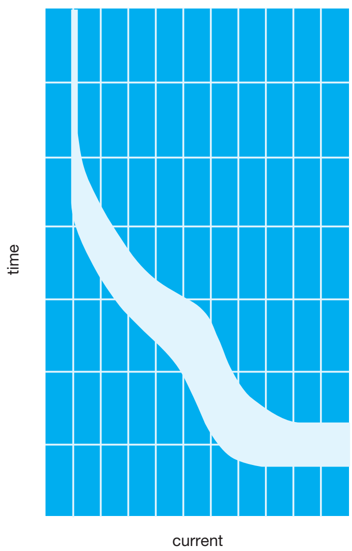
thermal-magnetic (TM)



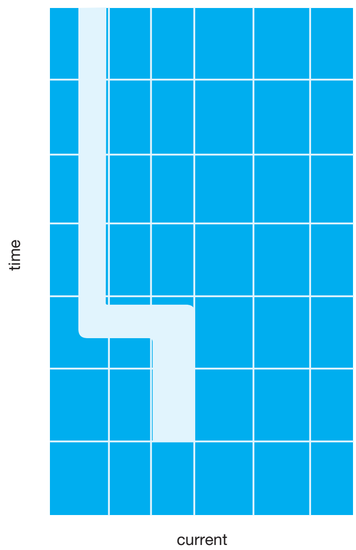
magnetic (MO) (no delay) (delayed magnetic curves available)



magnetic-hydraulic (HM)



electronic



Principal Types of CBE: Thermal Circuit Breakers (TO)

The tripping mechanism comprises a thermal actuator and mechanical latch, designed to discriminate between in-rush/ temporary current surges and prolonged overloads to ensure effective overcurrent protection. Applications include motors, transformers, solenoids and low voltage wiring.

Thermal-Magnetic Circuit Breakers (TM)

Combining a solenoid in series with a bimetal thermal actuator, these provide time/current characteristics with two distinct steps. A high overcurrent value causes the solenoid to trigger the release mechanism rapidly, the thermal mechanism responds to prolonged low value overloads. These circuit breakers are well suited to telecommunications, process control, and similar applications requiring precision performance.

Magnetic Circuit Breakers (MO or HM)

A well-proven design of solenoid coil with optional hydraulic delay provides tripping that is highly tolerant of changes in ambient temperature. A wide range of performance characteristics is available in single, double and three pole configurations.

Serie 808 is a fast acting magnetic device sensitive to small overload currents. Typical applications include printed circuit board and power semi-conductor protection.

High Performance Circuit Breakers

Where ultimate operation under adverse conditions is required, E–T–A high performance circuit breakers provide high interrupting capacity and excellent environmental specifications. Available in thermal and thermal-magnetic versions, they offer current ratings up to 500 A. Special models are designed for aerospace, defence and similar heavy-duty applications.

Electronic Overcurrent Protection

With electronic overcurrent protection the load current is measured via an integral current sensor. In the event of an overload the circuit will be interrupted after approx. 5 sec even with high cable attenuation. In the event of a short circuit in the load circuit the overcurrent will be limited electrically and then disconnected within a 10 – 100 ms range. This will prevent a voltage dip in the power supply. In the event of an overcurrent the electronic circuit breaker type ESS20 will also physically isolate the load circuit.
Electronic overcurrent protection with electronic characteristic curve: Protection of DC24V loads in Automation and Process Control (PLC, sensors, bus modules, actuators etc.) and in communication systems (-DC 48 V).

Manual Trip / ON-OFF Switches (to EN 60934)

Many models are available with a manual trip feature, either standard or as an option.
Others are specifically designed as combined switch/circuit breakers with rocker, push button, or toggle actuation, styled for front panel mounting. Rocker types are available with illumination as an option.
R = manual reset only
M = with manual release but not intended for frequent use as a switch
S = combined switch/CBE function
J = automatic reset

