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Contact materials used in low voltage electrical relays

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Low-voltage relays are widely used in many areas of electrical applications. There are used for such applications as protection, signalization or control of electrical installations. There all are similar in many ways were it comes to construction and operating principles. However for different applications different contact materials must be used. There are many materials used for contacts in electrical appliances. In this paper contact materials used especially in low-voltage electromechanical relays are described. Their electrical and mechanical properties are characterised.

KEYWORDS: contact materials, relays, rivets

1. Low-voltage electromechanical relays

Electric relay is a device designed to produce sudden predetermined changes in one or more electric output circuits, when certain conditions are fulfilled in the electric input circuits controlling the device. An electromechanical relay is a subtype in which the intended response results mainly from the movement of mechanical elements [1]. A classical electromechanical relay set-up with distinguished key parts is shown on Figure 1. Relay structural elements are: contacts, dust cover, drive mechanism (solenoid) and the main current paths (Fig. 2).

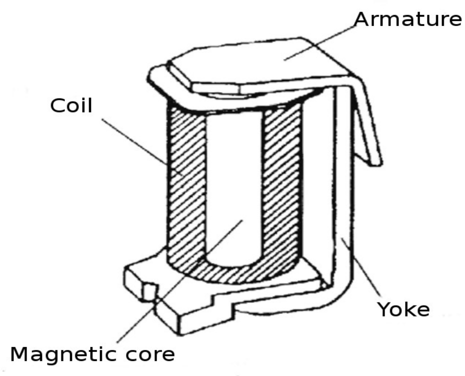

Fig. 1. Classical electromechanical relay set-up [2]

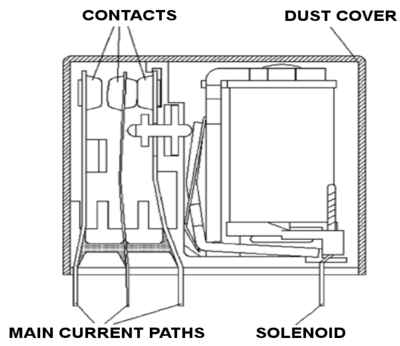

Fig. 2. Relay cross-section [2]

The relays can be characterized on the basis of the electrical and mechanical parameters. These parameters include:

- the amount and type of contacts,
- contact material,
- nominal / maximum contact voltage,
- rated operating current (power) load,
- maximum switching current,
- maximum switching frequency,
- the nominal voltage of the coil.

Key part of a electromechanical relay are its electrical contact rivets (Fig. 3). They role is to ensure proper electrical connection with little loss of energy and minimal contact resistance. They have to withstand considerable amount of contact operations. During these operations they can be exposed to potentially dangerous conditions, such as making and breaking of electrical arc [3] or closing a faulty circuit [4].

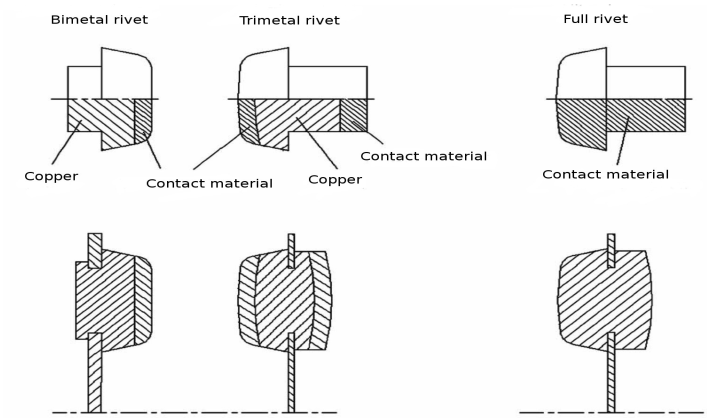

Fig. 3. Contact rivets used in electromechanical relays [2]

Bimetallic rivets are usually made by powder metallurgy technology or in the case of using metal oxides internal oxidation. Full rivets are often produced from the wire made of the contact material and their shape is obtained in the process of cold forging treatment.

