MARECHAL electric

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Technical Training Manual

2009 - Part 2

English Version

CONTACT RESISTANCE BASIC NOTIONS

Discontinuity of a conductor generates an additional resistance called contact resistance. This resistance is larger than that of the conductor itself if there was no contact.

The value of this resistance determines the quality of a contact: the higher it is the greater the quantity of heat released by the contact. If the temperature goes above a certain limit, the contact deteriorates.

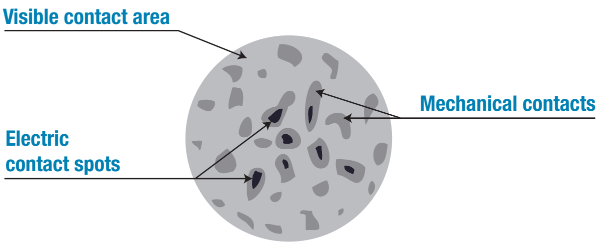
This phenomenon can develop quite rapidly as, the higher the heat the faster the deterioration.

The quality of a contact depends on two parameters:

- The status of contact surfaces,
- The force applied to the contact.

Contact area

The actual contact area between two surfaces is made of a certain number of spots, which represent an area smaller than the visible contact surface, due to the unevenness/roughness of the material.



Electron flux lines are moreover constricted through only some of these spots between the two contacts.

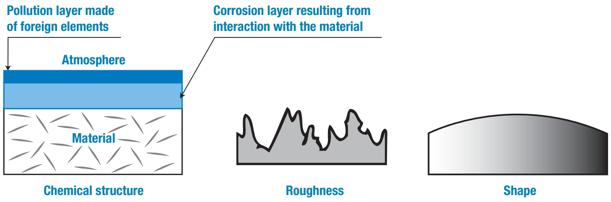
Electrons are transmitted in an Ohmic system[1] or by tunnel effect[2] or by thermo-electronic effect[3], depending on the thickness of the insulating surface layer generated by oxidization of the material and by pollution.

All manufacturers of switchgear use silver alloy butt-contacts, often domed, where the emphasis is put on the applied force rather than on the hypothetical contact area. This concept is widespread in the contactor or circuit-breaker industry. Plugs and socket-outlets that still use pins and contact tubes are an exception.

Status of contact surfaces

Three parameters determine the status of a contact surface:

- Chemical structure: foreign elements of the surrounding atmosphere (pollutants) react with the material and form a superficial layer called corrosion layer.
- The roughness of the surface which depends on manufacturing technology used and is often at random.
- The geometrical form of the contact which determines the visible contact area between two surfaces.



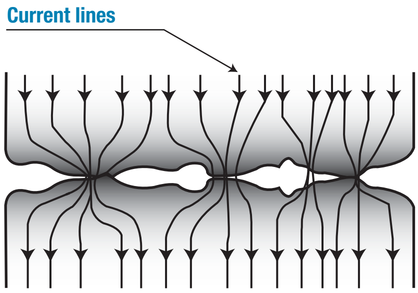
Evaluation of contact resistance

Contact resistance is made of two terms:

- Constriction resistance
- Film resistance

Constriction resistance

Constriction resistance is due to the deviation of the current lines when they travel across some of the electric contact spots.



Film resistance

Film resistance is due to the pollution and oxidation layers that are present at contact interface.

[1] Contact system in which electrons are directly transmitted from metal-to-metal.
[2] Travel of electrons across a "thin" film (insulating surface layer generated by pollution and corrosion).
[3] Travel of electrons across a "thick" film (insulating surface layer generated by pollution and corrosion).

Fretting corrosion

Fretting corrosion is an irreversible mechanical and electrical deterioration of contact quality due to the wear generated by friction and micro-movements between the two contacts and to the accumulation of oxidised particles in micro-cavities on the surface of the material.

These micro-movements are generated by vibrations, shocks or even in absence of external factors by thermal dilation of the material. These oxidised particles constitute a third material.

Fretting corrosion occurs in several steps:

- Production of particles, by adherence or shredding,
- Oxidisation and accumulation of these particles in surface cavities,
- Expulsion of oxidised particles in adjacent cavities,
- Formation of a layer of debris, transformed into powder, that acts as a lubricant and diminishes the efficiency of abrasion (self-cleaning) and increases contact resistance.

Some contact designs are very prone to fretting corrosion whereas others are not affected.

A comparison of currently available designs is made in a separate part of this document:

Technical Training Manual – Part 3
The advantages of Butt contacts
The DECONTACTOR™ Principle

Overall contact resistance therefore depends on:

- The geometrical form of the contact (which determines the visible contact area and its sensitivity to fretting corrosion),
- The applied force,
- The resistivity of the material and the conductivity of the surface layers,
- Its hardness and roughness.

Influence of material

The choice of contact material is of prime importance. The table hereafter gives, for a given applied force, the contact resistances obtained with the most common contact materials, at two different stages:

- New
- Tarnished or oxidised

Material	Contact resistance	
	New	Oxidised
Pure silver	6 μΩ	25 μΩ
Gold	31 μΩ	31 μΩ
Copper	29 μΩ	400 μΩ
Brass	370 μΩ	1 400 μΩ
Silver-nickel $_{85/15}$	23 μΩ	60 μΩ

Silver

From all commercially available materials, silver has the lowest contact resistance. It is unaffected by moist or dry air, as silver oxide (Ag_2O) is a good conductor. Silver retains excellent electrical properties at high temperatures or after tarnishing. Silver sulphur (Ag_2S - black silver) that appears at low temperature, is slightly more resistive but is also unstable. It disappears ca. 300 °C/570 °F and is easily eliminated under an arc.