Snap-Action Mechanism

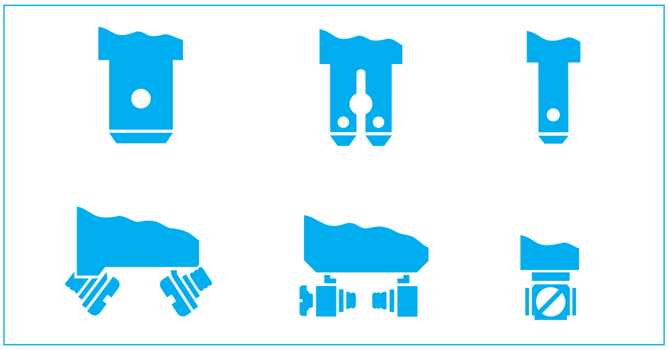
The snap-action mechanism featured in many E-T-A models ensures that the contact closing speed is independent of the speed of operation of the actuator (push button, rocker, toggle etc.). The moving contact is retained until the actuator causes a defined force to act in the closing direction of the contacts. Once this force is exceeded, the mechanical retention is overcome allowing the contacts to snap closed (tease free mechanism.) The closing speed is a function of this force alone.
Snap-action mechanisms eliminate contact welding upon switching on to sustained short-circuits and minimise the risk of contact wear over the circuit breakers' life.

Trip Free Mechanism

E-T-A circuit breakers cannot be held closed against an overload. This is achieved through the use of positively trip free designs in accordance with IEC 934/EN 60934 (with the exception of models 1410, 1610, 1658 and 808 which are designed for specialised applications).

Terminals

Most models are offered with either quick connect (also suitable for soldering) or screw terminals. Models with printed circuit board pins, stud terminals and round connectors are also available.



Auxiliary Contacts

Electrically separate low current contacts can be included for use with alarm and control switching circuits.
N/C (Si1) = Normally closed contacts are open when the main contacts are closed (break or b-contact).
N/O (Si 2) = Normally open contacts are closed when the main contacts are closed (make or a-contact).

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Solderability of Silver-Plated Terminals

E-T-A products with silver-plated terminals will not be adversely affected (e.g. by sulphur induced corrosion) by the packaging material. However, the solderability of silver-plated terminals can deteriorate with time. Provided these products are stored as required by CECC 32 101-002 and -003[1], solderability will be guaranteed for a period of six months from the date of delivery. If they are not required immediately, it is recommended that these products are packed and stored in polythene bags. No drying agents should be used as they may contain silicate gel which can impair solderability. Flux should be non-halogenous.

[1] The storage conditions required by CECC 32 101-002 and 003 are:
- relative humidity ≤ 75 % annual average, and ≤ 95 % for 30 days a year
- temperature between -25 °C and +45 °C (-13° F and +113° F)

Current Ratings and Typical Time/Current Characteristic Curves

Key selection criteria are the trip time zones determined at +23 °C/+73.4°F which are shown graphically for each E-T-A product on the relevant data sheet. Upper and lower curves show minimum and maximum adjustment tolerances. Unless otherwise stated, all thermal, thermal-magnetic and hydraulic-magnetic circuit breakers will carry 100 % rated current continuously and trip within one hour at 140 % rating. Adjustment to closer tolerances is available to special order.

Ambient Temperature Influence

To ensure optimum matching of circuit breaker performance to the system requirements, E-T-A thermal and thermal-magnetic circuit breakers are not normally compensated for fluctuations in ambient temperature. The circuit breaker is usually subjected to the same heat source as the system so will automatically track its protective requirements. However, some applications require the circuit breaker to operate continuously in either high or low temperatures. The following table shows the correction factors that typically should be applied. The performance of magnetic circuit breakers and type 1410 is not affected significantly within this temperature range.

Ambient temperature °C	°F	Multiplication factor (approximate values)
-20	-4	0.76
-10	+14	0.84
0	+32	0.92
+23	+73.4	1.00
+40	+104	1.08
+50	+122	1.16
+60	+140	1.24

Example:
I_N = 10 A at +50 °C. By applying the factor of 1.16 the current value obtained is 11.6 A. A 12 A CBE rating is recommended.

Close Mounting of CBEs

When several devices are mounted together, an air gap between each is recommended. If this is not possible, each device should carry only 80 % of its rating.
Horizontal installation is preferable.
Plug-in Mounted E-T-A Devices
The continuous rating capability of E-T-A sockets for plug-in circuit breakers is a function of the total number of circuit breakers fitted and the individual ratings of each. Please enquire with details of your application.

Typical internal resistance values

The internal resistance values shown are typical values for new devices. They may change through storage, life-span or overcurrent. Deviating internal resistance values do not affect the protective function of the circuit breaker.

ON Duty

Some applications require short-term loads with higher currents (e.g. remote disconnection coils or higher current ratings). In order to avoid excessive heating, the ON duty (% value referenced to the cycle duration) will be limited.
Examples: 50 % ON duty / 60 minutes:
allows a load duration of 30 minutes,
followed by a period of 30 minutes without load.

