

Copper in Electrical Contacts

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Copper Development Association

Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and user industries and maintains close contact with other copper development associations throughout the world.

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Copper in Electrical Contacts

Introduction

Large quantities of copper are employed in electrical applications as cable material, busbars and other conductors, transformer windings, etc. The amount used in electrical contacts is small but, nevertheless, important.

Copper has many advantages as a contact material, and these advantages are the reason for its use in small wiring cables in preference to aluminium, which can give much more trouble through deteriorating contact.

Copper is present in nearly all electrical contact applications, either in the material of the contacts themselves, as a backing material, or in the construction of the contact carrier connections and terminals of the switch contact assembly.

Most fixed and bolted contacts are in fact copper or copper alloys, as are plug and socket connections.

One of the great advantages of the metal is that there is a wide selection of alloys available, combining the excellent contact properties of copper with good mechanical properties thus making them directly usable as contacts, without the need for fixing to a backing, so avoiding the risk of contact detachment and resistance losses across the joint.

It is the purpose of this publication to look at the properties required for contact materials, and to identify those applications in which copper or copper alloys have special advantages.

Types of Contacts and Their Applications

Wherever electricity is used, it must be connected, conducted or controlled.

These applications incorporate various types of contacts, which are classified below, together with the requirements necessary for each category, and the types of copper or copper alloy which are most suitable.

The desirable physical characteristics for each application are given, and it is thus possible to decide whether the particular contact function can be met by pure copper, a copper alloy, or a copper backing faced with a specially formulated contact alloy.

Categories of Contact

The basic categories of contacts are:

- Make-break contacts -which may make or break on load
- Demountable contacts - which should be made or broken off load
- Sliding contacts - which maintain contact during relative movement
- Fixed contacts - which may be clamped together permanently for years and never opened.

Each of these types has common characteristics, with a wide range of different requirements dependent on the electrical and mechanical conditions of use.

Make-Break Contacts

The types of make-break contacts can be subdivided in order of rating, starting from high power:-

High current, high voltage circuit breaker contacts, which disconnect large electrical loads, and produce arcs which are contained within special arcing chambers. These may be in air at normal pressure, in a blast of air, or in oil or other arc extinguishing medium, including vacuum.

The large moving contact is often a massive rod of copper and the fixed contact, a ring of sprung copper contact fingers. The contacts may be tipped with arc resistant contact material to resist the erosion of the high power arc, and the surfaces may be plated (e.g. with silver) to improve stationary contact. The mechanical properties of copper combined with its excellent electrical conductivity and good arcing endurance under oil have made it the principal metal in this application.

In vacuum circuit breakers, the contacts are also generally copper, in special shapes to ensure proper distribution of the electric field and movement of the arc root.

Smaller airbreak circuit breakers (medium voltage), use copper in all internal conducting parts, but the contacts are often faced with a silver based alloy to resist welding. Such circuit breakers rarely open and close, being protective devices.

In low voltage circuit breakers (moulded case breakers) dissimilar pairs of contacts are sometimes used, in which one side is copper or copper alloy, while the other is a silver based compound.

When frequent making and breaking of current is required, contactors are used.

Necessary properties are resistance to erosion by arcing, and an ability to break the electrical circuit when required (e.g. the contacts should not weld together so that the contactor mechanism cannot operate).

Pure copper is, in general, unsuitable for the contact tips of double break designs at present in use, although some copper or copper alloys are used for large contactors with large breaking forces.

Copper or copper alloys are used in current carrying parts on to which the contacting tips are welded or riveted (these are generally silver-cadmium oxide), particularly in double break contacts where no roll or slide is available to break welds. The copper alloy used for the bulk of the moving contact member needs to be able to retain its mechanical properties when running hot, due to the light construction required, and thus special copper alloys are often selected which combine mechanical stability with good electrical conductivity.

In vacuum contactors, the contacts are copper with special "pockets" of low arc voltage material.

A much lighter make-break device is the control switch, and of lighter duty still is the relay, which has often to make and break very low currents and voltages. At the lowest end of the scale this is sometimes referred to as "dry circuit conditions", because the voltage switched is below the "melting voltage" of the contact material. For making and breaking such voltages and currents, pure copper is not generally suitable, and contacts tend to be faced with noble metals, although the bulk of the contact is still made of copper alloy, to give the required good conductivity at low cost, and the better mechanical properties necessary when the contact member is also required to act as a spring and to maintain the contact force between the fixed and moving contacts. Phosphor bronze and copper beryllium are frequently used in such cases.

Demountable Contacts

Under this heading come a wide range of devices:-

- plugs and sockets
- adaptors
- cable connectors
- isolators (not load breaking)
- off-load tap changers
- edge connectors on printed circuit boards
- spring-clip type fuse connections.

These contacts, like the make-break contacts, in (1) may be carrying high currents at high voltages (e.g. high voltage isolators or high voltage or medium voltage fuse contacts), or carry very small currents at very low voltages (e.g. edge connectors carrying only command signals). They have to carry current reliably for long periods, without overheating or loss of contact, but do not make or break current. These contacts are not subjected to the duress of arcing, hence do not get the inherent cleaning action associated with it. They are frequently designed to have some frictional action on closing to remove superficial oxide or corrosion films which might impede contact, and copper and its alloys are the most frequently used materials for the bulk of demountable contacts.

The characteristic of these contacts is that they have a high contact force, much higher than for circuit breakers of similar current rating, but not so high as the contact force in a bolted contact, because of the excessive mechanical wear which would be caused when separating the contacts.

Sliding Contacts

These can be of very different character, e.g.:-

- high speed, heavy current types: motors and generators, sliprings, brushes, commutators, current pickup contacts in electric transport
- low speed, light current types: potentiometers.