Because of differences in breaking power, current, and voltage, there is a great variety of breaking contacts. The breaking contacts can be classified as light-, medium- and heavy-duty [6]:

– Light-duty contacts carry very low currents, operate at voltages up to 250 V, and display no appreciable arc-related electrical wear. The successful operation of these devices depends mainly on maintaining relatively low and stable contact resistance and also on the selection of the contact materials. The factors that must be taken into account are tendency to oxidize (tarnish); presence of dirt, dust or other contaminants on the contact surface; and contact design (form, size, contact pressure, and finish). Light-duty contacts are intended for use in instrument controls, general automation, radio and data communication, and telecommunication systems.
– Medium-duty contacts carry appreciably higher currents (see 5A above) and operate at voltages up to 1000 V. For this group, electrical wear is of prime importance. The factors governing contact material selection to meet the very severe operating conditions include tendency to welding, material transfer, and erosion (pitting). Applications of medium-duty contacts are control devices for industrial, domestic, and distribution network applications.
– Heavy-duty contacts carry very high currents (tens of kA) and operate at very high voltages (hundreds of kV). The most common types of these connectors are contactors, starters, and circuit breakers.

2. Materials used for electrical contacts

There are many materials than can be used for contacts. These materials are:

– pure materials: copper (*Cu*), silver (*Ag*), gold (*Au*), tungsten (*W*), platinum (*Pt*), palladium (*Pd*) and molybdenum (*Mo*),
– alloys: *AgCdO*, *AgNi*, $AgSnO_2$, *AgPd*, *AgW*, *AuPt*, *AuAg*, *AuNi*, *PtIr*, *PtNi*, *PdCr*, *PdNi*, *CuW*, *AgNiW*, *CuCr*, *Ag*-graphite.

Basic elements used for contacts are copper and silver. Coper is a cheap metal, layer of oxide and sulphide are easily created, requires use of high contact force. It is used for example in high voltage connectors and oil circuit breakers. Silver is precious metal, sensitive to sulfur and sulfides, quite prone to material transfer. Pure silver contacts can be welded easily. Silver has low melting point; fairly easy for tooling. Silver-plated contacts are used for high frequency circuits. Not suitable for contacts subject to wear. It is not suitable for large currents [6].

During make and brake operations certain phenomena may occur, including contact heating and material transfer. Heating process is linked with rising contact resistance at brake which later changes into electrical arc. Joule's heat generated during that process may lead to high temperature rise, even over melting point of contact material. Material transfer may also negatively influence contact reliability, however it is less likely to occur in AC over DC circuits [6]. Another process that may appear is contact welding [8]. While the contacts are closed high current values are required in order to weld contacts. This phenomena may show itself with lower current values at make while contact bounces occur [7].

Because pure copper or silver contacts aren't always the best choice more often alloys are used. In order to improve properties of contact materials selected elements can be added to silver (Tab. 1) [6]. Addition for example of chromium *Cr* into copper contact is used in medium voltage vacuum circuit breakers, which influences their welding resistance [5].

Table 1. Effect of additions of different elements on different properties of silver [6]

Property	Additions
Arc resistance	Pb, Mg, Li, Zn, La, Sb
Abrasion resistance	Cu, Ni, Pd, Li
Lubrication	In, Zn, Sn, C
Weld resistance	In, Zn, Mn, metal oxides

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment states that Member States shall ensure that, from 1 July 2006, new electrical and electronic equipment put on the market does not contain, among others, cadmium. A later decision of the European Commission of 21 October 2005 amending for the purposes of adapting to technical progress the annex to Directive 2002/95/EC allows the usage of cadmium and its compounds in electrical contacts.

Electrical contact materials can be characterised by several parameters, among which are:

– chemical elements used for rivets,
– density [g/cm^3],
– melting temperature [ºC],
– boiling temperature [ºC],

- hardness [HV/HB],
- thermal conductivity [W/(K m)],
- electrical conductivity [m/(Ωmm^2)],
- elastic module [MPa],
- temperature coefficient of resistivity α [1/ºC].

Depending on the application of the electromechanical relay there is always a question about the best contact material to use for its contact rivets (Tab. 3). While switching pure ohmic circuits, like electrical heating or incandescent lamps, there is little electrical hazards that may appear and so the contact material that can be used doesn't need high weld and arc resistance. Electrical circuit with low power factor, either high inductance or capacity value, cause a lot worse conditions during switching operations. These conditions include electrical arc that occurs during breaking of inductive load and current spikes while making of capacity circuits. For these types of circuits it is imperative that contact rivets are made from the right material, that have high arc and/or weld resistance. Characteristics of selected contact materials alloys used for low-current contacts are presented in Table 2.