25 % ON duty / 20 minutes:
allows a load duration of 5 minutes,
followed by 15 minutes without load.

Interrupting Capacity I_{cn}

Overload and maximum interrupting capacities are specified for each series, defined as the maximum current levels that can be switched safely for a minimum of 40 operations, and a minimum of 3 operations respectively. For thermal circuit breakers back-up protection is advised if higher currents are possible. Please contact us for further advice on specific applications.

IEC 60934/EN 60934 defines interrupting capacity as the rated conditional short circuit current performance. According to category PC1, this is the value of rated conditional short circuit current (interrupting capacity) for which the prescribed conditions do not include fitness of the CBE for its further use. PC2 is defined as the value of rated conditional short circuit current for which the prescribed conditions do include fitness of the CBE for its further use.

Inductive and Resistive Load

Every circuit typically has a certain inductance which will intensify arcs. In order to reflect practical experience, the test requirements of IEC 60934, issue 2001, were amended so as to distinguish between inductive and resistive loads. As E-T-A devices are tested accordingly, our technical data show different values (e.g. for typical life) for inductive ($\cos \varphi \approx 0.6$, L/R ≈ 2.5 ms) and resistive load ($\cos \varphi \approx 1.0$, L/R ≈ 0 ms).

Switching Sequence

The switching sequence for short circuit tests is normally abbreviated as follows, according to relevant international CBE standards.

O: Break operation (open)
The circuit breaker in the closed position is caused to open through a short circuit current applied by means of a separate switch. Referenced as co (closed open) in earlier specifications.

CO: Make operation with subsequent break operation (close open)
The circuit breaker in the open condition is closed onto a sustained short circuit and must immediately re-open. This operating mode requires the circuit breaker to be fail-safe as the actuator cannot be released as quickly as the circuit breaker mechanism will open. Referenced as oco (open close open) in earlier specifications.

t: Time period between switching operations
Normally 3 minutes, or the period required before the circuit breaker can be re-set.

Common switching sequences are: O-t-CO or O-t-CO-t-CO.

First characteristic digit: Degree of protection against access to hazardous parts and against solid foreign objects		
	Designation	**Description**
0	Non-protected	No specific protection of persons against accidental access to live or moving parts. No protection of the equipment against solid foreign objects.
1	Protected against solid foreign objects of ≥ 50 mm	Protection against accidental access to live or internal moving parts, e.g. with the back of a hand, but no protection against intended access to these parts. Protection against the ingress of solid foreign objects of 50 mm dia. and greater.
2	Protected against medium-sized foreign objects ≥ 12.5 mm	Protection against finger access to live or internal moving parts. Protection against the ingress of solid foreign objects of 12.5 mm dia. and greater.
3	Protected against small solid foreign objects ≥ 2.5 mm	Protection against access to live or internal moving parts with a tool, or wires etc. of a thickness of > 2.5 mm. Protection against the ingress of solid foreign objects of 2.5 mm dia. and greater.
4	Protected against granular foreign objects ≥ 1 mm	Protection against access of live or internal moving parts with a tool, or wires etc. of a thickness of > 1 mm. Protection against the ingress of solid foreign objects of 1 mm dia. and greater.
5	Dust-protected	Protection against access to live or internal moving parts. Protection against harmful dust deposits. Ingress of dust is not totally prevented, but dust shall not penetrate in a quantity to interfere with satisfactory operation of the equipment.
6	Dust-proof	Full protection against access to live or internal moving parts. No ingress of dust.

Second characteristic digit: Degrees of protection against ingress of water		
	Designation	**Description**
0	non-protected	No specific protection
1	Protected against water drops falling vertically	Drops falling vertically shall have no harmful effects.
2	Protected against water drops falling vertically when enclosure is tilted up to 15°	Drops falling vertically shall have no harmful effects when the enclosure is tilted at any angle up to 15°on either side of the vertical.
3	Protected against water spray	Water sprayed at an angle up to 60° on either side of the vertical shall have no harmful effects.
4	Protected against splashing water	Water splashed against the enclosure from any direction shall have no harmful effects.
5	Protected against water jets	Water projected in jets against the enclosure from any direction shall have no harmful effects.
6	Protected against high-pressure water jets	Water protected in powerful jets against the enclosure from any direction shall have no harmful effects. *)
7	Protected against the effects of temporary immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under specified conditions of pressure and time. *)
8	Protected against the effects of continuous immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under specified conditions of pressure and time. *)

*) Certain equipment does not allow any ingress of water. If applicable, this is included in the relevant equipment specification.