Having a very low contact resistance, Silver is particularly attractive for high currents. On the other hand, silver is a soft metal that wears easily. It cannot withstand repeated arcing which vaporise it. Silver welds at relatively low pressure and temperature. It is, therefore, not adequate for switching equipment.

Gold

Gold has a very low contact resistance that does not vary over time as under usual conditions, it never oxidises. Solid gold is not economically viable and presents the same disadvantage as silver from a mechanical point of view.

Brass

Brass (copper and zinc alloy) is cost-effective and very suitable to machine parts to the shape required. Brass is, nevertheless, the poorest of all materials listed above. Brass tarnishes (oxidises) at ambient temperature, which increases its contact resistance. It has a significant contact resistance when new as the zinc it contains is a poor conductive material. When its copper oxidizes, it becomes unusable. Brass wears rapidly under friction. Under an arc, Brass pits, which allows in-depth oxidisation. This pitting does not help a quick extinction of the arc.

Copper

Copper is more expensive than brass and also more difficult to machine. Like brass, copper oxidises at ambient temperature, which increases significantly its contact resistance. Its exposure to environment or to common polluting agents such as Sulphur oxide, Nitrogen oxide, all acids (even at low concentration) or to halogens, creates a highly resistive surface layer of copper oxide (Cu_2O). As from 100-120 °C / 210-250 °F, copper monoxide (CuO) is produced and contacts become unusable.

Température °C	Thickness (10^{-10} m)	
	After 1 000 h	After 100 000 h
20	21,7	37
55	35	170
60	39	210
85	87	690
100	150	1 300

Cu_2O surface layer on copper built up depending on time and temperature (Rönnquist table)

Note: Oxidization of copper can be eliminated in vacuum or Helium or Sulphur Hexafluoride (SF6) enclosures. Its performances are then comparable to those of silver alloys in the air. This confinement is, anyhow, not possible for plugs and socket-outlets. In the air, in absence of plating, copper and its alloys are never used by the switchgear industry as contact material due to its resistive surface layer. Even in low-cost MCBs, copper is never used as contact material on both sides. Mating contact on copper is generally made of Silver-Graphite (AgC) to prevent welding.

Under an arc, copper pits, leading to in-depth oxidisation and becomes unusable. In addition, copper does not help a quick extinction of the arc: conversely to other materials, its cathodic point tends to remain in a stable position that does not allow the increase of its voltage. This “stability” also increases dramatically the pitting.

Cuproberyllium

Cuproberyllium is used to make contact blade inserts that are set inside the contact tube. Advantages of Cuproberyllium over brass are a far greater resilience and a better fiction coefficient that reduces wear and allows the plating of the pin to last longer. Its resistivity is anyhow comparable to that of brass. These blade inserts have anyhow the disadvantage of creating two contacts in series: one between the pin and the insert, the other between the insert and the contact tube.

Silver-nickel 85/15

Silver-nickel AgNi $_{85/15}$ (85% silver and 15% nickel) combines the outstanding contact performances of silver with the excellent mechanical properties of nickel. Silver-nickel only welds at extremely high pressure and temperature and, therefore, withstands electric arcs quite well. Under repeated arcs, silver-nickel gradually wears and contacts can then be seen as a consumable part.

Silver-Nickel is commonly used by all switchgear manufacturers for its performance regarding:

- Mechanical endurance,
- Interface electrical properties:
    - Resistance to transfer of metal particles from one contact to its counterpart,
    - Resistance to welding (static and dynamic),
    - Resistance to arc erosion on closing and opening,
    - Resistance to fretting corrosion,
    - Strong post-arc dielectric strength which reduces the average duration of arcs,
    - Mobility of arcs on contacts, which increases instability and minimises pitting.

Its property of resistance to transfer of metal particles avoids the accumulation of eroded metal particles in the arc chambers and the build up of a conductive layer that would deteriorate the dielectric strength. This is particularly advantageous in compact products.

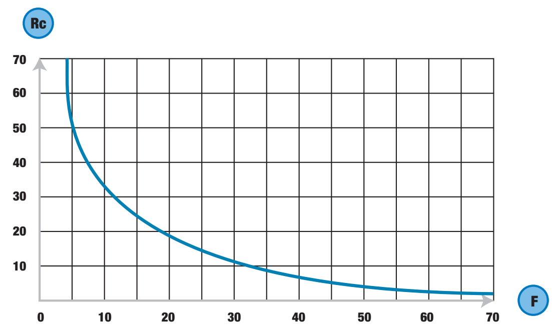
Other materials currently used in the switchgear industry for some other particular properties are Silver-Graphite (AgC), Silver-Tin Oxide ($AgSnO_2$) and Silver-Tungsten (AgW).

Control of the contact pressure

Contact pressure is the other key parameter that determines the quality of a contact.

In the case of plug and socket-outlet, there must be a minimum applied force when any plug is inserted into any socket-outlet. This force must remain constant over time.

A similar consideration must be given to the permanent contact pressure between the copper conductors and their respective terminals, plug side and socket-outlet side.



Variation of contact resistance depending on the applied force

The advantages of a particular contact technology are described in:

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