Table 2. Characteristics of selected alloys for low-current contacts: ρ – material resistivity, α – heat coefficient, λ – thermal conductivity, H_B – Brinell hardness, T_m – melting point temperature [5]

Alloy Composition	Density	ρ	α	λ	H_B	T_m
[%]	[kg/m^3]	[10^{-8} Ωm]	[°C^{-1}]	[W/(m°C)]	[-]	[°C]
Ag–Cu 97/3	10,5	1,8	0,0035	390	40	900
Ag–Cu 50/50	9,7	2,1	0,003	340	70	730
Ag–Au 90/10	11,4	3,6	0,0016	196	23	—
Ag–Cd 80/20	10,1	5,7	0,002	—	60	875
Ag–Pd 40/60	11,4	42	0,00025	20	—	1,33
Ag–Pt 95/5	10,88	4,65	0,0023	30	99	—
Ag–Ni 90/10	10,1	1,8	0,0035	—	90	961
Au–Pt 93/7	19,6	10,2	—	70	40	1,08
Pd–Cu 60/40	10,6	35	0,0032	38	80	—
Pt–Ni 95/5	23	20	0,00188	—	135	—
Pt–Ro 90/10	20	19,2	0,0018	—	90	—
Pt–lr 95/5	21,5	10	0,002	42	130	1,08
Cu–Cd 99/1	8,9	2,6	—	—	345	—

Table 3. Silver and Silver Alloys for Low-Level Switching [6]

Contact Material	Advantages	Disadvantages
Ag	High conductivity, 60 MS/m Inexpensive	Formation of Ag sulfides, sticking
AgNi 0.15	High strength	Formation of Ag sulfides, sticking
AgNi 10–20	High erosion protection	Contact welding Material transfer
AgPd 60	High resistance to sulfide formation Good resistance to material transfer	Polymerization
PdRu 10	High conducting reliability	Expensive
$AgCdO/AgSnO_2$	High erosion protection at high current (power circuit breaker)	High and unstable contact resistance in low-level applications

3. Low voltage electromechanical relays contact materials

Low voltage electromechanical relays are widely used in many electrical applications. Some of theme are used in control circuits, programmable logic controllers or as the execution elements in building automation systems. They are used mostly for switching of purely resistivity circuits (e.g. electrical heating, classical light bulbs), low power and relativity high inductance circuits that include coils or circuits with electrical motors (e.g. blinds or verticals at homes and office buildings).

Alloys of AgNi with Ni contents between 10% and 20% are suitable for heavier loads, e.g., for higher currents, as AgNi has a good resistance against contact erosion. The disadvantage is the contact resistance stability and tendency for the welding of nickel [6].

Materials with palladium have a very high chemical resistance against all kinds of erosion. When materials with high palladium content are used, there is a risk of brown powder generation, as previously mentioned. The major advantage is their excellent resistance against material transfer [6].

AgCdO and $AgSnO_2$ alloys are used to switch high loads. Due to their heterogeneity they have unstable contact resistance at low-level switching loads. Resistance values up to 1Ω must be expected [6].

There are few commonly used contact materials for relay rivets. These materials are: AgNi, AgCdO and $AgSnO_2$. Their properties and usage is as follows [2]:

1. Silver-nickel alloy (90% Ag-10% Ni) - is most appropriate alloy for switching DC loads, in order to avoid material transfer, it is also wildly used for switching low current non inductive AC loads.
2. The compound of silver-cadmium oxide (90% Ag-10% CdO) - has a wide range of applications in power load due to the high welding resistance and arc extinguishing effect. Its field of application is in the range of 12 to 380 VAC and 100 mA to 30A. It is especially used for resistive and inductive loads, such as motors load, heating resistors, lamps and other.
3. Silver material + tin oxide (carbon) $AgSnO_2$ - has similar properties to the silver-cadmium oxide, but has a higher thermal stability of the resistance and lower material transferring from one contact to another, which translates into higher stability in DC applications. $AgSnO_2$ contacts also feature a uniform wear and are recommended for applications with loads producing current surges and inductive loads. Some miniature relays offered contain small admixture of indium oxide (In_2O_3). In addition to the good results obtained switching lamps, this material also has excellent behaviour with resistive loads and switching currents up to 16 A.

Their selected material properties are presented in Table 4.