Degrees of protection of electrical equipment according to IEC 60529 / DIN EN 60529

Terms such as drip-proof, water splash protection, waterproof and dustproof are all in common usage but may be misleading unless standard definitions are applied. The IEC has developed a standard coding system defined in IEC 60529.

Protection categories are identified by the prefix letters "IP" followed by 2 digits, the first of which refers to the level of protection provided against access by solid foreign objects and to hazardous parts; the second digit shows the level of protection against water ingress.

Example: IP 4 4

Code letters

First characteristic digit

Second characteristic digit

Preferred degrees of protection

Protection against access to hazardous parts and against solid foreign objects	Protection against ingress of water						
Code letters and first characteristic digit	Second characteristic digit						
	0	1	2	3	4	5	6
IP0	IP00						
IP2	IP20	IP21	IP22	IP23			
IP3	IP30	IP31	IP32	IP33			
IP5					IP54		
IP6						IP65	IP66

Protection degree IP54 may apply to products with a splashcover, for example for front of panel protection whereas the terminals (IP00) will be in an enclosed area.

Tolerances in dimensional drawings

Applicable for nominal dimensions without direct tolerance indication: DIN ISO 286 ± IT13 (see table below).

nominal dimension in mm		IT 13	nominal dimension in mm		IT 13
above	up to	±	above	up to	±
-	3	0.14	315	400	0.89
3	6	0.18	400	500	0.97
6	10	0.22	500	630	1.1
10	18	0.27	630	800	1.25
18	30	0.33	800	1000	1.4
30	50	0.39	1000	1250	1.65
50	80	0.46	1250	1600	1.95
80	120	0.54	1600	2000	2.3
120	180	0.63	2000	2500	2.8
180	250	0.72	2500	3150	3.3
250	315	0.81			

Cable ratings to DIN EN 60934

Standard current ratings as assigned to different cable cross sectional areas (stranded copper cable).

Size mm²	1	1.5	2.5	4	6	10	16	25	35	50
Current rating (A)	to 6	>6 to 13	>13 to 20	>20 to 25	>25 to 32	>32 to 50	>50 to 63	>63 to 80	>80 to 100	>100 to 125

Cable ratings and sizes for road vehicles

Current rating (A)	Cable sizes mm²	Current rating	Cable sizes mm²
1	0.35 - 0.50	10	0.75 - 1.00
2	0.35 - 0.50	15	1.00 - 1.50
3	0.35 - 0.50	20	1.50 - 250
4	0.35 - 0.50	25	2.50
5	0.50	30	2.5 - 4.00
7.5	0.50 - 0.75		

Cable ratings and sizes for aerospace applications

Current rating (A)	AWG cable sizes EN 2350 EN 3841	MS 3320
0.5	20	22
1	20	22
2	18	22
2.5	18	22
3	18	22
4	18	22
5	18	22
7.5	16	22
10	16	20
15	14	18
20	12	16
25	10	

AWG	mm2
24	0.20
22	0.33
20	0.52
18	0.82
16	1.31
14	2.08
12	3.31
10	5,26
8	8.4
6	13.3
4	21.2
3	26.7
2	33.6
1	42.4

AWG = American Wire Gauge

Representation of operating status

In accordance with DIN 40719, part 3 the operating status of switching elements should be represented as follows:

- **Telecommunications**

The representation of the ready status as used by the telecommunications industry - fuses and circuit breakers are shown in the closed position.

- **Power engineering**

The representation of the open position is used by the power, installation, control and data processing industries.
Equipment is represented in the **de-energized** condition and without the effect of an operating force.
Power switches, disconnectors, circuit breakers etc. are shown in the **open** condition, which is the **normal position.**

Following these definitions, **E-T-A products are generally shown in the de-energized condition.**

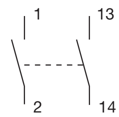
Definition of make contact and break contact

The definition of IEC Publication 50 (441) applies.

make-contact
a-contact
N/O (Si2) contact

A control or auxiliary contact which is closed when the main contacts of the mechanical switching device are closed and open when they are open.

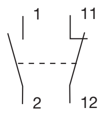
Example:



break-contact
b-contact
N/C (Si1) contact

A control or auxiliary contact which is open when the main contacts of the mechanical switching device are closed and closed when they are open.