The resistance to mechanical wear of contact brushes and sliprings must be very high, as the relative speed of the contacts may reach 50 metres/second or more.

Dissimilar brush material is usually employed to avoid excessive frictional wear. (This explains the runaway nature of the phenomenon of "copper picking").

The brush/commutator system is at even higher duress, because it is a combination of sliding contact and make-break contact. Tough pitch high conductivity copper, cold worked to a hardness of 80 to 85 HV and an ultimate tensile strength of 275 to 310 N/mm² is much used as a commutator segment material.

At the other end of the scale is the sliding contact on a potentiometer, which must maintain very good contact, even at low voltage and current, without appreciable wear of the track.

Fixed Contacts

These include a wide range of bolted and crimped contacts.

The busbar contact, if not welded, brazed or soldered, is usually made by bolting or clamping. A clamped joint avoids the reduction in cross section caused by drilling to insert bolts, and give a

more uniform distribution of the contact force, making the contact more efficient and hence running cooler. Bolting is used because it is cheap and convenient.

British industrial fuse links are made with copper or brass terminations bolted in position, giving a more reliable connection than the Continental types, which have demountable contact systems. The Continental types give more rapid interchangeability of blown fuselinks, but the British bolted joints have the advantage of lower contact resistance, more reliable contact, and less chance of being ejected during short circuits.

Crimped joints employ the ultimate extreme force of contact making, causing the metal to flow and make a permanent connection. The trouble-free nature of these joints, and the simplicity and rapidity of the crimping operation makes this type of joint very attractive for permanent connections.

Bolted or crimped contacts are used in all voltage and current ranges, from large busbars to crimped or screwed wiring connections on low voltage printed circuit boards.

The Nature of Contact and Problems with Contacts

Contact problems arise from the fundamental physical processes of contact making itself, plus the additional problems associated with making and breaking an electric current.

Make Break Contacts

On breaking, problems can occur from arc erosion, metal transfer and welding, while on making, contact resistance leads to voltage drop and temperature rise across the contacts. Welding can also arise. Contact resistance is also affected by environmental conditions, leading to the formation of surface films and corrosion products on the contact faces.

Contact Resistance

When contacts are at rest, and current is passing, the actual areas which conduct the current are only a small proportion of the total contact surface, as illustrated in Figure 1. The parts of the surfaces touching each other may be metallic and conducting, or may be non-conducting due to surface films or particles. The area in electrical contact depends on the force with which the contacts are pressed together. This is the reason why the contact resistance of a joint is usually very much greater than the bulk resistance of the metal itself, and why the contact resistance is more dependent on the force between the contacts and the condition of the surface, than on the size of the contacts. Holm, in his famous book *Electric Contacts*, derives the relation between contact "constriction" resistance, contact hardness, resistivity, and contact force, of the general form:-

$$R = \frac{\rho}{2} \sqrt{\frac{\pi H}{P}}$$

Because of the small number of spots making contact, and their limited size, the current density in the spots is large compared with the current flowing in the circuit, and this influences the behaviour of the contacts with respect to temperature rise, erosion, welding as well as contact resistance.

The order of importance of these properties is different for different kinds of contact, as shown below, and this determines the use of different materials for these applications.

High contact resistance leads to temperature rise, which limits the current carrying capacity of the contacts. If the contact force is increased to increase the area in contact and reduce the temperature rise, this will result in increased contact wear. It will also require a heavier switching mechanism, which will increase the size and price of the switching device. If the device is a contactor, this would require a more powerful coil, wasting electric power.

Other means of reducing contact resistance are the use of materials which produce good metallic contact with moderate contact force, or the designing of contact systems to give an effective cleaning action when the contacts are brought together. The softness of copper and silver means that contacts faced with these materials need lower contact forces.

Low contact resistance is particularly important for devices where the contacts may remain closed under current for long periods (e.g. switches for off-peak heating control).

Copper contacts have the advantage that their modest price permits them to be larger, so that bigger contact forces can be used and larger wear can be tolerated. Temperature rise will also be low, because of high thermal capacity and good conductivity.

Oxide films and corrosion products on the contact surfaces reduce real contact area and increase contact resistance. This causes overheating which in turn accelerates the rate of oxidation and attack. Copper contacts are troubled by oxide films, formed by the arc process, or by other causes. This may lead to runaway oxidation, which can very suddenly ruin a pair of copper contacts and cause a rapidly escalating temperature rise. A coating of silver usually solves this problem, but is itself subject to environmental attack, forming silver compounds on the surface. However, these will tend to decompose under the heating action of a temporary high contact resistance, and restore the contact resistance again to a low level. Tinning is cheaper and less subject to sulphide attack, but the resistance is higher than for silver. Nickel plating is also sulphide resistant, but can give oxide problems.

Contact lubricants can be used to protect contacts against external attack, but must be properly applied. In general they are effective on contacts which are not required to switch frequently at moderately high currents.

Environmental effects could be dangerous for contacts which must operate reliably at any instant (e.g. railway signals) or for long periods (inaccessible contacts), or those controlling complicated automatic devices (relays or control switches); (e.g. a pair of contacts which remain open for a long period and are suddenly required to close and cause either a safety device to operate or to trip a large circuit breaker in a dangerous situation), or where a large number of contacts are used in series - where the failure of one contact may result in failure of a complicated contact logic.