Table 4. Selected properties of contact materials used in low-voltage relays [9]

Material	Density	Melting temperature	Hardness	Thermal conductivity at 20 ºC	Electrical conductivity
	[g/cm^3]	[ºC]	[HB]	[W/(K · m)]	[m/(Ωmm^2)]
AgNi10	10,3	961	50	350	54
AgCdO10	10,2	961	70	313	48
$AgSnO_210$	9,9	961	70	307	49

Looking at material properties in table 4 there are little differences between their density and hardness and they have the same melting point temperature. Thermal conductivity has the highest value for AgNi together with the lowest value of electrical conductivity and there is only a small difference between the remaining two materials.

4. Contact material influence on electrical contact resistance

The existence of elementary contact areas on the contact surface, highly smaller than apparent contact surface, is locally reducing the cross-section of the conductor and therefore locally increases current density. In macroscopic terms, this means the creation of the additional resistance in the current path associated with a narrowing of conductor cross-section, which is defined as the so-called constriction resistance or shape resistance. The essence of the constriction resistance model is shown in Figure 4 [11].

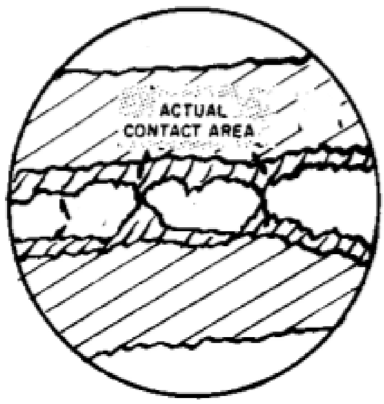

Fig. 4. Magnification of contact surface with visible contact surface roughness [10]

The actual (overall) contact resistance, also called the transition resistance, is actually higher because the contact surfaces adsorbs gas molecules and gas contact coating is easily created [11].

Electric current density increases locally with current flowing through the conductor with contacts present. Therefore, contact resistance is lower with lower degree of compaction of elementary current streams and with greater the number of contact points together with a more even distribution of them [11]. Dependence of the contact resistance can be represented as follows:

$$R = \left(\frac{\rho}{2} \sqrt{\frac{\pi \zeta}{2,5 \cdot 10^{-5}}} H^{0,1875} \right) \cdot F^{-0,6} + \frac{\rho_p \cdot \zeta \cdot H}{F} \tag{1}$$

where: ρ - resistivity of the contact material, Ωm, ρ_p - resistivity of the surface layers, Ωm, H – contact material hardness (as defined by Brinell or Vickers, N/m2), F – contact force, N, ζ – empiric coefficient with values between 0,3 and 0,6.

The non-metallic surface layer is formed naturally as a result of the surrounding gas adsorption and chemical reactions occurring on the contact surfaces. In view of how many factors are responsible for the above processes evaluation of thickness of the clear layer and the rate of their formation is extremely difficult. However analytical calculations allow to estimate their impact on the total value of resistance of electrical contacts [11].

Electrical contact resistance (ECR), as represented by equation 1, depends on such factors as contact force F and contact material hardness H and material resistivity ρ. Contact force is a parameter tied with electromagnetic coil and the entire mechanical mechanism. Material hardness and resistivity depends only on the contact material used on contact rivets. The resulting ECR value drops with the increase of contact force strength as shown in [11]. Increase both in contact material hardness and to its resistivity leads to rise on contact resistance. If the only factor determining the use of any particular contact material would be the resulting contact resistance, the lest hard and with the lowest resistivity would be the best choice. Table 4 shows that those two parameters do not correlate in such a manner. Furthermore the materials with higher hardness values, such as AgCdO and $AgSnO_2$, are used frequently. As mentioned earlier other phenomenons, such as resistivity to contact welding, material transfer or thermal stability, must be take under consideration. Because of this, the electrical contact resistance can not be the only factor which determines the proper contact material to be used for rivets. Nether the less it is important to keep the ECR value as low as possible, because it will determine for example contact heating during normal current flow and with that power losses and maximum temperature rise in contact chamber.

5. Summary

There are various materials that can be used for rivets in low-voltage electromechanical relays. In order to choose the right one many factors have to be taken into account. These factors include: welding and material transfer resistance, thermal stability and physical properties. These properties are, among others, resistivity of the material and its hardness. Both of them influence the electrical contact resistance, which is another parameter that have to be taken under consideration in the process of determining the proper contact material to be used. From the three contact materials presented, frequently used in many applications are $AgSnO_2$ and AgCdO with better properties than AgNi, however the later one is cheaper.

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