Contact Phenomena

Contact Phenomena

The function of a switch is to make, break or maintain the flow of current in an electrical circuit. This deceptively simple duty has to take account of many factors which affect the liability of the contacts to perform in a safe and efficient manner at the lowest possible cost. It is therefore important to have some understanding of the principal phenomena which influence contact performance and can be responsible for switch failure.

These can be considered under four main headings:-

Contact Resistance
Arc Erosion
Welding
Metal Transfer

Contact Resistance

The resistance of a contact pair in an unused switch can readily be measured to determine if it meets its design parameters. It is, however, the change of resistance during the expected life of the device which is of greater importance to the designer.

Contact resistance is not merely the ohmic resistance of the contact body, but, in addition, the constriction resistance and film resistance at the interface of the contact pair. Constriction resistance is the total resistance of the metallic peaks which touch each other in the microscopically rough surfaces of the mating contacts. These contact points deform during service due to the combination of heat and mechanical pressure and also wear caused by lateral (sliding) movement relative to each other. The latter may be a deliberate design intention - contact wipe - or unintentional due to secondary factors such as vibration during operation.

The net result is a change in the total area of metallic contact with time. Film resistance invariably increases contact resistance. The films are layers at the contact surfaces which are non-conducting or semi-conducting. They can be caused by chemical reaction of the contact materials with the surrounding atmosphere to form oxides and sulphides. Carbon compounds can be produced if oil, grease or organic vapours are present within the switch cavity, particularly in light duty devices. In heavier duty conditions, compounds volatilised in the arc can condense to give films on the contact surfaces.

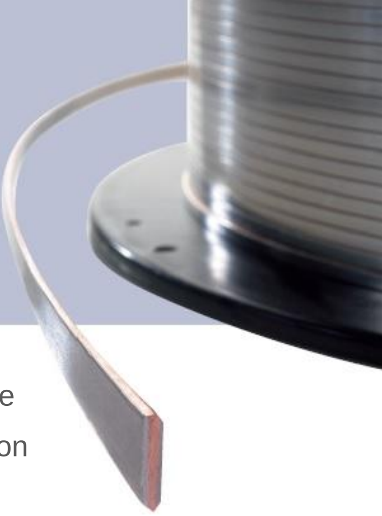
Material selection is particularly important in low voltage operation (i.e. below 10V). Sulphide films which form on silver are not readily broken unless there is a strong mechanical wiping action in the switch. Alloying silver with palladium or gold reduces the formation of sulphides. Platinum-group metals are tarnish resistant but may cause the formation of resistive "brown powder" compounds by catalytic reaction with organic vapours. Gold offers the best resistance to film formation but at a high cost. This can be minimised in the production of contact strip by seam welding or roll-bonding gold to the contact face and then reducing the thickness of the layer by subsequent rolling operations. Gold can also be applied as an electroplated layer to partially formed or finished contacts.

The effect of tarnish films on contact resistance becomes progressively less important with increasing voltage where arc erosion and welding assume greater significance. Silver is more widely used, although some wipe may still be necessary.

Arc Erosion

An arc occurs in an energised circuit as the contacts open providing that the voltage is above the minimum value for the contact materials. As the contact force approaches zero, contact resistance rises rapidly and the resultant heat causes melting and volatilisation of the contact surfaces. The metallic ions become entrained in the arc making it conductive; the circuit cannot be broken until the arc is extinguished. Whilst the arc exists, the energy produced causes further boiling of the metal surfaces with consequent loss of contact material and continued support for the arc. The loss of material due to arc erosion is of major importance in relation to the life of the contact.

Arcing also occurs during closure of the contacts on the make sequence. This is due to contact bounce occurring immediately after the circuit is energised, giving rise to several arcs of short duration. In most instances, much of the evaporated metal is re-deposited on the contact surfaces, which remain relatively cool. With high current devices utilising high closing forces however, the arcs may be prolonged and become much hotter, giving significant erosion. Contact welding can also occur in extreme cases. There are many interacting factors which govern arc erosion including circuit characteristics, dynamics of the operating mechanism, the size, shape and material of the contacts, moulding material and many others. The complex interactions between these factors make it impossible to provide a universal



formula to predict contact life. The switch designer may have to resort to a variety of arc control devices to limit the duration of the arc to obtain an acceptable life.

The contact material is the supplier of metallic ions which prolong the arc and also the principal route by which heat is absorbed. Materials which resist arc erosion are therefore tailored to reduce volatility at high temperatures without compromising the high thermal conductivity essential for cooling. In high energy arcs, materials such as platinum and tungsten give the greatest resistance to arc erosion due to their high densities, high melting points and low volatility. Other materials incorporate metal oxides which sublime at arc temperatures thus extracting heat and reducing the conductivity of the arc. Examples of these are oxides of cadmium, tin, tungsten and molybdenum. These are distributed within a silver matrix by two principal manufacturing procedures - internal oxidation of wrought alloys of silver/cadmium and silver/tin or by consolidation of mixed powders.

Nickel also confers better arc resistance because of its low volatility. It is insoluble in silver and therefore materials of this type are made from mixed powders; the mixture is sufficiently workable to permit the production of ductile wrought strip and wire forms.