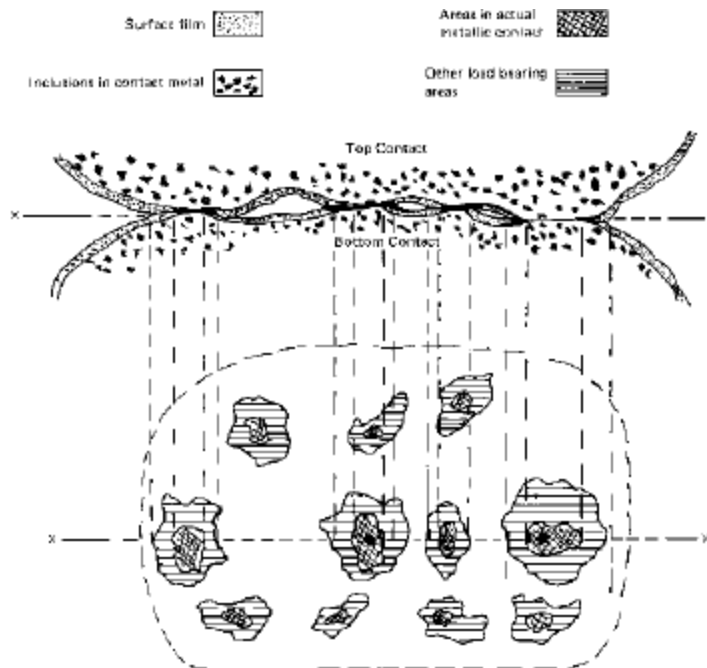


Figure 1 - Contact surface

Arc Erosion and Metal Transfer

As two contacts carrying current separate, the current becomes progressively concentrated over a diminishing area. As the last points separate, the current density is sufficient to cause local melting and the formation of a molten bridge across the contacts. This subsequently bursts and an arc is established. The arc causes erosion on the arc spots of each contact, and metal transfer occurs due to the polarity of the contacts, as illustrated in Figure 2.

Metal loss and contact damage of this type are particularly important for devices which perform a large number of switching operations during their life, e.g. motor starters and control contacts.

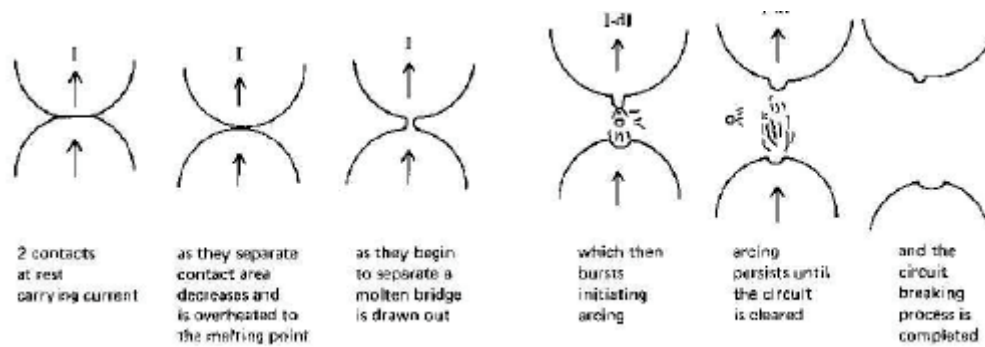


Figure 2 - The process involved in opening a circuit by means of contacts

Welding

Welding of contacts can arise in two ways. Firstly "dynamic welding" may happen when contacts bounce as they close under load. The arc thus generated produces pools of molten metal at the arc spots, and these coalesce to form a welded area when the contacts close finally, as shown in Figure 3. Secondly, "static welding" occurs when a short pulse of heavy current passes through a pair of closed contacts, such as a fuse-protected short circuit current. The high energy concentrated over a small contact area causes local melting and fusing together (see Figure 4).

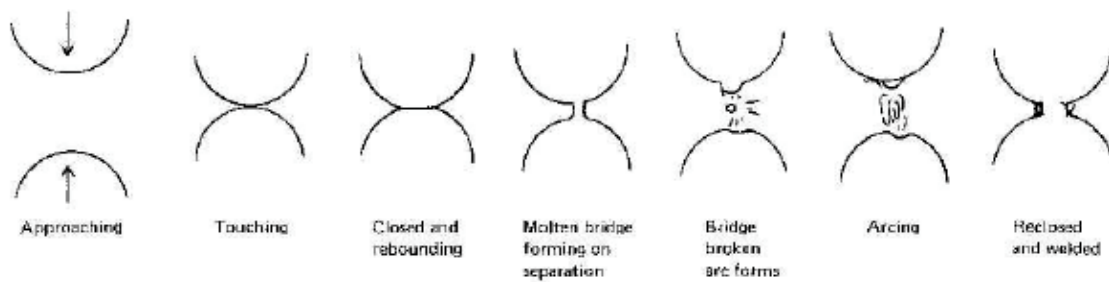


Figure 3 - Illustration of processes leading to dynamic welding due to bounce of contacts on make

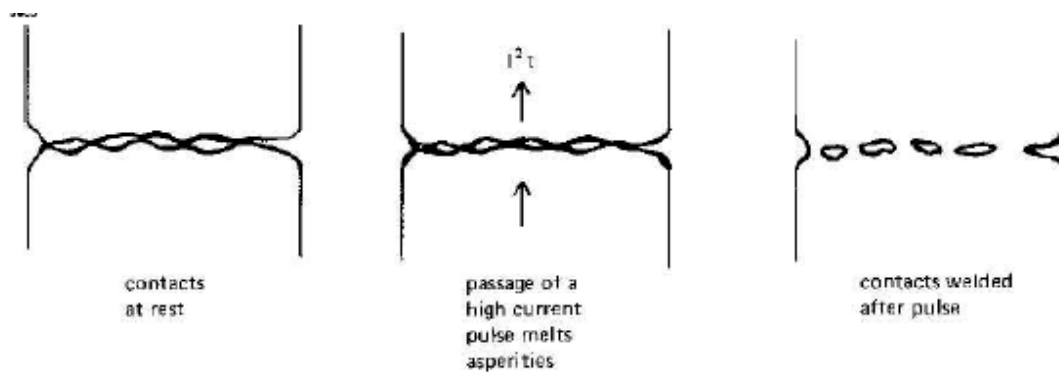


Figure 4 - Static Welding of closed contacts

Demountable Contacts

The problem of contact resistance again arises, but initially, with new clean contacts, is of less importance, because contact forces are higher than for make-break contacts. The temperature rise is thus usually lower, and unplated copper and brass contacts are frequently used, especially as arc damage should not occur. The bad practice of disconnecting running appliances by unplugging is usually accommodated by the design, which concentrates the breaking arc away from the contacting surfaces.