Example:



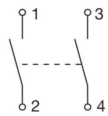
Note:
The common terminal of change over contacts is often shown as C (common).

Terminal identification

The following identifications are in conformance with DIN EN 50005. The diagrams for the examples were however adjusted to the more recent DIN EN 60917 (identical with IEC 617).

Main circuit
One-digit numerals - one pair of subsequent numerals per main switching element

Example:

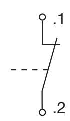


2 main switching elements

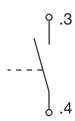
Auxiliary circuits
Two-digit numbers

Digit	First digit Ordinal numbe	Second digit Function numeral
1,2		b-contact and change over
3		a-contact
4	switching elements with identical function and belonging together	a-contact and change over
5,6		b-contact and change over with special functions (e.g. delayed)
7		a-contact with special functions
8		a-contact and change over with special functions

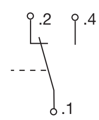
Examples:



b-contact



a-contact



change over contact

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Graphical symbols in accordance with DIN EN 60617/IEC 60617 and ANSI Y32.20/CSA Z99

Description	DIN EN 60617/IEC 60617	ANSI/CSA
Actuated by electro-magnetic effect	02-13-23	
Actuated by electro-magnetic device, for example for protection against overcurrent	02-13-24	
Actuated by thermal device, for example for protection against overcurrent	02-13-25	
Manual actuator, general symbol	02-13-01	
Operated by pulling	02-13-03	
Operated by pushing	02-13-05	
Operated by turning	02-13-04	
Operated by stored mechanical energy	02-13-20	
Trip-free mechanism	07-13-11	
Actuated by liquid level	02-14-01	
Actuated by fluid flow	02-14-03	
Operated by electric motor	02-13-26 M	MOT
Pressure sensor, making	p>	p
Operating device, general symbol, relay coil, general symbol	07-15-01	
Operating device with one effective winding		
Relay coil of a slow-operating relay	07-15-08	SO
Relay coil of a slow-releasing relay	07-15-07	SO
Operating device of a thermal relay	07-15-21	OL
Electro-magnetic overcurrent protection	I >	SOL
Electro-magnetic undervoltage release (undervoltage release module)	U <	
Relay coil of a polarized relay	07-15-15	
Make contact	07-02-01 or 07-02-02	
Break contact	07-02-03	

Description	DIN EN 60617/IEC 60617	ANSI/CSA
Change-over break before make contact	07-02-04	
Change-over contact with off position in the centre	07-02-05	
Circuit breaker	07-13-05	
Disconnector (isolator)	07-13-06	
Switch-disconnector (on-load isolating switch)	07-13-08	
Manually operated switch, general symbol	07-07-01	
Push-button switch with detent, non-automatic return (push-push)		
Three-position switch, manually operated, positions 2 and 3 are locked positions	1 2 3 2,3	
Pull-switch with make contact and automatic return	07-07-03	
Turn-switch with make contact without automatic return		
Contactor (contact open in the unoperated position)	07-13-02	
Static switch, general symbol	07-25-01	
Static (semiconductor) contactor	07-25-02	
Static switch, passing current in one direction only	07-25-03	
Static relay, general symbol, shown with semiconductor make contact	07-26-01	
Semiconductor operating device with semiconductor make contact	07-26-04	
Contactor or relay with three make contacts		x with code
3-pole contactor with three electro-thermal overcurrent releases		OL
3-pole disconnector		DISC
Single pole disconnector with detent, manually operated, 1 break contact and 1 make contact	1 11 13 2 12 14	1 11 13 2 12 14
Single pole disconnector with 2 parallel contacts, manually operated, with detent and remote trip coil (FA), e.g. E-T-A type 921	2 FA	DISC
3-pole circuit breaker		CB
3-pole circuit breaker with latching mechanism, electro-thermal and electro-magnetic overcurrent releases	I> I> I>	

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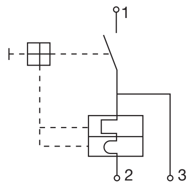
Contact resistance

At first sight, the measurement of circuit breaker contact resistance may seem a trivial problem which could quickly be solved by use of an ohmmeter. However, on closer inspection, it becomes apparent that contact resistance is a more complex subject which deserves more careful attention.