Welding

Spontaneous welding together or sticking of a pair of contacts in service is one of the more serious contact phenomena because of the possibility that the circuit may remain unbroken and constitute a hazard. Furthermore, a permanent weld may terminate the life of a switch even though no appreciable wear of the contacts or other components has taken place.

There are two principal means by which contacts weld together and in each case the contacts become attached as a result of molten metal solidifying while the contacts are, momentarily at least, closed.

Static Welding

This form of contact welding occurs due to resistance heating of closed contacts and therefore has similarities to the metallurgical manufacturing process of resistance or butt welding. It arises when a high current is passed, for example during fault conditions. Even where a circuit is protected by a fuse, the peak current reached before the fuse finally breaks the circuit may be many times the fuse rating and more than sufficient for contacts in a closed switch to weld. The magnetic field arising from a high current surge may further contribute to the weld by opposing the force holding the contacts together so that contact resistance rises and more heat is generated. In the critical condition, where the magnetic force opposing the contact force reduces it to zero so that the contacts just lift apart, a particularly strong "quasi-static" weld can occur.

In situations where static welding is a strong possibility it is usual to ensure that contact resistance is kept to a minimum, by providing a high contact force. A low resistivity contact material would also be applicable. However, where very high currents may pass, such as in circuit-breaker applications, contact forces and release forces may not be high enough to prevent welding-on of a material such as silver. In such cases a composite material containing a refractory component, such as silver-tungsten or silvertungsten carbide, is usually preferred. Alternatively, where erosion can be kept to an absolute minimum, such as in the modern designs of current-limiting circuit-breakers, silvergraphite is preferred.

Dynamic Welding & Contact Bounce

The second form of welding, known as dynamic welding, also has similarities to a metallurgical manufacturing process because it is, in effect, arc-welding. It occurs when contacts close onto molten metal pools produced by arcing and it is of particular concern in respect of relays and contactors in which arcs are drawn as the contacts bounce on the make.

Although it is not generally realised, contacts almost always bounce on the make and the overall bounce time can last for several milliseconds. The bounce pattern is frequently a complex one, partly due to inertial forces associated with contact impact, armature closure and the reactions of other moving parts. It is also affected by magnetic and vapour pressure forces, including arc blow-off, which vary according to the point-on-wave at which make occurs. It is for these latter reasons that measurements of bounce under load usually show more variation and greater average bounce durations than those made off-load.

Whilst contact bounce is largely a function of the mechanics of the switch it is rarely possible to eliminate it and so it is often necessary to select a contact material with resistance to dynamic welding. The usual approach is to consider a grade of silver-cadmium oxide or silver tin-oxide since these are not readily wetted by the arc-melted metal and hence the possibility of welding is minimised.

Material Transfer

There are two types of transfer to be considered – fine transfer and arc transfer. They are caused by different conditions.

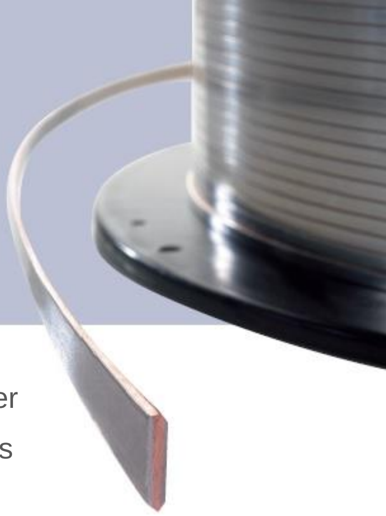
Fine transfer is most common in low-voltage DC circuits and is characterised by a build-up of material on one contact surface by transfer from the mating contact. The effect is due to the polarity of the circuit where build-up occurs on the negative contact as the contacts separate under non-arcing conditions. Transfer can occasionally appear in the reverse direction due to the effects of current, inductance and the contact materials employed.

As the contacts separate, contact resistance rises and a molten bridge forms as a result of resistance heating. As the contacts separate, the bridge breaks asymmetrically to give build-up on one contact face due to metal lost from the other. During repeated operations this process continues to eventually generate a pip and crater configuration. In extreme cases the two faces can become mechanically locked together so that the contacts will not separate.

Arc Transfer

During arcing, some metal atoms evaporated from a contact are transferred to the opposing contact. Under DC conditions this arc transfer tends to occur from the positive to the negative contact when the contacts are separated by a gap of less than about one micron and in the opposite direction for larger gaps. In the AC circuit the transfer is of course periodic. Cooling at the arc root, particularly at the anode, is important in reducing arc erosion as we shall explain.

In the case of an arc at break, metal is lost first from the anode, which is heated by the bombardment of high-energy electrons. As contact separation progresses, the anode spot increases in size and is therefore more efficiently cooled than is the cathode spot. As a result, there is a transition from an anode dominated arc to a cathode dominated arc in which metal is lost principally from the cathode, owing to



ion bombardment, while electrons reach the anode only after losing much of their energy in collisions. If, however, there is insufficient cooling of the anode spot, due perhaps to a limitation in contact size, then its rate of evaporation increases. At high currents of, say, a thousand amps or more, evaporation tends to become violent and liquid metal droplets may be blown out of the contact.

The contact materials giving the best 'resistance to material transfer are silver-nickel in low and medium current applications and silver-tin oxide for medium and high currents; an alternative which can give good results is to use dissimilar materials for the contact pair.

In extreme cases pure tungsten or noble metal alloys based on platinum and palladium are used.