In plugs and sockets of Continental design, which tend to be under-size for the current carried, it becomes necessary to plate the pins, because the thermal capacity is insufficient to give trouble-free operation without this extra processing.

High contact resistance combined with low thermal capacity will give a high rate of temperature rise of contacts. This can become excessive due to oxidation or corrosion effects, and if the wrong alloys are used. For example, some designs of fused plug employ pure copper for the spring contacts to clip in the fuse. These can be bent back when replacing a blown fuse, and if the elastic properties are inadequate, give poor contact thereafter, resulting in severe overheating. A copper alloy, retaining its elastic properties, is preferable (e.g. heat treated beryllium-copper).

Corrosion can be caused by polluted atmospheres, or may be electrochemically accelerated by the use of dissimilar metals in contact. If frequently plugged and unplugged, a plug and socket contact has a self cleaning action which helps to reduce the effect. Contact lubricants are useful in this case, providing they do not dissolve any aggressive pollutant to increase its surface attack. Specialised lubricants are available, but it is not always convenient to use them (e.g. on household plugs or in very dusty atmospheres where they might be covered with adherent abrasive). The main use is in contacts which remain closed for long periods (e.g. isolators).

Frequent plugging and unplugging results in abrasion of the pins of plugs and sockets, and a compromise must be found between the requirement of good mechanical contact and that of minimum wear.

Lubrication can help, but the lubricant must be chosen carefully and must not produce high resistive films between mating contacts. It should also be a stable material, not polymerised in the presence of copper. Copper or its surface oxide can act as a catalyst for chemical reactions with certain organic compounds in contact with air.

Very thin layers of silver can also act as "lubricants" in these cases, and can considerably increase the life of brass plug-in connectors.

Sliding Contacts

The major problems are associated with high sliding speed contacts, i.e. brush/commutator and brush/slipring in motors and generators. The rubbing surfaces rapidly become coated with a

"patina", consisting of oxide, graphite particles and ash generated by the burning of the brush material. Contact resistance is high, resulting in high local temperatures. The formation of this "patina" is very necessary for suitable operation of the brush, and the reduction of mechanical wear. Brush lifting caused by surface roughness, contaminants, or bouncing, creates an arc and results in arc erosion and severe wear. Proper adjustment and bedding-in is essential for satisfactory running and long life.

Surface roughness is equally harmful for other sliding contacts. It gives rise to poor, variable contact and arcing at high currents, and "noise" on light current audio-contacts. Sliding contacts in resistance boxes, range change switches, etc., must be specially designed to avoid this variability which affects their accuracy. Plating is used, or the copper or copper alloy surfaces can be lubricated.

Special bronze has been used for telephone contacts, both for fixed and sliding contacts, brass for fixed only. Silver alloy contacts and copper-gold alloys have been found to give good contact at very low force.

Sliding contacts are troubled by oxidation and corrosion in the same way as other contacts, but the cleaning action of the sliding tends to remove corrosion products, and the "patina" itself gives a measure of surface protection.

Fixed Contacts

The nature of the contact between the two surfaces involved is the same as that described under "make-break contacts", but as these contacts remain in position for years, and the contact forces are high, the initial areas in contact are large, giving a low resistance. As corrosion and oxidation proceeds with time, the area of metallic contact is progressively reduced, and finally the time arrives when the contact points practically disappear. The reduction in contact area increases the contact temperature, and this accelerates the attack, so that sudden failure may occur, as illustrated in Figure 2, if the surface film is caused to spread deep into the areas in metallic contact by intrusion of corrosion and/or oxidation.

Problems can arise when the bolted material is too soft, and hard drawn copper conductors are usually preferred for busbar purposes. They have greater strength and stiffness, and superior surface finish compared with annealed bars. Disadvantages are slightly higher resistance and greater difficulty in working, resulting in the use of annealed bars where many bends are required.

A pair of contacts under continuous load tends to exhibit a slow yielding under the load. This process, known as creep, results in some slackening of the contact force. In copper and silver, the rate of yielding falls to a very low value after a certain degree of creep has taken place, which makes copper and silver particularly suitable metals for fixed contacts under high stress. Aluminium and zinc, on the other hand, continue to creep at a significant rate. This fact, together with the better, more permanent contact available with copper, may be contributory to the superior behaviour of copper clad aluminium conductors compared with the pure aluminium types.

The small amount of creep in copper contacts is advantageous, in that it results in a spread of metallic contact area, causing a low percentage drop in contact resistance over a long period.

The rate of creep in all metals is greatly increased by rise in temperature.

With fixed contacts relying on bolted joints or pinch screws bearing on a conductor in a tunnel, the dissimilar metal effects can be greater than with other types of contacts. Differential thermal expansion can result in distortion of the contact, or loosening of the joint after temperature cycling. The intimate contact of two dissimilar metals in damp conditions can result in enhanced electrochemical corrosion of the less noble member, especially where the two metals are far apart in the electrochemical series (e.g. steel and copper). Thermoelectric effects also exist, and

can raise the temperature of the contact point by as much as 10% with certain combinations of metals (e.g. gold and palladium).

All these effects have significance in the joining of copper to aluminium, and the probable deterioration in service where this combination is used must be borne in mind, the large electrochemical difference being also significant.