Firstly, measurement across the external terminals of a circuit breaker will indicate its overall resistance. For thermal magnetic devices, for example, that reading will comprise the resistances of the coil, the bimetal, internal wiring and connections (e.g. soldered connections), as well as the contacts. To establish contact resistance alone, it is necessary to partially open the circuit breaker and to measure the voltage drop across the contact assembly at a defined current.

Some circuit breakers have an additional terminal which is connected directly to the movable contact arm (-3). With this arrangement, the values measured between the contact terminal and the -3 terminal can be considered as a first approximation of contact resistance.



The ratio between contact resistance and total circuit breaker resistance is very high at low current ratings, reflecting a contact resistance of only a few mΩs, compared with the circuit breaker resistance which is in the ohms to kohms range.

At high current ratings the contact resistance will be equal to or even higher than the resistance of the rest of the circuit breaker.
In order to precisely measure contact resistance it is necessary first to understand some fundamental principles.

1. The physical causes of contact resistance

The causes of contact resistance can generally be divided into two groups according to whether they can or cannot be avoided. An avoidable cause of contact resistance is contamination (tarnishing film resistance) arising through air pollution or particles. Contact resistance can generally not be avoided on clean metallic surfaces; it is caused by contact constriction, according to Holm's model, through microscopically small contact touch points (constriction resistance, R_E) and by the formation of molecular skins (impurity layer R_F) .

If we assume an idealised circular micro contact spot with a radius a, a so-called "a-spot", and a specific resistance ρ, this results in the constriction resistance to R_E to

$$R_E = \frac{\rho}{2 \cdot a}$$

If the thus defined micro contact spot is covered with a thin impurity layer, this leads, according to Hom /1/, the surface contamination resistance to

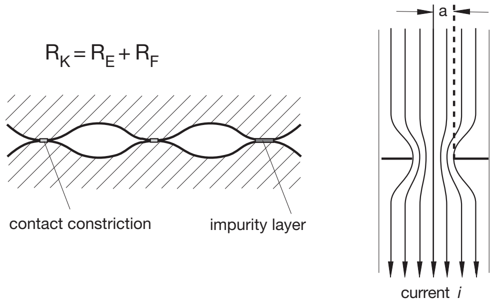
$$R_F = \frac{\sigma}{\pi \cdot a^2}$$

σ is an empirical value which designated as skin resistance.

The total resistance will then be $R_K = R_E + R_F$.

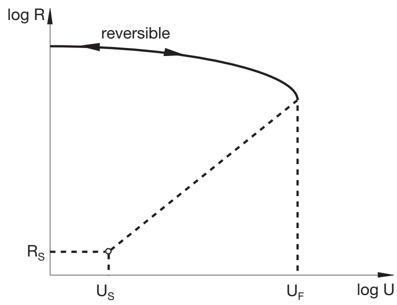
Avoidable contamination may be introduced during production processes or may arise during operation of the contacts. It may simply be the result of air pollution. This tarnishing can be differentiated as either an inorganic corrosion coating or an organic polymer coating. Both can be mechanically destroyed by contact dynamics, e.g. when the contact is moved by operating forces.

Current constriction model



Inorganic coating may additionally cause a process which is usually called fritting. An explanation follows as this term is not widely understood: „With a low voltage applied across contaminated contacts, the resistance value will at first be very high. If the voltage is slowly increased, the resistance will slowly decrease. At a certain voltage, depending on the type and thickness of the contamination, the resistance will suddenly break down to a constant residual value. This phenomenon is called fritting."

The voltage at which fritting occurs is called the fritting voltage, U_F, and the final voltage then arising across the contacts is called the final fritting voltage U_s. The final fritting voltage is generally lower than the voltage which would cause the contact material to melt. The value of the fritting voltage is a function of the thickness of the contamination.



Typical values found in general practice are a few volts.
It is assumed today that fritting in semi-conducting coatings of contamination is initiated by some form of field emission. The strong local electrical field causes more and more electrons to tunnel through the coating until eventually there is a metallic conductive path. This process is generally called "A fritting" in technical literature.

If metallic touch surfaces already exist on a contact, or if these have developed previously through "A fritting", the micro-surfaces may expand as a result of the temperature increase caused by constricting the current flow. The contact resistance will then decrease as the current rises, so that the final fritting voltage U_S is maintained. This process is called "B fritting". As the current decreases again, the contact resistance is maintained.

Fritting should not be mistaken for "contact cleaning" which occurs when contacts are switched at higher voltages, during production processes for instance.