Types of Copper and Copper Alloys used for Contacts

Copper

Commercially pure copper has an electrical conductivity exceeded only by silver, and this, together with its ready availability in a wide variety of forms, and its low cost and plentiful supply compared with precious metals, makes it an obvious choice as a contact material. Full details of the commercially available grades and relevant British Standards, together with their mechanical, physical and electrical properties, are contained in CDA publication TN20 - Copper Data. (now superseded by TN 27)

Copper has a high melting point (1083°C) and high corrosion resistance. There are no difficulties of attachment by brazing or soldering, and its thermal conductivity is high 397 W/m°C. The disadvantage of copper for contacts is its tendency to form heavy oxide films of relatively high resistance, especially when arcing occurs. This effect is particularly disturbing at lower currents and voltages and at low contact forces. At higher currents the contact surfaces are kept clean by the arcing on make-break contacts, and high contact forces can move the friable oxide from the conducting area, while high voltages can break the oxide film down. Copper can therefore be used for the higher current range as far as contact resistance is concerned, although the welding and erosion performance must be taken into account.

When contacts remain closed for long periods, however, the growth of oxide on copper contacts can become excessive, and lead to overheating, sometimes followed by complete loss of contact. If sustained arcing at low current is initiated, runaway oxide growth can penetrate deep into the contacts. Silver facing of copper contacts prevents oxidation troubles in such a case. Such considerations explain the superior behaviour of copper in vacuum, compared with its performance in air.

The effect of surface layers can be overcome for airbreak contactors with frequent switching by suitable design, for instance by introducing a sliding and rolling action of the contacts, or by high contact force. This increases mechanical wear, and implies that pure copper contacts must be larger than necessary electrically, in order to accommodate this wear.

Very important, especially for high current operation, is the erosion of material due to arcing. The relation between rate of wear (in microgrammes/sec) and arc current (in amperes), valid between 5 amp and 800 amp, is of the form:-

$$\frac{dW}{dt} = k.i^{1.6} \text{ in which } k = 2.4 \text{ for copper.}$$

This relation only applies at currents where bulk melting of the material and spraying of droplets does not occur. Above 800A (the "discontinuous erosion current") where bulk melting occurs, a similar power law is followed, with a numerical erosion factor (k) of 36.

In vacuum contactors special designs of copper contact are used to prevent effective current from reaching discontinuous erosion.

In contactors for d.c. use, the erosion of the two contacts may be quite different. Although the transfer of material is generally from the anode, this is not the case for all values of current; in fact the transfer of metal by the arc has a number of regions dependent on the mode of arcing, and the formation of jets from anode and cathode. For copper between 10 and 300A the transfer is from cathode to anode in air, and the rate of transfer is approximately proportional to a power function of the arcing current: (rate of transfer) = $k i^{2.25}$. At approximately 300A the transfer is

such that the anode keeps constant weight, and above this current it increases in weight. This kind of arc transfer is a different phenomenon from the "fine transfer" occurring in relay contacts at low currents, which is due to the rupture of metallic bridges, and is generally from anode to cathode.

Static and dynamic welding of copper contacts is discouraged to a certain extent by the existence of oxide layers, dependent on the contact force. The threshold of static welding is of the order of 4 kiloamp at 100N contact force, with a weld strength of 330N/mm², while the threshold of dynamic welding lies at about 50 amp for 25N contact force, with a weld strength of the order of grammes. Weld strength rises with current, until at 200 amperes it is approximately 100/mm², measured by direct pull. A "knuckling" action is needed in a contactor design to assist the breaking of welds in copper contacts. A recent explanation of the lower strength of the dynamic weld of given area attributes this to the imperfections (e.g. inclusions of air or oxide) in the welded area.

Copper Alloys

A number of copper based alloys are used for contact and contact backing manufacture, because of their particular properties which suit them for the required application.

Full details of the range of copper alloys available, their composition, mechanical properties and relevant British Standards, are contained in CDA publication TN10 - Composition and Properties of Copper and Copper Alloys. Those alloys most frequently used for contact or contact backing manufacture are briefly described in the following sections.

Silver-bearing copper

The addition of small amounts of silver (generally below 0.12%) has the effect of raising the annealing temperature of copper without any appreciable reduction in electrical conductivity. Assemblies made from this alloy can be connected by soft soldering without loss of hardness. Commutators of high performance motors are frequently made from this alloy.

Alloys with higher silver content (2 - 8%), plus in some cases up to 1.5% cadmium, have been used for anti-weld contacts in transformer load switches.

Silver-copper

These alloys have improved hardness, wear and dynamic welding properties. They are used for contacts rather than contact backing. Well known alloys are hard silver (3% copper), standard silver (7.5%) and coin silver (10%). A material used for sliding contacts because of its hardness and resistance against mechanical wear and transfer, is silver-copper-phosphorus (2% Cu, 0.1% P).

Silver-copper is not normally used in contactor contacts, although alloys with 7.5% and 10% copper have been found to have a threshold of dynamic welding at about the same current as for copper or silver, but with a much lower weld strength up to 250 Amperes. Silver-copper oxide has a considerably improved performance in this respect, being highly resistant to dynamic welding.

The physical properties of the silver-copper alloys vary with percentage copper and with heat treatment, which can produce a tensile strength range for hard silver, for instance, from 450 to 1150 N/mm², or for a 50% copper alloy, from 800 to 1550 N/mm².

Copper-beryllium

This is a heat treatable alloy, and has a particularly high tensile strength and hardness, dependent on the amount of Be present and the heat treatment. In the UK the standard alloy (CB101) has a beryllium content of 1.7 - 1.9%, which after full heat treatment has a tensile

strength of 1200 - 1400 N/mm², with an electrical conductivity in the range 25 - 35% IACS, a combination not found in any other alloy of comparable mechanical properties.

Copper-beryllium has been used for heavy current contacts working at high voltage with a high frequency of operation. More usual however, because of its excellent spring properties, is its use as a contact backing material, e.g. the trident contact in microswitches.

Copper-cadmium

This material generally containing up to 1% of cadmium, has a slightly lower conductivity than copper (80 - 90% IACS) but a higher strength. It is not generally used for contactor contacts, but it finds application for other current carrying parts, contact supports requiring strength which is maintained at moderately elevated temperatures, and for trolley wires, where its improved mechanical strength, fatigue and wear resistance are advantageous, especially since these are maintained at higher temperatures than for pure copper.

Copper-chromium

This alloy contains up to 1% of chromium. The material develops its properties by heat treatment and in the fully heat treated condition has a higher tensile strength and slightly lower conductivity than pure copper (80 - 85% IACS). The material is useful for contacts in resistance welding machines, but not for switching contacts, because of the ease of formation and strong adherence of chromium oxide layers on the surface which prevent good contact making. It is easily worked, and takes inlays of other materials well, so that it can be used as a contact base, where strength and hardness are required. It can be used at temperatures up to 350°C without impairment of properties.

Copper-nickel

The addition of nickel to copper improves the mechanical properties and resistance to oxidation and wear. Copper-nickel alloys are widely used in electrical engineering, but the amount of nickel added is generally small because of the drastic effect on conductivity (alloys with higher nickel content are used as resistance alloys). Consequently they find little application as heavy current electrical contacts, but they are used as relay contacts at moderate currents, sometimes with a tinned surface.

Low nickel content alloys (below 10%) are widely used for slipring manufacture, the wear rate being very low. Copper nickel has also been used for uniselector contacts.

Copper-nickel-zinc

This range of alloys, containing 12 - 20% nickel, are commonly known as "nickel-silvers" and occasionally as "German silver". They can be cold worked to high hardnesses, and in this condition have excellent spring properties. They also have good tarnish and corrosion resistance and are readily solderable. They are widely used for the manufacture of contact springs and contact supports, but their tendency to form insulating surface films under the effects of arcing precludes them from being used as contacts.

Copper-sulphur

The addition of 0.3 - 0.6% sulphur to copper is basically made to improve its machining properties while maintaining a high electrical conductivity (90 - 98% IACS). From the contact viewpoint it has other advantages, improving the resistance to dynamic welding and arc erosion. There is a possible problem however, due to the formation of sulphide films on the surface as a result of arcing.

Copper-lead

The addition of lead to copper, in amounts up to 10%, improves the resistance to dynamic welding due to the formation of a liquid phase above 325°C. Large amounts of lead are difficult to alloy with copper by conventional techniques, and a material with better lead distribution is made by powder metallurgy techniques. Copper lead contacts can be used against other materials, e.g. silver-graphite, as the opposing contact.

Copper-palladium

The alloy with 40% Cu is used because of its hardness, resistance to metal transfer, mechanical wear and tarnish resistance in catenary contacts. The conductivity is only moderate (4.9% IACS).

Copper-gold

The use of these alloys is restricted to relay and light duty contacts only, because of their price. Metal migration in relay contacts is reduced by using these alloys.

Copper-silver-gold

There are several forms of copper-silver-gold available, with percentage of gold between 60% and 70%, the remainder being a silver-copper mixture. A very hard alloy, conductivity 12% IACS, is used for light duty sliding contacts, operating against palladium, rhodium or palladium alloys. Its spring qualities are comparable to those of phosphor bronze, and it is completely resistant to tarnish at room temperature. A softer form of this alloy is used for headed rivets and inlaid bi-metal. An alloy with 10% copper is used for printed circuit edge connectors, it will stand up to frequent insertions because of its durability and freedom from tarnish, without increase in contact resistance.

Copper-tin

These alloys, more widely known as the "phosphor bronzes", contain up to 8% tin in the wrought forms, though in castings the tin content can be as high as 12%. All the alloys contain a small amount of phosphorus (0.02 - 0.4%), hence the common name.

When cold worked, the alloys are hard and springy, but tin has a marked effect on conductivity. They tend therefore to be used as a contact backing material rather than as contacts, in switches and relays. One exception is "conductivity bronze", an alloy containing 1.0 - 1.5% tin, which is used for trolley wire, having high strength and wear resistance.

Copper-zirconium

This alloy, containing 0.1 - 0.15% zirconium, is a heat treatable alloy retaining good electrical conductivity (85 - 90% IACS) with improved strength, and a high resistance to softening at elevated temperatures. It has improved resistance to static welding, and is used for the manufacture of spot welding electrodes.

Powder Metallurgy

Certain metals, metal oxides and non-metallic materials have desirable characteristics for contact applications, such as erosion and welding resistance, but are of low conductivity. Combination of these with copper, to give acceptable conductivity, should therefore produce a material with optimum properties. Unfortunately the metals concerned are of high melting point and do not alloy with copper, consequently it is not possible to produce them by conventional melting techniques. This also applies to the metal oxide and non-metal combinations with copper. The only viable manufacturing procedure to produce such combinations is powder metallurgy.

The method generally consists in mixing the powders of the components, pressing and sintering at a temperature below the melting point of the lowest melting component. High densities are obtained by repeating the process. Another possibility is to form a matrix of the higher melting material, by pressing and sintering, and to impregnate this afterwards with the molten low melting component by capillary action.

The powder metallurgy method can result in fibrous or laminated structures, where the properties of the contact material become dependent on the direction of the fibres. Sintering can also be used to produce multilayered contacts, by pre-pressing, sintering and final pressing of the layers. This method can be used, for instance, to produce contacts with a high tungsten content in the arcing tip (more refractory), a high silver or copper percentage in the contact area (high conductivity) and also at the base (for ease in brazing to the backing).