Contaminated contacts are the cause of the following three characteristics:

- Insulation
  Voltage insufficient to frit the contact
- Fritting
  Voltage sufficient to frit the contact
- Metallic contact
  Contact force sufficient to mechanically destroy the contamination coating.

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Note: The contact surface A_K which develops with metal contacts is a function only of contact force F_K and hardness H of the contact material.

$$A_K = \frac{F_K}{H}$$

2. Influence of outside environmental conditions on contact resistance

Contamination on silver contact materials is produced mainly by the formation of silver sulphide crystals. This is clearly indicated by the contacts turning black. The long silver sulphide crystals break off easily and in most cases are destroyed by the movement of the contacts. Sulphur emission from cardboard packing material is a further possible source of contamination. The condition is not at all critical although customers may reject finished products exhibiting such contact contamination. Shipments to tropical countries are particularly at risk as they are also exposed to high air humidity. E–T–A therefore uses only sulphur-free packing materials.

Gold-flashed silver based materials can suffer a more serious condition when sulphide ions develop in the pores of the gold layer. Silver sulphide contamination creeps over the gold and grows into a solid layer. The resulting black halo around each pole can be seen with the naked eye. These silver sulphide halos can easily be removed. The contacts of nearly all E-T-A circuit breakers are therefore designed to move relative to each other. This effect is not so efficient however on nickel or copper substrates.

The problem of so-called hot contacts should also not be overlooked. The phenomenon occurs particularly with copper bus bars, but also with nickel. Even if large micro contact surfaces at first result in low contact resistance, diffused corrosion from the edges of the contact surfaces may result in a slow increase in contact constriction, thereby causing an uncontained rise in the contact surface temperature. As this diffusion increases exponentially with temperature the contact will ultimately fail.

To summarise, it can be said that silver is attacked by the development of silver sulphide. A critical factor is then whether or not the contact force is still sufficient. There must be some dynamic effect (impact, pressure) through the design of the contact assembly. The contact force should be ≥ 10 cN as current alone cannot be relied upon. A dust-proof enclosure generally will be sufficient to overcome this form of contamination. Additions to the silver base material do not have a significant influence.
Encapsulation will, however, create a micro-climate which will introduce new problems:

3. Influence of microclimate on contact resistance

In closed devices there is generally a so-called micro-climate. The development of this micro-climate is accelerated by either internal (coil, self-heating) or external (environmental) temperature increases. In particular, the surrounding plastic materials may emit gases. For example, in the enclosed Spacelab project approximately 400 organic vapours were found. Depending on load, these gassing products, which are deposited on the surfaces of silver-based contacts, will result in values of contact resistance which are typical but subject to relatively wide variation. Gold-plated contacts, by comparison, have practically no variation as long as the gold layer is intact. However after a certain number of operations, the gold layer will be damaged causing the performance of such contacts to gradually deteriorate to that of pure silver-based materials.

4. Typical applications for different contact materials

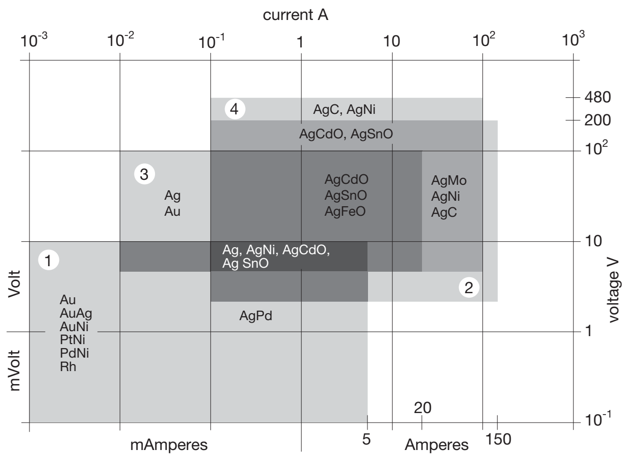
Materials normally used today for motor protection switches and CBEs, in current ratings from 0.1 A to 100 A at voltages between 5 V and 500 V, are silver metal oxides such as silver cadmium oxide, silver-tin oxide and silver-iron oxide. With higher power devices, contact materials often combine silver nickel with silver-graphite. For special applications it is also possible to use silver-molybdenum. Because of its tendency to form oxide, silver-tungsten is used only for medium and high voltage applications (e.g. with pre-travel contacts, burn-off contacts, etc) where the operating voltages are high enough to break down the tungstate layers, and/or the contact forces are high enough to mechanically clear the contamination.