Copper-tungsten

Copper tungsten sintered materials are manufactured with different copper contents, from 20% up to 70%, depending on the use to which they are put. The method of manufacture depends on the percentage of tungsten present. Materials with large percentages of tungsten (around 80%) are generally made by the impregnation process, where it is advantageous to use a coarse grain tungsten powder to decrease arc erosion. For percentages of the order of 60%, liquid phase sintering is more appropriate, and for materials with less tungsten, powder mixtures without a liquid phase are sintered together.

Materials with a low copper content are used for high currents to improve contact life and breaking capacity. With a higher copper content, about 67%, the material erodes slightly less than pure copper, at low currents (around 20 amp), and the improvement in erosion resistance is enhanced at higher currents, but this is accompanied by considerable deformation of the contact surface. The contact resistance increases considerably on arcing, due to oxidation and depletion of copper in the interface.

For larger contact forces, the static welding limit of copper-tungsten (60/40) is very much higher than for any other material of this type, although at low contact forces the hardness of the material produces very small metallic contact areas, resulting in high contact resistance and low welding limit.

Copper-molybdenum

This material is occasionally used instead of copper-tungsten, but its properties are in general not as good as those of copper-tungsten.

Copper-alumina

This dispersion strengthened material has superior resistance to softening at high temperatures and has good electrical and thermal conductivity.

Copper-graphite

Copper-graphite can contain up to 70% graphite, dependent on application. All copper-graphite mixtures have higher conductivity and lower contact resistance than pure graphite, but the graphite content continues to give a lubricating effect, which reduces electrical contact losses, without increasing mechanical wear. Even small proportions of graphite have considerable influence on the rate of wear. Copper-graphites with low percentages of graphite are used for slip rings and low voltage d.c. machines with very high current densities. For lower current densities and better cooling conditions, higher percentages of graphite are used because of their lower wear rate.

Typical uses of Copper in Contacts

As has been previously stated, copper can be used in contact applications either as the pure metal, or in the form of alloys or compounds made by powder metallurgy, as the contact itself, or as a support for a layer of special surface coating, the nature and thickness of the latter varying with the severity of application in terms of voltage, current broken, frequency of operation, life requirement, etc.

The wide range of applications for copper and copper alloys, and methods of contact construction, are summarised in table form:-

Table 1 - summarises a variety of contact uses and lists the practical combinations of copper with other metals necessary or suitable to the function required. The properties required for different applications are also listed in this table, to enable the user to identify the type of materials which may be used for applications not listed in the first column, but with similar requirements.

The applications are listed approximately in order of current rating, starting with negligible current at very low voltage and ending with applications in which currents of the order of tens of thousands of amperes are broken. For applications not listed, the appropriate materials can be found by considering the current and voltage required, and looking in the region of the table covering that current.

Table 2 - summarises a variety of ways in which the mechanical problems of making contact reliably are solved in practical designs by the use of copper or its alloys as the main component, faced where necessary with a specialised coating to match the type of voltage and current to be switched.

No attempt has been made to arrange these in order of current, because of the wide range of currents and voltages over which each method may be used, when an appropriate set of materials is selected from Table 1.

The method to be chosen from Table 2 depends on the size of the contact, the mechanical duty it has to perform, and the number of contacts to be manufactured.

Typical materials which are made into contacts of stated size are given in the table, together with the present main types of application.

Type of device or contact	Required properties	Material *	Shape of Contact
Pushbuttons for radio and TV	Constant low resistance, cheap construction, slight friction on make	Hard silver, Ag/Cu, plated with Au, Pd or Rh	Plated blades. Thin gold on Ni-plate
Rotary switch on printed circuit	Resistance to frictional wear, low contact resistance	Fixed: Au on Ni; Sliding: AgPd, AgCu	Fixed: plated; Sliding: plated, welded or riveted
Sliding in very small motors	Very resistant to frictional wear, good contact for very low force	Ag or Au-alloy, AgPd, AgCu	Sliding: flattened or formed wire; Collector: Au-plated or formed from profiled wire
Dialling contact in telephones	Sliding contact for frequent use, antifriction, fairly low contact resistance	Fixed: brass, bronze Sliding: bronze, Ag-alloy, Au-alloy	Segments pressed out, the sliding ones with special Contacts
Sealed relay in metal can	Very reliable and long life, fast bounce-free switching	PdCu, Mo with Au-plating	Fixed: plated parts or welded foils; Blades: FeNi-plated with Mo and Au
High power relays	Low erosion, weld resistant, low and constant contact resistance	AgNi, AgCdO, AgCu	Rivets, solid or headed, welded On automatically welded blades
Light switches	Low contact resistance, low erosion, no weld on overcurrent	AgCu, AgCdO	Solid or bimetal rivets, automatically welded parts
Temperature controllers	Definitive contact even for slow movement or low force, high operating temperature	Ag, AgCu, AgNi	Rivets, welded contacts, welded parts
Sequence and time switches	Reliable contact for low contact force and small dimensions	Ag, AgCu, AgNi, AgCdO	Rivets, solid or bimetal, automatically welded parts, pressed bimetal, rolled or inlaid profiled strip
Small circuit breakers	Anti-weld on short-circuit, low temperature rise at rated current, moderate erosion	Dependent on rating and construction Cu, AgCdO, AgW, AgWC, AgC mixed: AgC against Cu	Profiled, pressed, brazed, welded
Control switches	Reliable contact for prolonged operation	Ag, AgCu, AgNi, Au-faced	Rivets, solid or faced, faced pressed parts, gold plated rivets
Rotary switch, Manually operated	Reliable switching of rated and overcurrent with compact shape	AgCu, AgNiCu, phosphor bronze	Rivets, solid or faced, automatically welded, profiled
Motor controls switching under oil	Resistant to arcs in oil	Cu, WCu	Solid contacts, brazed material
Large L.V. contactors with arcing contacts	Withstanding high short circuits On make and break, low resistance on rated current, anti-weld	Arcing contacts Cu. WAg. Main contacts AgCu, AgNi, AgCdO, AgZnO, AgSnO	Solid contacts in Cu. others brazed or welded

Isolators	Low contact resistance for high current, sufficient mechanical strength. Operation generally on no-load	Ag, AgCu, AgNi	Electroplated, welded
Isolators for outdoor use	Low mechanical wear for high forces, low contact resistance, generally operated on no-load	Silver plated Cu, AgCu against Cu	Profiled Cu
On-load isolators	As isolators, and low erosion of arcing contacts	Arcing: WCu, MoMain: Silver plated Cu. AgCu. AgNi	Welded, brazed Plated, welded
Circuit breakers L.V. and H.V	Low erosion, low metal vapour, low temperature rise for closed contacts; low temperature rise at high current, sufficient strength against deformation	Arcing parts: WCu, Mo, CuClosed contacts: Cu. silverplatedCu. AgCu, AgNi AgW	Mechanically fixed, welded, brazed
Transformer tap changers	Low temperature rise for continuous high current ,good sliding, low wear when switching no load under oil	Cu, silver plated Cu, AgCu	Cast or pressed parts with welded or brazed onlay
Transformer on-load tap changers	High resistance to erosion under Oil	Wcu	Contacts brazed or cast on
Oil breakers	High resistance to erosion and arcing under oil	Cu, Wcu	Contacts solid or brazed
High current d.c. breakers	Low transfer, low erosion at high current low contact resistance	Cu	Laminated strip
Vacuum switches	Low transfer and erosion under vacuum	Cu + inserts - very low gas content	Specially shaped
Generator, commutator alternator	Hard, creep resistant low contact resistance	Cu + 0.1% Ag	Solid
Sliprings	Low mechanical wear under brushes easy manufacturing	Cu, gummetal, Cupronickel, "Monel", for corrosive atmospheres	Cast and machined
*Ag – silver, Au - gold, Pd - palladium, Rh - rhodium, Ni - nickel, W - tungsten, Zn - zinc, Cd - cadmium, Mo - molybdenum, O - oxide, e.g. CdO = Cadmium oxide, C - carbon, Sn - tin			

Table 1 - Applications of copper and copper alloys in contacts

Contact type	Usual material and size	Main area of application
Faced rivet	Ag and Ag-alloy on Cu over 3 mm dia .Au, Pt, Pd-alloy on Cu. 1.3 to 4 mm dia.	For all kinds of switching devices in telecommunication and low voltage power applications
Rivet with brazed facing	Tungsten and materials made by powder metallurgy on Cu (or Fe),2 to 20 mm dia	Power switching devices, W used for regulators with high switching rate
Contact screws	Any contact metal on steel or brass screws 1 to 10 mm dia.	Adjustable contacts for regulators and interruptors
Welded contacts	Ag and Ag-alloys on steel, nickel or Monel 3 to 10 mm dia. Weld pip on bottom of preformed contact	Welded on to steel springs or thermo-bimetal for temperature regulators, on thick brass base for small switches and control switches
Brazed onlay	Any material or size. Base Fe, Cu and Cu-alloy, if strength required,Copper-chromium or Copper-beryllium	L.V. and H.V. switching devices of medium and high rating
Contact bimetal either completely covered or with banded inlay	Ductile precious metals on Cu and Cu Alloys, minimum thickness of layer 2% of total for Ag, 0.5% for Au-alloys. Strip width from 2 mm	Plated springs, stamped and formed parts for telecommunication and power switching devices
Profiled to play	Ag and Ag-alloy on Cu, bronze, brass. Total width 10-100 mm base0.3 to 5 mm thick	Contact arms and bridges for small to medium sized L.V. switching devices
Schlatter-welded profiles	Wire, tape or profiled form in ductile precious metal welded on to base of Cu-alloy. Facing 0.3 to 3 mm dia., or up to 5 mm width	Relay springs, contact parts for control switches, small contactors and changeover switches. Sliding contact brushes
Faced profiles	Ag and Ag-alloys on Cu or brass, all sizes Which can be drawn or rolled	Contacts for H.V. and L.V. switching devices
Arcing rings and plates	Impregnated WCu sizes 10 to 100 mm dia.	On contact "pokers" and "tulip" contacts in H.V. circuit breakers, arcing contacts in L.V. circuit breakers, tapchangers and load breaking switches in transformers
Cast contacts	W or WCu on Cu backing, shaped rings and contact tops up to 100 mm dia	.Arcing tips in H.V. switching devices of high rating for heavy duty
Silver plated	Plating up to 20 mm on to Cu or Cu-alloys	Terminals and contacts switching on no load, rotary switches, plugs and sockets
Gold plated	Plating 0.2 mm on Ag and Cu alloys, for hard gold 0.5-5 mm often on nickel interface	Contacts at low voltage and current, plugs, Rotary switches, contacts on to printed circuit boards
Selective plating on strip	Gold or silver strips plated on to Cu or Cu alloys, Ni-alloys (thermo-bimetals), stainless steel, all in strip form. Ag 1-20 mm,Au 0.2-10 mm, width from 2 mm, separation min. 2 mm, strip0.1 to 1 mm thick, 5-100 mm width	Contacts for plug and press-on connections, press buttons, rotary and sliding switches, terminals
Ultrasonically welded contacts	Cu to Cu. Ag, AgCdO etc on to Cu backing. Ag backed contacts on to Cu	New technique proposed for general purposes

Table 2 - Methods of contact construction involving copper either in the contact itself or as backing

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