It is also possible to use pure silver materials or gold-plating for current/voltage ratings of 100 mA/100 V or below 5 A/5 V. A material specifically used in relay manufacture is silver palladium.

Combinations of precious metals such as gold-nickel, platinum-nickel, palladium-nickel or rhodium are used only for mA/mV and µA/µV ranges. With CBEs, motor protection controls and high performance circuit breakers these materials are only used for auxiliary contacts required for direct signalisation in an electronic control unit. As gold is very expensive the plating thickness of gold-plated (gold-flashed) contacts is only a few µm.

If such contacts are used for supplying more than milliamps and above 10 V, arcing will quickly wear off the gold-plating thereby eliminating the very low contact resistance needed for electronic applications. This may cause control circuits to respond incorrectly if the electronic system mistakes a high resistive closed contact for one which is open. It would also be incorrect to select silver metal oxide contacts for such applications because silver based materials are not pure enough to eliminate contamination and the operating voltages available are too low.

In mA/mV ranges, silver materials may be better than gold-plated material, provided the contact surface areas are large enough.
Unfortunately there is not a single ideal contact material. It is therefore necessary to select the appropriate contact material for each application as a function of current/voltage rating range, current to be switched and ambient conditions. It should be possible to find a compromise for special applications such as a 10 A rated circuit normally operating at 100 mA for use on oil platforms. In this case a standard device would almost certainly prove unsuitable



Contact materials – typical applications

1. Metrology, data system engineering, electronics in general
2. Aviation, transportation, marine, high technology applications
3. Telecommunications, process control, robotics, medical equipment
4. Installation engineering, electronic entertainment, machine tools, office machines, professional tools, household/hobby equipment, process control, medical equipment

5. Measuring contact resistances

Resistance measurements in the range from 10^{-5} to 1 Ω require the use of methods such as the Thomson bridge where current and voltage are supplied separately via current and voltage (potential) terminals, to eliminate the effect of the resistance of the connection leads (four-wire measurement).

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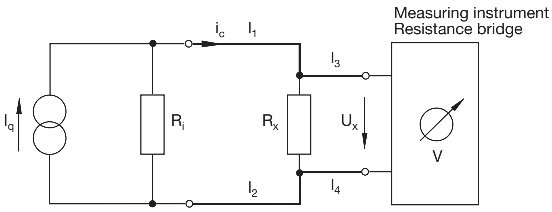
Due to the physical properties of contact resistance described above, it will be evident that the current and voltage required to determine resistance values will have a significant influence on the actual results obtained.

In most cases digital ohmmeters or continuity testers have a measuring voltage of only 5 V with a current range limited to a few hundred mA. Although such meters are suitable for gold-plated contacts, they cannot be used to measure contact resistance of silver metal contacts, for example.

Measurements with 1 A/10 V are effective for power contacts operating in the range of a few amperes and some tens of volts. In this case the test sample is supplied with 1 A from an electronic constant current source. The voltage drop across the contacts is tapped as if it were a high resistance by means of two separate measuring leads (see diagram), thus obviating incorrect measurements and misinterpretations such as ”infinite contact resistance“.



Measurement of conctact resistances

R_x	contact resistance unknown
i_c	constant current
U_x	voltage drop measured across the contact
I_1, I_2	supply of measuring current
I_3, I_4	supply for voltage measurement
i_q	ideal power supply
R_i	internal resistance of actual power supply

$$R_x = \frac{U_x}{i_c}$$

If $i_c = 1$ A is selected, the instrument reading in V will directly indicate the contact resistance in ohms.

The no-load voltage at the open or contaminated contact is set by rating the current source appropriately. The internal resistance value R_i and current value I_q of the ideal source provide for the test voltage for the contact distance $U_{no\ load} = R_i \times I_q$.

The parameters are now defined which will allow an exact and physically correct measurement of contact resistance.

Literature:

[1] R. Holm: Electrical Contacts, Springer Verlag Berlin Heidelberg New York Tokyo 1967
[2] A. Keil, W. A. Merl, E. Vinaricky: Elektriche Kontakte und ihre Werkstoffe, Springer Verlag Berlin Heidelberg New York Tokyo 1984
[3] Paul G. Slade: Electrical Contacts Principles and Applications, Marcel Dekker Inc. New York Basel 1999
[4] W. Rieder: Elektrische Kontakte – Eine Einführung in ihre Physik und Technik, VDE Verlag Berlin Offenbach 2000